FLAMN-25

FUNDAMENTALS OF LASER-ASSISTED MICRO AND NANOTECHNOLOGIES

24 — 27, JUNE 2025
SAINT PETERSBURG, RUSSIA

DEDICATED TO THE 60TH ANNIVERSARY OF ITMO
SCIENTIFIC SCHOOL OF LASER TECHNOLOGIES

Abstracts

FLAMN-2025 GENERAL INVORMARTION

International Symposium Fundamentals of laser-assisted micro and nanotechnologies take place in Saint Petersburg on 24 – 27 June, 2025. The symposium includes 10 scientific sessions and 2 special events.

Registration fees

Regular * – 25 000 RUB (Early bird 20 000 RUB)
Student – 10 000 RUB (Early bird 7 000 RUB)
Listener (without presentation) – 10 000 RUB
Accompanying person – 10 000 RUB

* Regular registration fee includes admission to the technical sessions, coffee-breaks, symposium attendee kit, symposium program & book of abstracts, visa invitation service (including mailing), welcome reception and publication of results.

Publications

The papers of the Symposium may be considered for publication in special issues of peer -reviewed journals **Optical & Quantum electronics** (paper submission dates are July, 1st – October, 30th 2025) and **Journal of Optical Technology** (paper submission deadline is September 15th, 2025). Detailed information about submission process is on the website.

Language

The official language of the Symposium is English.

Venue

Saint Petersburg

Saint Petersburg has earned the reputation of being one of the most beautiful cities in the world thanks not only to its unique palaces and churches, but also to its inimitable architectural ensembles of streets, canals, and squares. Saint Petersburg is a city of splendid palaces and beautiful buildings, its most common architectural styles being baroque and classical.

There are more than 90 museums in the city and its surroundings, including the State Hermitage museum - one of the world's leading treasures stores of art. Saint Petersburg is the home of the famous Russian classical ballet school, and numerous ballet and opera theaters will be available during Symposium time.

Symposium time is a time of world known White Nights when many cultural events (musical, theatrical and art show) take place here.

ITMO University

The Symposium will take place at ITMO University, in the heart of the city. This location offers excellent transport connections and various dining and leisure options. At the request of participants, we can organize excursions to the university's laboratories and the Museum of Optics.

Transport accessibility

All the main events of the Symposium will take place at **9 Lomonosova Street**. This location is a 5-minute walk from the Dostoevskaya and Vladimirskaya metro stations, or a 15-minute walk from either the Nevsky Prospekt or Gostiny Dvor subway stations.

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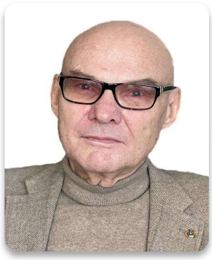

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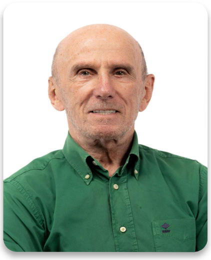

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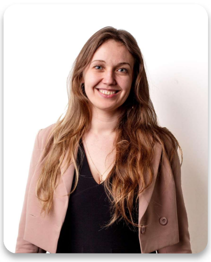

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TABLE OF CONTENT

PLENARY SESSIONS 7

Fundamentals of light-matter interaction 14

Nanophotonic phenomena & materials 31

Laser-assisted surface functionalization & related phenomena 51

Laser-induced periodic surface structures 65

Laser chemistry and materials science 76

Biomedical laser technologies 89

Light sources & optical solutions for laser technologies 112

Nano- and molecular systems for optical and biomedical applications 121

Industrial laser technologies: automatization & application of ML 145

Ultrafast laser-based microstructuring and modification of transparent materials 162

Poster session I. Laser-matter interaction & laser microtechnologies 173

Poster session II. Laser nanotechnologies & nanophotonic applications 218

PLENARY SESSION

Prof. Vitaly I. Konov*, Maksim Komlenok, Taras Kononenko, Vitalii Kononenko, Vladimir Pashinin, Pavel Pivovarov, Evgeny Zavedeev
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FORMATION OF ATOMIC SCALE SURFACE STRUCTURES BY MULTI-PULSED LASER NANOABLATION TECHNIQUE

Feasibility of short-pulse laser induced fabrication of surface ultra-shallow (atomic scale) reliefs is discussed. Formation of surface nanostructures can be performed by two basic regimes: physical (material heating and vaporization) or photochemical. For the thermal regime being the most investigated laser ablation case, the thickness of heated and ablated surface layer is defined by the maximal value of radiation penetration depth and pulsed heat conduction length. It always exceeds 1-10 nm per pulse for all materials studied, different laser pulse duration and intensity. It has been also shown that low intensity pulsed chemical etching can result in production of sub-nanometer surface structures. In this case multi-pulsed irradiation should be performed in a chemically active gas, reaction products need to be volatile. The depth of etched structures depends on the number of active gas molecules that take part in chemical reactions induced in each laser pulse. This value is limited by the thickness of the adsorbed layer formed by active gas molecules in the periods between laser pulses. It depends on the sample temperature, active gas pressure and contaminations. Chemical regime has been studied for nanoablation of various carbon materials (diamond, diamond-like carbon, graphite) in air or oxygen and silicon etching in chlorine. In all cases extremely small etching rates <1 nm/pulse, sometimes down to 10^{-5}-10^{-7} nm/pulse, were detected. Until now minimal structure depth of ≃1-2 nm was demonstrated in the chemical regime, being limited by the initial sample surface roughness. Obviously, to realize and control ultra-low rate formation of surface structures by laser nanoablation technique, really numerous (sometimes up to 107) pulses are needed. Fortunately, advanced laser systems that are available nowadays, can be utilized in such experiments: they have fs-ns pulse duration, repetition rate up to 1MHz and mean power ≥10W.

The presented activities are currently supported by the Russian Science Foundation (project №24-12-00137).

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CYBERPHOTONICS

Key words: cyberphotonics, photonic sensorics, optical computing, diffractive neural networks, laser telecommunication

Cyberphotonics is the branch of photonics dealing with basic research, design and manufacture of sensory devices, data transmission, computing, decision-making and control, which comprise an implementation base for solving cybernetic problems. Constituent parts of cyberphotonics include photonic sensorics, optical computing, diffractive neural networks, laser telecommunication, and photonic actuators. This talk does not claim to cover the topic in full but rather reflects the research interests of the author. In particular, hyperspectral sensors and their use onboard space vehicles for Earth remote sensing are discussed. In such sensors, the key unit is a dispersive element implemented as a diffraction grating on a spherical substrate. The talk discusses results of space experiments conducted with four CubSat satellites, which prove the efficiency of the proposed methods for hyperspectral image generation and processing. Considerable attention is given to analog photonic computing implemented on planar diffractive micro- and nano-structures. A variety of mathematical operations, including differentiation in space-time, computing a Laplace operator, and space-time transformations, have been realized. Diffractive neural networks (DNN) are analyzed from a perspective of their use for pattern recognition and image analysis. Diffractive optical elements (DOE) realized using the proposed methods provide high recognition accuracy (higher than 98%) of handwritten digits, alphabetic characters, and other objects from standard datasets. Besides, multi-wavelength DNNs operating at N wavelengths are discussed. The talk gives substantial attention to vortex laser beams generated with DOEs, discussing their application in data transmission systems. The final part of the talk presents a collective monograph "Cyberphotonics" published in 2025 under the editorship of the author.

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APPLICATIONS OF POLARITON LASERS IN QUANTUM TECHNOLOGIES

For a long time, the general believe in the polaritonics community was that the quantum coherence cannot be preserved in macroscopic bosonic condensates of exciton-polaritons for a time exceeding the single-polariton life-time. This was based mostly on the similarity of polariton condensates to laser modes, which may be treated as classical coherent light.

Experiments contradicted this intuition, showing that the spatial coherence of polariton condensates is extremely robust, and, in particular, polariton vortices with specific winding numbers may live as long as the condensate exists. The sceptics are never discouraged, and their next claim was that though a single polariton condensate may keep its coherence for a long time, any superposition of two eigen-states of trapped polariton condensates (that is a polariton qubit) would not survive longer than a single polariton lifetime. Our experiments on quantum beats of trapped polariton condensates provide evidence that this statement is also wrong. The T2 coherence time of a superposition of two polariton condensates in an elliptical trap appeared to be only 30% shorter than T1 coherence time of a stationary state of the condensate, with both times being on a nanosecond scale.

The third claim of polaritonic sceptics concerned an entangled state of two trapped polariton condensates, each being in a superposition state. Sceptics were confident that the life-time of this entangled state (even if one manages to generate it) would be as short as the emission time of a single photon by the system of two condensates, i.e. something on a femtosecond scale. To check if this is true, we have studied two exciton-polariton condensates in coupled elliptical traps. We verified that, initially, both condensates occupied stationary eigen-states of the corresponding traps, and the whole system was in a coherent state. Then we perturbed the system by sending nonresonant control laser pulses in carefully chosen locations. Clouds of electron-hole pairs and excitons created by the femtosecond control pulses generated the time-dependent perturbation potential for coupled polariton condensates. This perturbation helped transferring the system from the initial pure state to a final entangled state. The negativity of the density matrix of the system measured by means of time-resolved interferometry jumped from 0 to about 30% under the effect of control pulses.

We conclude that the quantum entanglement in a system of two coupled polariton condensates is indeed possible. The entangled state is not destroyed by radiative decay of exciton-polaritons. In contrast, it is stabilized due to the stimulated scattering of pairs of excitons from two reservoirs to two condensates. Therefore, trapped polariton condensates can be used for quantum computation. Furthermore, we have built the single-qubit Hadamard and Pauli-Z gates characterized by fidelities of 0.95 and 0.97, respectively, and a double-qubit CNOT gate characterized by a fidelity of 0.90.

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FEMTOSECOND LASER NANOTECHNOLOGIES FOR PEROVSKITE PHOTONICS AND OPTOELECTRONICS

Recently, nanostructured halide perovskites [1] have attracted enormous attention due to their exceptional optical and electrical properties being useful various optoelectronic devices [2] as shown in Fig.1. As a result, this family of materials can provide a prospective platform for modern nanophotonics and meta-optics [3,4], allowing us to overcome many obstacles associated with the use of conventional semiconductor materials. Here, we review the recent progress on laser ablation for application in halide perovskite nanophotonics starting from single-particle light-emitting nanoantennas [5,6] and nano/micro-lasers [7] to the large-scale designs working for surface coloration, anti-reflection, optical information encoding [8]. Moreover, we discuss high potential of the femtosecond laser ablation for improvement of perovskite solar cells [9,10], creation of microscale light-emitting devices [11] and photodetectors [12].

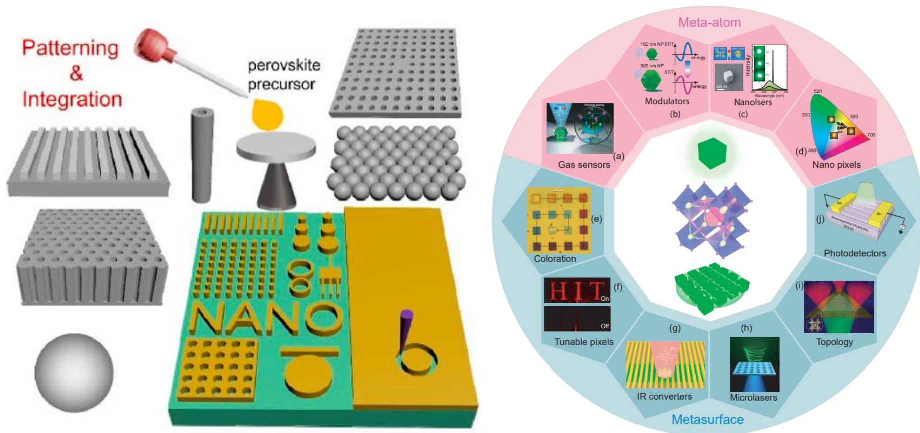

Figure 1. Schematic illustrations of methods for patterning and integration (left side) as well as applications of perovskite nanostructures in nanophotonics and optoelectronics (right side).

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LIGHT AS A FACTOR IN CONTROLLING PLANT GROWTH AND DEVELOPMENT

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INTERACTION OF OPTICAL RADIATION FROM UV TO TERAHERTZ RANGE WITH BIOLOGICAL TISSUES UNDER CONDITIONS OF IMMERSION OPTICAL CLEARING

Tissue optical clearing (TOC) is based on temporary and reversible suppression of light scattering in tissues and organs using biocompatible immersion optical clearing agents (OCAs) [1,2]. Delivery of the appropriate OCA to living tissue ensures its temporal transparency over a wide spectral range from deep UV to NIR and further to THz, thereby providing higher image depth and contrast for optical imaging modalities and better precision of laser treatments. This lecture summarizes the latest advances in the development of the TOC method for solving problems of intravital optical imaging, diagnostics and therapy. TOC can significantly improve advanced multimodal spectroscopy/imaging and light therapy technologies. The combination of optical techniques with X-ray CT and MRI is possible through the use of commercial contrast agents. The TOC method provides additional markers for monitoring diabetes mellitus complications and cancer detection, as well as important data for optimal cryopreservation of organs.

This work was supported by RSF grant #23-14-00287.

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[2] D. Zhu, V.V. Tuchin, Tissue optical clearing imaging from ex vivo toward in vivo, BME Front. 5, 0058 (2024).

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LASER FOR NANO (BIO-MEDICAL). PIONEERING PULSED LASER SYNTHESIS OF COLLOIDS

Key words: laser, small-particle, clusters of atoms, pulls radiolysis, stop flow techniques

During the past several decades, "small-particle" research has become quite popular in various fields of physics, chemistry and in biomedical. By "small particles" are meant clusters of atoms or molecules of metals, semiconductors and others materials, ranging in size between single atoms or molecules and bulk materials. In the year 1991 it has been assumed, that all substantial facts and technologies regarding nanoparticles were already known. We have been using methods: Pulls radiolysis, Stop flow techniques, and chemical synthesis in liquid system, in solutions, chemical dissolution of big particles to small nanostructures. What more was left besides tuning of existing manufacturing technologies and developing clever applications? Could lasers be put to a good use? Attempts were made, but without any particular breakthrough...

At that time, we aimed to new type of nanostructures and we really had not expected that usage of lasers could bring us something revolutionary [1]. But there was a surprize waiting around the corner... We hoped that by an absorption of intense laser beam by a solid-state material, producing temperature of plasma of many thousands kelvins (similar like in sonochemistry, where several thousand kelvins are reached in oscillating gas bubbles in a liquids [2]), similar effects could be reached. Nothing more, nothing less.

A quarter-century of nanoparticle generation by lasers in liquids: Where are we now, and what's next? New sophisticated forms of matter to revolutionize future science and technology development Opening the door into extraordinary scientific and engineering future. See the lecture...

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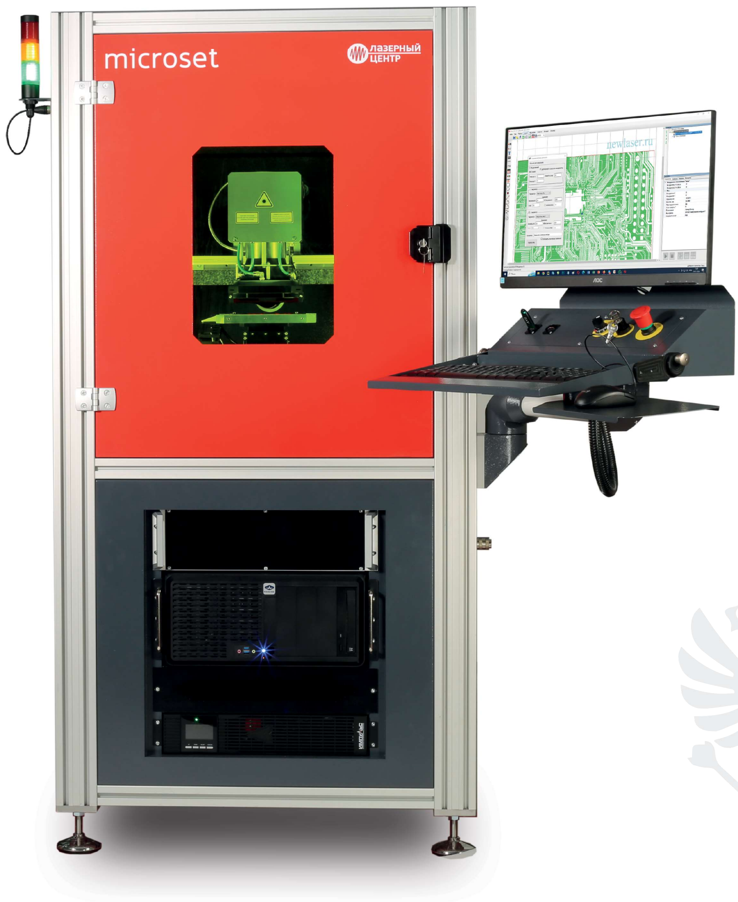

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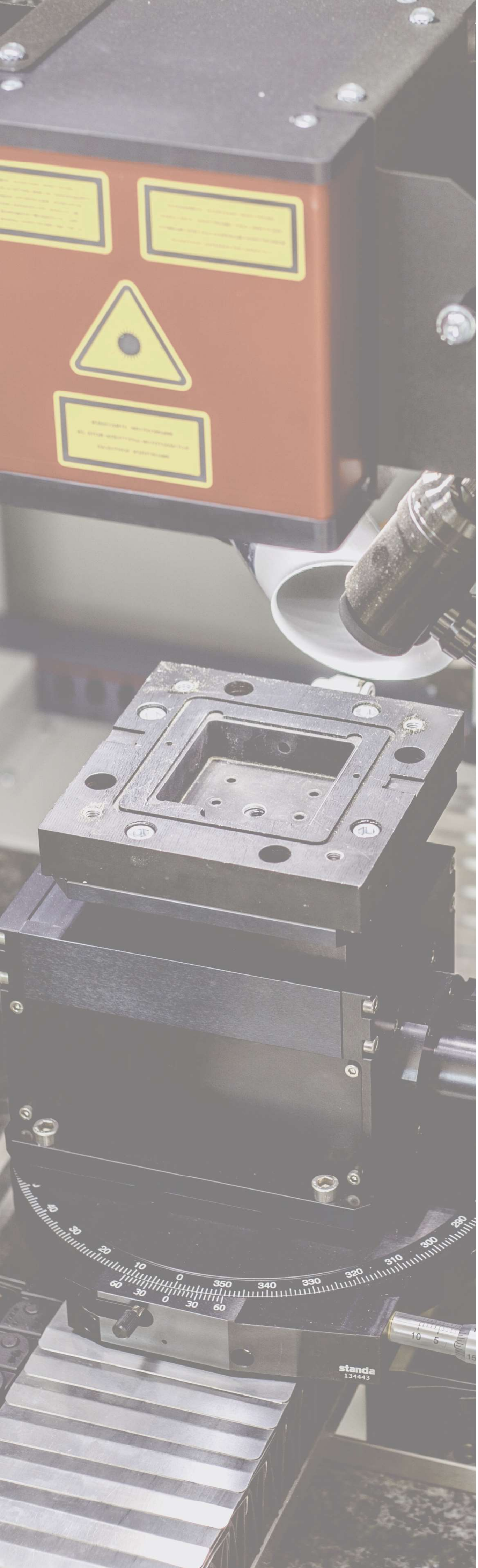

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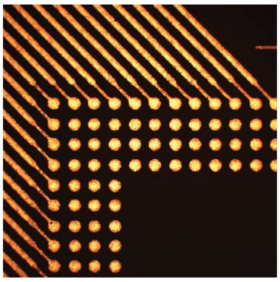

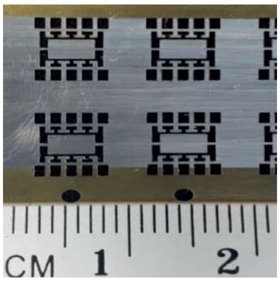

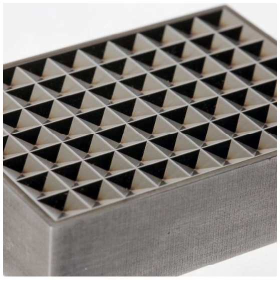

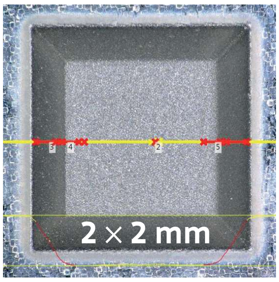

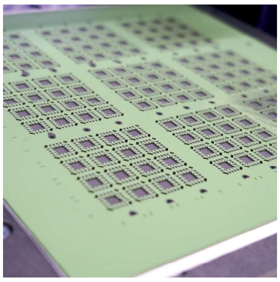

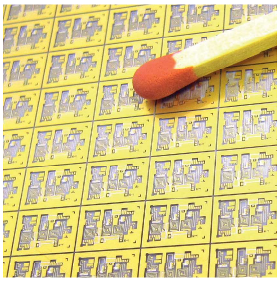

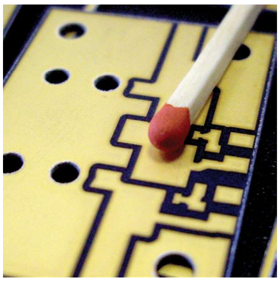

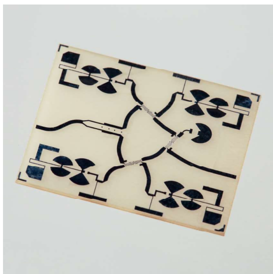

3D/mesoscale semiconductors structuring
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Wafer scribing

Fundamentals of light-matter interaction

SCATTERING OF RADIATION BY A PERIODIC STRUCTURE OF MICRO CAVITIES IN A PLANAR MULTIMODE OPTICAL WAVEGUIDE

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Key words: optical waveguide, micro cavities, periodic structure of micro cavities, radiation scattering, multimode fiber

This work is devoted to modeling the scattering of radiation by a periodic structure of micro cavities of different shapes, formed as a result of optical breakdown, in a flat optical waveguide modeling a multimode optical fiber of 62.5/125 μm. The aim of the work is to estimate the intensity of radiation scattered by the structure depending on the variation of its geometrical parameters and mutual arrangement.

For practical applications of radiation scattered by a periodic structure of micro cavities, it is necessary to ensure maximum homogeneity and monotonicity of the radiation pattern (power distribution) along the optical fiber. The power distribution of scattered radiation along a periodic structure depends on the shape, size, and mutual location of micro cavities in it. Intensity distributions of scattered optical radiation with a wavelength of 1310 nm from the side surface of the waveguide are obtained. It is shown that the shape and size of micro cavities significantly affect the side scattering pattern. Micro cavities with a small diameter practically do not scatter radiation. The intensity distribution of scattered radiation on large defects comparable to the diameter of the fiber core depends on their shape, size, and mutual location.

This work can be useful for the application of the periodic structure of micro cavities in medicine as a light source in therapeutic probes during surgical operations requiring additional illumination and uniform irradiation of the affected areas of the body. In addition, a promising direction for using the results of the work is the development of sensitive elements for fiber-optic sensors. Micro cavities formed in the scattering part of the fiber represent sensitive Fabry-Perot interferometers. The results obtained in this work will serve as a basis for the development of scattering structures from micro cavities with the most homogeneous directional pattern of scattered radiation.

DYNAMICS OF SI LATTICE AFTER NANOSECOND LASER IMPACT (INVITED)

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Key words: optical-pump X-Ray probe, laser-matter interaction, shock waves, phase transition

Using the optical-pump and X-ray probe technique in combination with molecular dynamics simulation, we have demonstrated that under nanosecond laser impact, the laser-induced dynamics of the Si lattice occurs in three stages. On the (sub)nanosecond timescale, the transmission of energy from the electron plasma to the atomic subsystem leads to the formation of a shock wave with sub-TPa pressure, resulting in the drop of the X-ray rocking curve intensity. In the next stage, the propagation of the shock wave causes the broadening of the rocking curve width, and a phase transition to Si-II is initiated at the leading front of the shock wave, while the transition to Si-III and Si-XII occurs at the trailing front. In the final stage, thermodiffusion processes from the laser impact area destroy the Si-III and Si-XII phases, with only a small amount of these phases observed at the periphery of the ablation crater and in the "traps" inside the lattice. At this stage, the X-ray rocking curve slowly relaxes to its initial state. When the laser peak fluence is lower than the threshold after ~20 ns after laser impact the X-Ray rocking curve grows which is caused the propagation of running acoustic wave.

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LASER ABLATION IN NEAR CRITICAL REGION OF LIQUID-VAPOR PHASE TRANSITION (INVITED)

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Key words: critical point, laser ablation, pressure recoil

Some resent achievements and unresolved problems in laser ablation theory and experiment are discussed together with brief history of its development. While appropriate laser pulse action now easily brings any matter in its critical or supercritical states it is not perfectly clear how and what information about equilibrium critical parameters can be obtained from such non-equilibrium processes. For this reason, in particular, critical parameters of most metals are not well defined.

There is also another problem which is due to possible metal-nonmetal transition in near critical liquid state [1]. Transformation of recoil pressure behavior observed during Hg nanosecond ablation in [2] can be probably considered as manifestation of the metal-nonmetal transition in this case. In laser metal ablation with intense sub-nanosecond pulses it was observed very much delayed (for many microsecond) perturbation after the pulse action [3]. This phenomenon is not sufficiently investigated and understood yet. It has been supposed in [4] that the phenomenon can be connected with cavitation effect when collapsing bubble generates strong perturbation in melted layer.

Recent molecular dynamic simulation [5] shows the delayed pressure signals due to the cavitation effect. Preliminary experimental results obtained in GPI RAS also give some evidence for the realization of the considered phenomenon.

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ON RESONANCES OF NANOSPHEROIDS WITH A SILVER SHELL AND VARIOUS INTERNAL STRUCTURES IN THE RAYLEIGH APPROXIMATION (INVITED)

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Key words: double layers non confocal nanospheroids, the resonances: Rayleigh approximation, T-matrix numerical calculations

The study of plasmonic nanostructures with diverse geometries and internal structures is vital for technical devices improvements. This research investigates how the structure of nanospheroids with a glass core and a silver shell influences resonance behavior. A key innovation is the removal of the confocality requirement for shell boundaries, enabling multiple resonances, unlike confocal spheroids, which typically exhibit only one. We apply the Drude–Sommerfeld theory to describe the metal optical properties. Plasmon properties depend on the nanoparticle materials and shape. Breaking confocality introduces additional resonances, depending on the internal structure.

Our model uses the Rayleigh approximation, treating electric fields as static. Scalar potentials, expanded in spheroidal harmonics, are applied to solve the Laplace equation, with different coordinate systems used for non-confocal shells to better capture geometry. Fields inside the shell are "matched", yielding a T-matrix that links external and scattered fields. The dipole component, related to the polarizability tensor (α), determines scattering characteristics and is connected with the T-matrix's principal term (T11). Due to axial symmetry, the tensor is diagonal. While only T11 is needed to find the physical quantities, a large part of the T-matrix must be involved to ensure accuracy. The solution's validity is confirmed by T-matrix symmetry and consistency with spherical T-matrix elements, obtained by transitioning from spheroidal to spherical coordinates. Numerical calculations are performed for spheroidal nanoparticles with cores ranging from nearly spherical to highly elongated or flattened, ensuring that the core occupies half the total particle volume.

THE ROLE OF THERMAL EFFECTS IN NONLINEAR ELECTRODYNAMICS OF FEMTOSECOND LASER ABLATION AND STRUCTURING OF METALS (INVITED)

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Key words: laser ablation, instability, surface plasmon-polaritons, Biermann battery, eddy currents, metal

Interaction of intense optical pulses with metals is accompanied by inhomogeneous electron heating and interband transitions. This leads to significant change of the medium optical properties and causes a set of nonlinear electrodynamical phenomena. In the talk we will focus on two ultrafast effects of thermal nature: laser pulse decay into surface plasmon-polaritons (SPPs) and low-frequency eddy currents excitation.

We showed, both analytically and numerically, that an intense femtosecond optical pulse incident normally on a metal surface tends to decay into a pair of counterpropagating SPPs. The interference field heats the medium periodically, which causes a periodic permittivity perturbation being resonant for the incident wave conversion to SPPs. The instability growth time at laser fluences of about 1 J/cm^2 was estimated as 15-50 fs for typical metals, and the calculated temperature contrast is of about 3-5 times. This makes the decay mechanism perspective for understanding of laser-induced periodic surface structure (LIPSS) formation in a single-pulse of few-pulse pumping regime. At the same time, inhomogeneous electron heating and interband transitions should lead to the excitation of bulk eddy currents due to the misalignment between the gradients of free electrons' pressure and density, similarly to the Biermann battery effect. We studied this effect for typical conditions of laser ablation of metals and showed that eddy currents should significantly heat the material at subpicosecond time scales.

Also, the generation of quite strong magnetic field of several Tesla takes place. The estimated heating depth reaches several hundred nanometers (much larger than the optical skin-layer depth), which coincides with the ablation depth of metals at optical fluences of several J/cm^2.

LASER-ASSISTED PHASE TRANSITIONS IN COULOMB CRYSTALS IN PAUL TRAPS

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Key words: Paul traps, optical traps, Coulomb crystals, phase transitions, charged particles trapping

Coulomb crystals are a unique type of matter that occurs when more than two charged particles are simultaneously trapped in an external potential, for example, electrodynamical field of a Paul trap. Coulomb interaction between the charged particles forces them to form a semi-periodic structure where each particle occupies a local stability point. Changing the properties of the trapping potential or introducing new particles in the ensemble leads to a phase transition between different possible stable configurations: one-, two- or three-dimensional. By their nature, Coulomb crystals are perfect candidates for the experimental simulation of complex many-body systems and solids and might lead to a break-through in modern fundamental and applied sciences like solid state physics and quantum information science. To fully implement the usage of Coulomb crystals in those fields of physics, it is necessary to understand limitations and possibilities in manipulation of the so-called crystal structure.

In this work, we focus on studying phase transitions in Coulomb crystals trapped in a Paul trap when an additional external trapping potential is introduced. The additional potential is created by the optical or dipole trap that is a focused gaussian beam. We numerically simulate phase transitions in Coulomb crystals when one or more particles in the crystal are additionally trapped by an optical trap, and the properties of the electrodynamic potential, such as amplitude and frequency, are changed. We determine points of phase transitions and conditions when they occur and compare the results with the case of sole electrodynamic trapping. After that, we study the oscillation spectrum of the collective waves ("phonons") in Coulomb crystals in the presence of the optical trap and without it.

FROM WEAK TO STRONG AND HARD: PHOTONICS/OPTOACOUSTICS AND INTENSE FEMTOSECOND X-RAYS (INVITED)

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Key words: photonics, optoacoustics, metasurface, intense femtosecond XFEL beams

1. Photonics and nanosensing. We consider Ni films which are formally optically thick – thickness 70 nm or 5-6 skin depths 13 nm. But due to their special structure, these films transmit light [1]. Thus, the film operates as photonics device. At the same time, the film remains an effective transducer of terahertz sound in the film and substrate [1]. Thus, our device combines the properties of photonic and optoacoustic devices. The films are created by magnetron sputtering inside few Pa Argon atmosphere.

2. Applications in material processing. A comparative analysis of ablation by femtosecond high intensity soft ($I \sim 10^{15}$ W/cm^2) 92 eV and hard ($I \sim 10^{18}$ W/cm^2) 9 keV X-ray [2] lasers has been performed. Modern XFEL produce X-ray beams with low divergence. To increase the intensity, the beam is focused into the smallest possible spot. In our work, the minimum size for soft X-rays is 3 um and 0.4 um for hard X-rays. The difference in ablation is that the attenuation length is very different for soft (few tens of nm) and hard X-rays (~ 1 mm for light elements, 7 mm in Be). This fact leads to a qualitative difference in the nature of the induced flows. In the hard X-ray case mm long empty cavity is formed not by ablation outside but due to radial indentation of matter along cavity.

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ULTRAFAST ELECTRON HEATING AND TRANSIENT OPTICAL RESPONSE OF ALL-NICKEL PLASMONIC CRYSTAL (INVITED)

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Key words: plasmonics, ultrafast optics, carrier dynamics, pump-probe spectroscopy, nickel

Powerful ultrashort pulsed lasers allow one to directly study the processes occurring in solid matter in real time via so-called 'pump-probe' femtosecond spectroscopy technique. The 'pump' pulse induces changes in material properties, while the 'probe' pulse detects the consequent modification of dielectric permittivity by measuring reflectance or transmittance. This technique has been widely used to investigate hot electron dynamics in bulk metals. In the case of a nanostructured surface, inhomogeneous electric field localization of 'pump' pulse alters the overall electron dynamics, while detected optical response dynamics of the 'probe' pulse may not follow underlying solid-state processes due to optical resonant effects.

In this work, the set of three 1D all-nickel plasmonic crystals with sinusoidal surface profiles and different corrugation depths alongside with a reference nickel plate were experimentally studied by femtosecond spectroscopy “pump-probe” technique. The studied samples support excitation of surface plasmon resonances. The differential reflectance transient trace at resonant wavelength of plasmonic crystals reached maximal values at longer times with respect to the reference plate, and the lag increased with corrugation depth. The effect is associated with non-thermal electron diffusion along the plasmonic crystal surface. Furthermore, spectral tuning of probe wavelengths near the plasmon resonance reveals non-monotonic relaxation dynamics of the optical response, contrasting with the monotonic decays observed off-resonance. The effect is caused by the strongly wavelength-dependent temperature non-linearity of effective dielectric permittivity near plasmon resonance. The observed effects allow precise control over ultrafast optical response dynamics offering the pathway to design optically reconfigurable metasurfaces and picosecond photonic neuromorphic synapses.

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ELECTRON BEAM GENERATION FROM CLUSTER JET WITH A SUB-TW LASER EXCITATION

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Key words: sub-TW laser, electron beam, clusterized gas, THz radiation

The results of an experimental study of generation of electron flow and accompanying THz radiation under the irradiation of ultrashort laser pulses with sub-relativistic intensities (up to 10^{17} W/cm^2) on a gas-cluster jet are presented. Ti:Sapphire regenerative amplifier with 35 fs pulse duration and energy of up to 6 mJ per pulse at 1 kHz pulse repetition rate was used as an excitation source in our experiments. Gas-cluster medium was formed as a jet during the adiabatic expansion of gas into vacuum through a supersonic nozzle and consists of non-clusterized gas and nanoscale clusterized targets. Due to the high local and relatively low average density of the matter, clusterized gas targets demonstrate high nonlinear properties and are able to interact effectively with high-intensive femtosecond laser pulses. High-pressure gas is fed into the interaction chamber in the pulse-periodic mode with 2 ms pulse duration and repetition frequency of few tens of Hz.

Various photoexcitation conditions of the jet formed from pure gases and gas mixtures are investigated. The possibility of efficient generation of directed electron beam with average energy of 100 keV under laser pump of the jet with sub-TW pulses is shown. Dependencies of electron and THz radiation yields on laser pulse energy, location of laser focus in the jet and stagnation pressure of working gas are presented and discussed as well.

Namely, it was shown that optimal positions for electron and THz generation have qualitative difference. Also, it was shown that varying the polarization state of pump radiation one can increase the yield of the THz radiation (in the case of circular polarization) or electron yield (in the case of linear polarization).

NONLINEAR ABSORPTION OF SINGLE-WALLED CARBON NANOTUBES ON INTERSUBBAND PLASMONIC TRANSITIONS

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Key words: optical fiber lasers, carbon nanotubes, nonlinear absorption, intersubband transitions, plasmon

Single-walled carbon nanotubes (SWCNTs) absorb infrared (IR) light due to low-energy interband transitions between Van Hove singularities, with transition energy inversely proportional to nanotube diameter. Increasing light power suppresses these transitions due to the Pauli principle, which leads to decrease of absorption up to a certain saturation level. Such the nonlinear effect is characteristic for a saturable absorber (SA) utilized for generation of femtosecond laser pulses.

The modulation depth – difference between maximal and minimal absorption – influences pulse generation and depends on the chemical potential, adjustable via electrochemical doping. The method consists in covering an SWCNT film with an ionic liquid droplet and applying voltage to alter charge carriers on nanotube surface. At low voltage (< 2V), the chemical potential remains below the second Van Hove singularity, suppressing interband transitions and reducing the modulation depth. At higher voltage, it intersects multiple energy levels, enabling inter-sub-band plasmonic (ISBP) transitions, which affect nonlinearity.

ISBP transitions create plasmons on the nanotube surface in the azimuthal direction. Plasmon energy also lies in the IR range and depends not only on the SWCNT diameter, but on the chemical potential too. By the current moment, it has been established that an increase of the chemical potential blue-shifts the plasmon absorption peak. The present research is the first to explore nonlinear plasmon response as a means to enhance SA performance.

We investigate nonlinear absorption in randomly oriented SWCNT films, deposited on a side-polished fiber and irradiated by femtosecond pulses with peak power up to 5 kW and central wavelength 1550 nm. Tight-binding model calculations of electronic band structure, dielectric susceptibility and permittivity explain trends in film optical properties. We observe the nonlinear ISBP absorption also exhibits saturation, and the modulation depth peaks at specific voltage for a given incident wavelength. The findings suggest tunable SAs for ultrafast lasers.

HYBRID ATOMISTIC SIMULATION OF METALS WITH ELECTRON-ION INTERACTION (INVITED)

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Key words: femtosecond laser, two-temperature hydrodynamics, molecular dynamics simulation

Two-temperature hydrodynamics (2T-HD) is widely used for simulation of metals irradiated by femtosecond laser pulses. This approach is applicable for electron and ion subsystems of metal starting from subpicoseconds. The 2T theory is also utilized together with the classical molecular dynamics method (MD), in which the continuous electron media is represented on a spatial mesh. But it leads to computational difficulties in interaction between the mesh electron functions and the freely movable atoms.

A new hybrid atomistic simulation technique is developed with the aim to make more accurate representation of 2T states of metal with hot electron subsystem and its interaction with atoms, in which the molecular dynamics method for atoms is combined with the well-known smoothed particle hydrodynamics (SPH) method for electrons. Each electron SPH particle (eSPH) represents conductive electrons assigned to their host atom, which move together to guarantee the charge neutrality. Such massless eSPH particles are governed by a conservation equation for electron energy balance with terms of electron-atom energy exchange and work of electron pressure. The equation of atom motion has the corresponding terms, which provides conservation of total. Electron thermal conductivity between eSPH particles is also included in the energy balance equation.

The new meshfree MD+eSPH method is applicable for 2T material flows leading to formation of density jumps, free surfaces, cavities, jets, and droplets. MD+eSPH is tested in simulations of nickel in 2T states by comparison with 2T-HD modeling. It is also demonstrated that 2T physics manifests itself in the nonequilibrium distribution of electron temperature around a shock front in metal. Since the electron pressure always pushes apart atoms, it leads to effective reduction of cohesive energy with increase of electron temperature. This effect is illustrated by a notable downshift of the calculated liquid-vapor binodal line nearby the critical point.

LASER-DRIVEN SHOCK WAVES AND EQUATION OF STATE FOR MATTER (INVITED)

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Key words: equation of state, shock compression, powerful lasers, laser-driven shock waves

The current state of possibilities of modern theoretical approaches and experimental methods for investigation materials will be presented. An illustrative discussion of equation of state of matter will be presented on example of aluminum. The description of aluminum phase diagram includes theoretical and experimental data available at high pressure, high temperature, physical transformations, the phase boundaries of melting and evaporation, the effects of restructuring of the electronic structure, ionization, and others. The most important information on materials properties at extreme conditions has been obtained with the use of shock-wave methods. Nowadays these are results obtained with the use of different types of high-explosive generators and powerful lasers. The comparison of experimental results in a wide region of dynamic pressure tens of TPa will be presented for optically transparent materials and selected metals. Novel experimental methods and demands to the experimental accuracy will be discussed as well.

GENERIC SINGULARITIES IN OPTICS (INVITED)

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Key words: electromagnetic singularities, caustics and ray tracing

A brief overview of the current state of the problem of electromagnetic field singularities arising from the refraction and scattering of light by material objects is given. The discussion begins with caustics arising from ray tracing in geometric optics and consistently moves toward increasing the accuracy of consideration and decreasing the scale, ending with a description of singularities in light scattering by subwavelength particles. Common and distinctive features of various types of singularities, the role of the symmetry of the problem and the law of conservation of energy are revealed. Physical foundations and methods for overcoming the diffraction limit are discussed. The theoretical description is illustrated by experimental examples. Various practical applications of the effects under consideration are indicated.

THE ROLE OF METASTABLE STATES IN ULTRASHORT LASER ABLATION OF METALS (INVITED)

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Key words: metastable phase diagram, multiple laser pulses, nucleation and destruction, ablation efficiency

Ultrashort (with a duration of the order of a picosecond or less) laser pulses have found numerous applications in various fields of science and technology over the past decades, from materials processing to medicine. This is due to the unique property of such pulses: due to the short time of the process, the effect on the substance surrounding the focus area is minimal. Another important property of ultrashort pulses is the realization of nonequilibrium states in matter. Since electromagnetic radiation is absorbed mainly by electrons, it is possible that electrons have a significantly higher temperature than ions. As a result, for some metal crystals (copper) with heated electrons, the melting temperature can increase significantly, while other metals (tungsten) exhibit instability of the crystal lattice. Modeling the effects of ultrashort laser pulses on metals is an extremely difficult problem. Thus, in classical atomistic approaches, the main problem is to take into account the electronic subsystem explicitly, while kinetic models are currently not formulated for strongly interacting systems.

Therefore, for modeling ultrashort laser pulses of low and medium intensity, a two-temperature, single-fluid hydrodynamic approach is most often used, which assumes local electroneutrality of the system, but the temperatures of electrons and ions are different. For metals, the analysis can be carried out in a one-dimensional approximation, since the thickness of the skin layer in which the laser radiation is absorbed is much smaller than the laser focus spot. The report will cover the physics of the ablation process, the phenomena of shock and rarefaction waves, and the features of models of multiphase equations of state, transport properties, electron-phonon exchange, and electromagnetic radiation absorption.

Special attention will be paid to the role of metastable states and the issues of substance destruction. Modeling shows that laser ablation of ultrashort laser pulses is always associated with metastable states: atomization of matter in the region of supercooled vapor, nucleation in the region of a metastable liquid at positive pressures, and spallation in the region of a metastable liquid at negative pressures. Calculations for single, double and multiple laser pulses will be demonstrated.

PHOTOSTRUCTURAL CHANGES IN FUNCTIONAL CHALCOGENIDES: FROM PHENOMENOLOGY TO NANOSCALE MECHANISMS (INVITED)

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Key words: chalcogenide glasses, phase-change materials, two-dimensional chalcogenides, neuromorphic networks

In this talk three classes of functional chalcogenides used in photonics will be considered: (i) chalcogenide glasses, (ii) phase-change chalcogenides and (iii) two-dimensional van der Waals materials.

The interest to chalcogenide glasses was ignited in the mid-1950s when B.T. Kolomiets and N.A. Goryunova found that some glasses were semiconductors. This finding was highly unusual because the presence of the forbidden gap had been, until then, associated with the long-range order of crystals. The presence of the energy gap in glasses changed the existing paradigm of the nature of the forbidden gap in solids and opened the era of amorphous semiconductors. Due to a very special electronic structure, where the top of the valence band is built from non-bonding electrons, chalcogenide glasses easily undergo structural transformations under the action of external stimuli such as light. The accompanying change in various properties makes chalcogenide glasses interesting materials for fabrication of passive photonic elements. Recently the interest to these materials has raised again due to their possible applications in the recently proposed by the leading memory manufacturers of the so called "selector-only-memory".

Phase-change chalcogenides are characterised by fast and reversible crystallisation-amorphisation process, which has been commercialised in optical and electronic nonvolatile memory devices. Recently, these materials are widely studied as candidates for development of electronic and photonic neural networks.

Finally, layered van der Waals chalcogenides, of which an example is MoTe2, will be discussed, where electronic excitation causes ultrafast phase transformation between semiconducting and metallic phases.

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COMPUTING WITH QUANTUM FLUIDS OF LIGHT (INVITED)

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Key words: optical computing, photonic structures, Bose Einstein condensation

Modern digital computers have changed our lives in a variety of ways, but the technology on which they are built is rapidly reaching a hard limit due to inherent quantum effects. Two of the main pillars of our modern digital computers are the electronic transistor and the von-Neumann computer architecture. While the von-Neumann architecture established the physical separation of computing tasks like storage and processing, transistors are the fundamental building blocks in digital computers. The drive for faster and more powerful computers can be realized by increasing the number of transistors in a processor and the clock frequency. However, Moore's law will soon come to an end, whilst the breakdown of Dennard's scaling law means that clock frequencies have remain unchanged since 2006. This leads to the pressing quest to develop new kinds of transistors and alternative computing architectures that could one day allow us to solve currently intractable problems.

In our labs, we combine state-of-the-art photonic structures and light emitting materials in which light and matter fuse to form new types of particles called polaritons. In a sense, polaritons bridge the fields of electronics and photonics by controlling the amount of light vs matter in these hybrid particles. At high densities, polaritons undergo 'Bose Einstein condensation' forming micron scale droplets of quantum fluids of light, with all particles within the droplet being indistinguishable from one another. In this talk, I will describe the fundamental properties of polariton condensates, and their applications both in analogue (simulators/optimizers) and digital optical computing.

ATOMISTIC-CONTINUUM MODELING OF LASER-INDUCED PHASE TRANSITIONS IN SILICON: MELTING, ABLATION, SOLIDIFICATION, AND AMORPHIZATION (INVITED)

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Key words: modeling, ultrashort laser pulses, laser-matter interactions, molecular dynamics, non-equilibrium phase transitions

Modern semiconductor applications demand precise laser processing at the nanometer scale, requiring a detailed understanding of phase transition and structural modification mechanisms. Accurate control over laser-induced processes in semiconductors is essential for generating predesigned surface structures and modifying the surface properties.

In this study, we present a numerical investigation of non-equilibrium laser-induced phase transitions in silicon (Si) using a hybrid atomistic-continuum model [1]. The model combines the strengths of Molecular Dynamics (MD) simulations for atomistic-scale descriptions of non-equilibrium phase transitions with a continuum approach to account for the effect of laser-generated free carriers. As compared to the ordinary continuum or MD approaches, this advanced framework, therefore, captures the kinetics of melting and ablation phenomena on one hand, and generation and diffusion of the electron-hole pairs, thermal diffusion, and the electron-phonon coupling processes during laser energy deposition on the other hand. We applied the model to determine the melting depth as a function of fluence for a 100 fs laser pulse at 800 nm. The results show that the stand-alone continuum approach underestimates the melting threshold as compared to the hybrid atomistic-continuum model by 46% originating from the detailed description of the melting kinetics. Additionally, we explored the effect of crystal orientation on melting dynamics and compared the results with the corresponding experimental measurement.

Finally, the MD model is used to identify the conditions leading to the amorphization of the Si surface and corresponding cooling rates are referred to the experimental conditions. These findings provide valuable insights into experimental observations of Si surface structuring induced by ultrashort laser pulses. Acknowledgements: The simulations presented in this study were performed at Lichtenberg Computational Facility TU-Darmstadt.

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UNIVERSAL MODEL FOR COUPLED ORTHOGONAL GRATINGS FORMATION ON CONDENSED MEDIA BY ULTRASHORT LASER RADIATION (INVITED)

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Key words: condensed matter, laser radiation, orthogonal nano- and microgratings, surface plasmon polariton interference, universal model

The problem of investigation of the physical processes behind the formation of the anomalously oriented gratings (G⊥E) on the condensed media surfaces by ultrashort laser radiation (LR) accounts more than 25 years [1]. Here E is the electric field vector of LR. As the solutions some special models have been proposed for special cases of used materials and laser regimes [2, 3]. We have suggested the universal physical approach [4-6] to elucidate the phenomenon of anomalous grating formation valid for condensed media of different physical properties. The approach is based on the consideration of surface plasmon polaritons (SPP's) mutual interference of nearby propagation directions. The interference of the SPP's with laser radiation produces "brackets" in the Fourier transform of morphology of irradiated zone, which are usually identified as the grating g of normal orientation g||E. Within the narrow range of waves angles for SPP's propagation directions their mutual interference produces the gratings G⊥E which are suprawavelength for most cases that is their periods are $D>2\lambda/n$. According to nonlinear mathematical model in framework of universal polariton model [7] for laser induced damage of condensed media the spatial periods d of formed gratings g have the discrete (quantized) values which in general case obeyed to nonlinear sequence of Sharkovsky order. Our analysis and experimental data have shown that the periods D of gratings G also are quantized and obey to Sharkovsky order. In the discussed model coupled orthogonal gratings of normal (g) and abnormal (G) orientations are considered in the process of their evolution in conditions of varying energy density or number of laser pulses (N). In this review the experimental examples illustrate the realization of proposed model for metals [4], semiconductors [5] and dielectrics [6]. So the model is substantiated for condensed media with sufficiently different physical properties. In addition, for dielectrics the correctness of the model was elucidated also for the bulk. The extension of the model was made for semiconductors (Ge, Si) and ultrashort middle-IR laser radiation. In this case the first gratings are the result of the interference with waveguide TE-type modes (WM) of nonlinear (Kerr) laser induced waveguide, and the second (orthogonal) one – by the mutual interference of WM [7].

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Nanophotonic phenomena & materials

EXCITONIC DIFFRACTIVE OPTICAL ELEMENTS (INVITED)

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Key words: exciton, diffractive optical element, ion beam irradiation, quantum well, halide perovskites

Excitonic diffractive optical elements (DOEs) are new elements in information photonics that merge controlled light scattering with the resonant and nonlinear properties of exciton resonance in semiconductors. In my presentation, I will highlight the fundamental distinctions between these resonant-material-based elements and conventional non-resonant DOEs. The functionality of excitonic DOE relies on spatially modulating the intrinsic resonant properties of excitons. It could be done by local introduction of intrinsic defects leading to the resonance broadening. I will show how focused ion beam irradiation enables such modulation in semiconductor materials, including A3B5 quantum wells and halide perovskites. Additionally, I will discuss the optical characteristics of the most basic excitonic DOE – the exciton diffraction grating. Periodic spatial modulation of the exclusively inhomogeneous broadening of the exciton resonance leads to the appearance of a distinct diffraction beam only when the wavelength of the incident light and the wavelength of the exciton resonance coincide. For all other wavelengths, the modulation contrast is absent and diffraction from the element is not observed.

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FEMTOSECOND LASER NANOSTRUCTURING IN PHOTONIC INTEGRATED CIRCUITS (INVITED)

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Key words: photonic integrated circuits, femtosecond lasers, local nanostructuring

Basic planar CMOS technology of photonic integrated circuits 32 ossesses intrinsic limitations, lacking post-processing local integration. This talk overviews the perspective role of diverse ultrashort-pulse laser nanotechnologies in site-selective integration of passive and active components in photonic integrated circuits, presenting a few practical examples.

CRAFTING AXION RESPONSE IN PHOTONICS (INVITED)

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Key words: metamaterials, non-reciprocal photonics, material parameters

Complex electromagnetic media unlock a variety of ways to craft the propagation of light and obtain unconventional material responses. An interesting option of this kind is axion response which does not affect the propagation of light in the bulk of the material, but manifests itself at the boundary of the structure, breaks both inversion and time-reversal symmetry and satisfies the same equations of electrodynamics as those describing hypothetical axions. The axion response in condensed matter is known for a long time, though its magnitude is quite small. In photonics, such materials, known as Tellegen media, have recently been realized experimentally. In this talk, I will review this area discussing the mechanisms behind emergent axion response in metamaterials. I will present our recent theoretical prediction of a novel type of electromagnetic response in photonic and condensed matter systems which has some parallels with the axion (Tellegen) media but features distinguishable optical properties.

This work was supported by the Ministry of Science and Higher Education of the Russian Federation (Project No. FSER-2025–0012).

LOCALIZED PLASMONS AND PLASMON RESONANCES OF DOME-SHAPED BUMPS AND DIMPLES OF A FLAT METAL SURFACE (INVITED)

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Key words: localized surface plasmon, localized plasmon resonance, dome-shaped bumps and dimples, analytical model

In this work, we consider the case of a vertical incidence of a plane electromagnetic wave on a flat surface of a plasmonic material with a single dome-shaped trochal irregularity (bump or dimple) of subwavelength height and a low aspect ratio. Within the framework of the electrostatic approximation, the distribution of the surface density of charges arising at the interface of such inhomogeneities with the environment is analytically calculated. In turn, this made it possible to obtain an expression for the electric field created by both the bump or dimple. On the one hand, this additional field presents the near field of the inhomogeneity, i.e. the field of the local surface plasmon. On the other hand, it modifies the distribution of the total electric field (i.e. the sum of the field of the incident wave and the surface charges) in the vicinity of the bump or dimple. The received general analytical expressions for the distributions of these charges and fields were applied in case of Gaussian profile both of such inhomogeneities. In this case, gold was chosen as the plasmonic material for such structures. To verify the obtained results, numerical calculations were carried out using the finite element method in the frequency domain. They fully confirm the results of analytical calculations, at $a < 0.5$. Expressions for the wavelength of the local surface plasmon resonance structures under considerations are also analytically obtained and numerically confirmed. The corrections to the Born approximation for dipole momentums of such inhomogeneities are analytically calculated and verified by numerical simulations.

ULTRAFAST TRANSIENT DYNAMICS OF RESONANT SEMICONDUCTOR NANOSTRUCTURES AND METASURFACES (INVITED)

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Key words: nanophotonics, metasurfaces, semiconductors, ultrafast modulation, non-equilibrium carriers

In this talk, we will discuss the effects of non-equilibrium carriers' generation under strong optical excitation, which results in rapid and ultrafast modulation of the optical properties of resonant photonic structures. These transient effects can be harnessed to create spatio-temporal optical structures even within homogeneous semiconductor films. Alternatively, we will suggest a method for ultrafast optical modulation of metasurfaces supporting bound states in the continuum through temporal breaking of the symmetry of the lattice.

This work was supported by the Ministry of Science and Higher Education of the Russian Federation (Project FSER-2025–0012).

NOVEL MIRRORS, CAVITIES, AND ANALYTICAL RESULTS FOR CHIRAL NANOPHOTONICS (INVITED)

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Key words: nanophotonics, cavities, chirality, polaritons

Geometrical chirality is a universal phenomenon that surrounds us on many different length scales ranging from geometrical shapes of various living organisms to DNA and drug molecules. Acting on a chiral biological receptor, opposite enantiomers of the same molecule cause a different response, perceived as a different odor or taste. In pharmaceutics, the opposite enantiomer of a drug molecule can be useless at best, but often it is insidiously toxic for the chiral human body. The majority of molecules involved in biological processes, such as neurotransmitters (norepinephrine, ephedrine, and others), are chiral. In this regard, there is a great demand from the pharmaceutical industry to develop effective methods of separating chiral enantiomers. Interaction of chiral matter with circularly polarized electromagnetic fields leads to the effect of circular dichroism, which underlies numerous methods for distinguishing molecular enantiomers. However, those interactions are usually weak and can be well understood.

AUTONOMOUS DISCRETE TIME CRYSTALS (INVITED)

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Key words: discrete time crystal, autonomous system, spontaneous symmetry breaking

Discrete time crystals are new states of matter in which spontaneous breaking of time translation symmetry occurs. Previously, spontaneous breaking of time symmetry has been observed in systems with periodic external driving and in dissipative systems. In our work, we predict a spontaneous breaking of time translation symmetry in an autonomous system without external driving. We consider an autonomous system consisting of two coupled single-mode cavities, one of which interacts with a ring resonator. The time of light bypass of the ring resonator determines a timescale of the system. We demonstrate that there is a parameter range in which a system state returns to its initial state only after two bypasses of the resonator. In this parameter area, the Loschmidt echo oscillates periodically in time, which is a criterion for the non-ergodic behavior of the system.

That is, the system evolution is time-reversible, and the system retains a memory of the initial state under the action of small perturbations. This behavior reveals the presence of a time-crystalline order in the autonomous system. An increase in the coupling strength between the single-mode cavities leads to a transition from periodic oscillations to an exponential decay in time of the Loschmidt echo. This corresponds to the transition from non-ergodic behavior to ergodic one in the system and is accompanied by the disappearance of time-crystalline order. We demonstrate that at the transition point, the time-averaged variance of the number of photons reaches a maximum, which serves as a signature of such a transition. Based on the obtained results, we conclude that in the parameter region where the time-crystalline order exists, the autonomous system is a new class of time crystals - autonomous discrete time crystals.

MIE MODE HYBRIDIZATION IN TELLEGEN MEDIA

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Key words: magnetoelectric effect, Tellegen medium, non-reciprocal propagation, axion response

In this work, we investigate the influence of the Tellegen response on radiating multipoles by analytically solving the problem of a radiating multipole encapsulated within a sphere composed of a Tellegen medium. Our analysis reveals that, irrespective of the type of the seed moment or the multipole order, the resulting solutions exhibit characteristic features of the Tellegen response. In particular, nonradiative surface current configurations—known as magnetic and electric anapoles—emerge at specific frequencies dictated by the zeros of spherical Bessel functions.

Furthermore, when the medium possesses nontrivial permittivity and permeability, the inherent Mie modes of the sphere hybridize under the action of the Tellegen response, leading to a distinct double-peak structure in the Mie spectra. This hybridization effect is suppressed for low-order multipoles and higher harmonics due to lower resonance quality factors but becomes prominent in high-order, high-quality multipole resonances. Collectively, these phenomena—the hybridization of electric and magnetic components, the formation of anapole states, and the double-peak resonances—provide a sensitive and unambiguous probe for detecting parity- and time-reversal symmetry breaking in nonreciprocal metamaterials, thereby offering a robust platform for Mie-resonant nonreciprocal photonics.

Moreover, we demonstrate the application of these features in the experimental distinction between the conventional axion response and the recently proposed dual axion response. Although these two material responses are indistinguishable in the absence of sources and challenging to differentiate through standard reflection-transmission experiments, the characteristic signatures identified in our study enable clear experimental discrimination.

This work was supported by the Russian Science Foundation, grant No. 23-72-10026.

EFFECTIVE CONTROL OVER NONSPECIFIC BINDING OF SINGLE MOLECULES IN A ZERO-MODE-WAVEGUIDE (INVITED)

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Key words: zero-mode-waveguides, nonspecific binding, single-molecule-detection, single-molecule-real-time-sequencing

The detection and localization of single molecules in space is still a current problem in spectroscopy, analytical chemistry and biochemistry. Single-molecule optical technologies based on the use of zero-mode waveguides (nano-holes in a metal film) are the most effective for single-molecule detection and allow significant scaling of this task to observe a gigantic number of single molecules simultaneously (up to 25 million molecular events). In our study, we show how zero-mode waveguides can be used to detect non-specific binding of single molecules - dye molecules, labeled hexaphosphates (the basic elements of single-molecule optical detection). We discover and present different methods to control non-specific binding based on the modification of the local surface potential. We discuss an approach that enables the localization of a single fluorescent molecule with a characteristic localization time of up to several seconds due to the formation of relatively weak hydrogen bonds between molecules and the quartz bottom of zero-mode waveguides.

With this approach, the advantages of ZMW can be exploited: (a) localization of molecules on the nanoscale, (b) investigation of single molecules in solutions with physiological concentrations, (c) increase of the signal-to-noise ratio in zero-mode waveguides due to QED effects. The results obtained are important for the development of methods for the determination of ultra-low concentrations of analytes with a sub-atto-molar concentration level of detection, the development of a new generation of DNA sequencers (real-time single-molecule sequencers) that allow the use of the mechanism of non-specific binding for the controlled localization of single molecules and their detection using zero-mode waveguides.

INTERPRETATION OF EXTINCTION SPECTRA OF COMPLEX NANOSTRUCTURES WITH FANO RESONANCES

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Key words: Fano resonance, extinction spectrum, quasinormal mode, Mie scattering

Fano resonance is a general phenomenon that occurs in any wave physics, including quantum mechanics, acoustics and photonics. However, the theory remains phenomenological and does not offer physical intrinsic foundations for a particular domain, and therefore a more valuable result is the development of a precise approach.

In this work, we report an ab initio theory of Fano resonances in the extinction spectra of complex nanoresonators. Using quasinormal mode theory, we show that each individual mode response in the extinction spectra exactly follows the shape of a Fano line and derive closed-form expressions for the intensity and the Fano asymmetry parameter q. The theory is applicable to any reciprocal photonic system containing resonant material dispersion, arbitrarily shaped nanoparticles and nanostructured substrates.

We demonstrate theoretically and experimentally that the line asymmetry of low-order Mie resonances can only be controlled by strong coupling between eigenmodes, which is due to the almost constant excitation field distribution in the resonator volume. Meanwhile, for high-order modes, it can be modified by polarization and the type of excitation field.

The theory can be used for improved optimization of photonic or plasmonic sensors and accurate interpretation of spectral signatures, even in cases of dense line overlaps and exceptional points. In addition, we found a special type of behavior of the Fano parameter in cases where resonances are almost not excited due to the symmetry of the structure. Here the Fano parameter can take any value, changing rapidly depending on the angle of incidence.

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HOT SPOTS IN PHOTONICS: FROM METALS TO DIELECTRICS (INVITED)

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Key words: hot spots, photonics, metals, dielectrics

The creation of highly enhanced and localized electromagnetic fields in metallic and dielectric structures, that is, hot spot technology, is an important applied and fundamental problem. Interest in hot spots is largely associated with the development of the method of Surface Enhanced Raman Scattering (SERS) at the end of the last century. Raman scattering of molecules in proximity to the hot spots can be amplified up to 10–11 orders of magnitude depending on the chosen metal structure [1]. However, the plasmonic mechanism is not necessary for the regeneration of hot spots and the observation of SERS [2]. By calculating the efficiency of electric field enhancement at the surface of a GaP dielectric sphere based on Mie theory, it was shown that the electromagnetic mechanism of Raman scattering amplification can work even for a non-metallic particle [3].

In addition to a detailed historical review, we present original results on the detection and study of hot spots in two dielectric structures. First, we found combs of equidistant hot spots in the spectral scale in a narrow gap between the square-cross-section dielectric ring and the inner disk. Secondly, we observed combs of hot spots equidistantly located along the length of a narrow slit in a rectangular dielectric plate.

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SUBSTRATE-EMBEDDED PLASMONIC NANOANTENNAS: PROPERTIES AND APPLICATIONS

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Key words: plasmonics, nanoantenna, surface plasmons, refractometry, bio- & chemosensing

The optical properties of nanoantennas in the form of subwavelength plasmonic nanoparticles buried to varying depths in a substrate are studied in detail. The effect of the substrate on the optical performance of the nanoantennas is examined, with particular attention given to the effect of the burial depth as well as of the presence and thickness of the hollow gap between the particle and the material of the substrate. Considerable enhancement of the near electromagnetic field in the gap region of the nanoantenna is demonstrated and quantified. Various shapes and materials of the particle and substrate are considered and compared. Enhanced transmission coefficient of a metal film with arrays of embedded nanoantennas is demonstrated, resulting from the tunneling of the enhanced electromagnetic field from the gap regions to the opposite side of the film. Finally, potential applications of substrate-embedded plasmonic nanoantennas are discussed with particular emphasis on the near field excitation of surface plasmon waves on the substrate and refractive index sensing for bio- and chemosensing applications.

LASER FRAGMENTATION OF METAL NANOPARTICLES FOR PRODUCING HIGH ANISOTROPIC AND CHIRAL PLASMONIC METASURFACES (INVITED)

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Key words: nanoparticles, plasmon, laser, fragmentation, circular dichroism, linear dichroism

We present a technique for producing high anisotropic and chiral silver plasmonic metasurfaces from initially isotropic nanoparticle films during fragmentation using high-intensity polarized laser radiation. Silver films were prepared by physical deposition of metal vapor in a vacuum onto glass substrates, which were then annealed to form individual nanoparticles. The films were exposed to high-power pulsed nanosecond laser radiation at the second and third harmonic frequencies (532 and 355 nanometers) of Nd:YAG laser, with linear and circular polarizations in the regions of dipole and quadrupole plasmon resonance.

Laser radiation led to the spectral holes burning at the radiation wavelength. This is accompanied by a decrease in optical density within the laser radiation area and a shift of the plasmon resonance to the shorter wavelength region of the spectrum, due to selective heating of nanoparticles and alterations in their shape. Additionally, a maximum has been observed in the long-wavelength region of the spectrum. Furthermore, depending on the polarization of the radiation, linear and circular dichroic signals have been detected in the acquired samples across the entire absorption spectrum of the samples.

SEM images reveal that when exposed to high-power laser irradiation, particles break down into smaller fragments to form a closely packed structure of interacting particles. When irradiated within the dipole resonance region, laser radiation prevents the formation of chiral and anisotropic structures that selectively absorb light of the same polarization. However, when irradiated in the quadrupole resonance area, the radiation does not resonate with the structures formed during fragmentation. In this case, it is possible that particle fragmentation occurs primarily in the direction of the linear polarization of the radiation. There is no obvious directivity for the circular polarization of light, which results in a significantly reduced CD signal compared to irradiation within the dipole resonance.

RECONFIGURABLE NONLINEAR ABSORPTION OF NANOMATERIAL COVERED WAVEGUIDE (INVITED)

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Key words: carbon nanotubes, nonlinear photonics, saturable absorbers, optical gas sensors

Optical absorption is known to be governed by the imaginary part of refractive index: higher means more absorption. In my talk we will consider a very simple system - a few tens nanometer film of the carbon nanotubes on the optical waveguide - where this simple dependence of absorption on the fails and even turns into the opposite. Consider propagation of intense light in the carbon nanotube covered waveguide when nanotube absorption saturation takes place. We show that for some nanotube film parameters the increase in propagating optical power (nanotube decreases with power) leads to decrease in transmittance (i.e. optical limiting) in contrast to what is expected under absorption saturation. To understand the effect, one needs to remember that absorption is defined not only by refractive index, but also by the overlap integral of the waveguide mode and the overlaying film. Change in the refractive index may lead to the mode reshaping and change in the overlap integral. We will demonstrate the experimental results supported by numerical modeling and analytical theory and discuss how this effect manifests itself in practical applications – design of the saturable absorbers for fiber laser ultrafast pulse generation and carbon nanotube based optical gas sensors.

INSTANTANEOUS LUMINESCENCE OF NV– CENTER IN DIAMOND PUMPED BY A FEMTOSECOND LASER PULSE

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Key words: luminescence, NV–center, diamond, Rabi oscillations, quantum light, up-conversion method, spectrochronogram

One of the important characteristics of quantum light is the speed of absorption and radiation of photons. Typically, a quantum light source is excited by coherent pumping - the falling coherent light causes coherent fluctuations in the dipole. Interaction with the internal degrees of freedom (for example, phonons) leads to relaxation from excited levels to the working level and subsequent radiation. The spectrum of emitted light consists of a coherent response - Rayleigh scattering and a noncoherent - luminescence. The quantum nature of the radiated light is contained, in particular, in the fluorescent part of the spectrum. Thus, quantum sources with the rapid formation of luminescence are very important for applications in quantum information processing.

The process of luminescence excitation of negatively charged NV centers in diamond is investigated by the up-conversion method with a femtosecond resolution. Our experimental technique allowed us to register that NV–center luminescence starts in the whole 600–800 nm spectral range in a time not exceeding 30 fs after excitation by the second harmonic of the femtosecond ytterbium laser. We have established that there is no time-dependent Stokes shift in the luminescence spectrum of the NV–center, which could be caused by relaxation of coherent phonon excitation.

The theory of instantaneous dynamics of luminescence of NV–centers was developed, which ensures quantitative consent to experimental data. It is shown that the cause of the ultra-fast formation of NV–luminescence are non-resonant Rabi-oscillations of the polarization of NV centers. The obtained results open the path to the creation of quantum light sources with an instantaneous formation of luminescence.

PHASE SINGULARITIES IN ANISOTROPIC MATERIALS FOR BIOSENSORS

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Key words: phase singularity, anisotropic material, sensor, shot noise, ellipsometry

Topological phase singularities in optical response functions offer a wide range of practical applications, from analog signal processing to the creation of innovative biosensor platforms for ultrasensitive molecular detection. However, existing approaches to implementing phase singularities are technologically complex and cumbersome.

The question of the resistance of the phase singularity-based sensors to noise and imperfections also remains open. In our work, we propose a uniaxial absorbing material as a new system exhibiting phase singularities in the reflection function. Using the analytical condition of zero reflection, we demonstrate the emergence of phase singularities in the reflection of a p-polarized wave in the space of the incidence angle and the frequency of the incident wave, caused by the Brewster phenomenon. We study the behavior of the system depending on the material parameters and show that their choice not only affects the position of singularities in the parameter space, but also their number and the total topological charge. We also note the possibility of implementing a phase singularity in the space of tangential components of the wave vectors.

Next, we investigate the stability of the refractometric sensor based on the proposed system to the influence of shot noise. We develop a theoretical model for a spectroscopic ellipsometry scheme with an integrated shot noise model operating near a phase singularity. We note two mechanisms of influence on the sensor resolutions associated with theoretical sensitivity and the influence of shot noise. The results of numerical simulations demonstrate that the incidence angle serves as an effective parameter for achieving the best resolution for measuring the analyte refractive index changes. This capability allows topological darkness sensors to function efficiently even at low light source power, making them suitable for use in compact devices.

LASER PRINTING OF SILICON-ERBIUM PARTICLES FOR SECURITY LABELS APPLICATIONS

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Key words: laser fabrication, security labels, erbium photoluminescence, hybrid nanoparticles

Counterfeit products are a widespread problem in today's world. One way to combat counterfeiting is through the use of security labels. However, these labels can often be copied using the same technologies and equipment as those used to produce the original labels. Stochastic processes are employed during the production of physically unclonable security labels, making them difficult to replicate using the same methods and equipment. This manufacturing process ensures that each label is unique, making it nearly impossible for counterfeiters to create an exact replica.

Silicon-erbium particles were produced using a femtosecond laser ablation method. We used an annealed multilayer silicon-erbium film as the donor material and glass as the acceptor. The space between the donor and acceptor was filled with isopropyl alcohol.

Scanning electron microscopy was used to determine the size and shape of the particles. The analysis showed that they ranged in size up to 800 nanometers in diameter. Raman spectroscopy revealed a characteristic peak for crystalline silicon in the particles' spectra, as well as a photoluminescence peak typical of erbium ions with a wavelength of 1.5 micrometers. Due to their varying sizes and internal structures, different particles exhibited distinct scattering spectra and colors.

The internal structure of the particles was studied using transmission electron microscopy and energy dispersive X-ray spectroscopy. These methods revealed the presence of randomly distributed crystalline silicon nanoparticles within an amorphous matrix consisting of a mixture of oxidized silicon and erbium. Based on silicon-erbium particles and resonant silicon nanoparticles, a physically unclonable security label has been developed. These labels can be verified by using photographs and the photoluminescent spectra of the particles in the near-infrared range.

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TWO-DIMENSIONAL FLAT BANDS IN P-MODE OPTICAL WAVEGUIDE LATTICE

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Key words: flat bands, femtosecond laser writing, Aharonov-Bohm caging, photonic orbitals

Photonic flat bands provide an important pathway to control and limit light diffraction [1]. All-bands-flat lattices push this concept to the limit by creating a finite Aharonov-Bohm cage for any input excitation. Although one-dimensional periodic photonic lattices with all nearly-flat bands have been realized [2], two-dimensional realization remained challenging. Here, we realize the two-dimensional nearly-all-bands-flat physics experimentally in an optical honeycomb waveguide lattice fabricated via the femtosecond laser writing technique. We achieve the nearly-all-bands flat phase by utilizing the concept of invisibility angle (coupling cancellation) arising for dipolar modes in the waveguides at certain lattice anisotropy. We experimentally observe more than three cycles of Aharonov-Bohm caging for the bulk point excitation, suggesting diffraction suppression similar to one-dimensional analogues despite the more prominent long-range couplings. Moreover, we observe even better diffraction-free propagation for the point corner excitation due to its significant overlap with the tightly localized topological corner state [3]. Localization characteristics extracted from experiment show excellent correspondence with theory accounting for both long-range interactions and non-orthogonality corrections, which start playing a major role close to the flat-band limit. Wavelength scan shows especially good localization and light caging for smaller wavelengths close to 700 nm due to diminished effect of long-range couplings of more tightly localized individual waveguide modes. The p-mode honeycomb lattice platform could find applications in diffractionless beam steering and diffractionless image transmission tunable by wavelength for optical on-chip technologies [4]. Additionally, if properly modulated, this structure could achieve diffractionless transfer of light in analogy to one-dimensional proposal [5].

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TIME-OPTIMAL STATE TRANSFER IN LONG QUBIT CHAINS (INVITED)

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Key words: quantum optimal control, time-optimal state transfer, quantum brachistochrone, qubit chains

Ongoing progress in quantum hardware has enabled the fabrication of large arrays of qubits with intricate internal designs, providing a promising platform for scalable quantum processors. On the other hand, dissipative and decoherence processes remain the main challenges on the path to building fault-tolerant quantum processors. The optimal control of these systems is essential to perform quantum protocols with high fidelity and in minimal time.

In this work, we focus on quantum state transfer in a one-dimensional array of qubits with nearest-neighbor coupling. By dynamically varying the coupling amplitudes over time, we transfer a single-particle excitation from the left edge of the chain to the right. We apply a variational approach to derive the quantum brachistochrone equations with appropriate boundary conditions. Using numerical methods, such as the shooting technique and gradient-based search algorithms to solve boundary value problem, we determine the optimal control functions for the coupling amplitudes, enabling maximum fidelity transfer in a minimal time.

Interestingly, our results reveal that the optimal transfer time scales linearly with the size N of the qubit chain. We also compare our findings with previously known protocols for full state transfer, including step-wise switching and perfect transfer methods. While the step-wise switching protocol, where only one coupling is activated at a time, also exhibits linear scaling, it requires a longer transfer time. In contrast, the perfect transfer protocol relies on static couplings but suffers from a slower, nonlinearly increasing transfer time proportional to approximately $\sim N^{3/2}$. Our findings provide an insightful example of time-optimal control for large-scale qubit arrays, offering new strategies to significantly enhance the performance and efficiency of quantum processors.

FABRICATION AND OPTICAL PROPERTIES CHARACTERIZATION OF NANOSTRUCTURED ALUMINUM THIN FILM ELECTRODES FOR ELECTROCHEMILUMINESCENT SENSORS

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Key words: nanoplasmonics, plasmonic electrodes, anodic alumina, nanotemplates, optical coatings

Aluminum plasmonic nanostructures are actively investigated nowadays due to their low cost and wide range of practical applications. Nanohole arrays in aluminum thin film are the most attractive from the point of fabrication, numerical modelling and opto-electrical properties. The electrical conductivity of aluminum film, coupled with nanohole array optical transparency, may be used in electrodes for solar cells and electrochemiluminescent sensors. The processes in such devices are also boosted near the nanoholes due to plasmon resonance and Purcell effect, as a consequence. However, fabrication techniques of such structures are usually based on electron beam lithography, which is time and resource consuming, or nanosphere lithography, which requires additional nanostructure fabrication and deposition. In this work an aluminum thin film nanohole array fabrication method has been developed, and the optical properties of the obtained nanostructures have been studied. Aluminum thin films have been obtained, using magnetron sputtering and physical vapor deposition. Anodic alumina, grown on aluminum film surface, was used as a mask for wet chemical etching. The anodization process was conducted in an ice-cold oxalic acid electrolyte and was optically controlled, using He-Ne laser. During the anodization the voltage was decreased for several times to thinner the oxide barrier layer, potassium chloride solution and reversed bias have been applied to etch the barrier layer, and iron chloride solution was used as an etchant to obtain nanoholes.

It was established that with the increase of voltage decrease times, the barrier layer becomes thinner, which was confirmed at the reversed bias etching stage. The obtained nanostructure has maxima that we attribute to plasmon resonance, according to numerical modelling. It's position depends on remaining aluminum film thickness and etching time.

The results of this work may be used in fabrication of aluminum film based plasmonic nanostructures for applications in photonics devices.

CHIRAL PEROVSKITES FOR FUTURE PHOTONICS (INVITED)

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Key words: *perovskites, chirality, circular dichroism, self-assembly*

Chiral perovskite nanocrystals with high values of absorption and photoluminescence dissymmetry factors are promising for applications in photonic devices. Although development of such materials is underway, chiral perovskite nanocrystals with optical transitions in the blue and red spectral range have low-intensity circular dichroism signals and poor stability. We have developed protocols for the synthesis of $CsPbX_3$ (X=Br, I) nanocrystals, which can self-assemble into micron-sized structures. In this way, nanorods and nanowires with transverse dimensions ranging from a few units to tens of nanometers and with longitudinal dimensions up to a few micrometers were obtained. $CsPbBr^3$ quantum dots, nanorods, and nanowires exhibit photoluminescence with a peak at 460 nm and quantum yields of 95%, 52% and 67%, respectively. Based on the analysis of dissymmetry factors for absorption (gabs) and photoluminescence (glum) and aspect ratio (R), we found that with the increasing of R value from 0 to 0.07 and 0.11, |gabs| increased from 9×10^{-5} to 1.5×10^{-4} and 3.5×10^{-4}; and at the same time, the |glum| grew from 1.4×10^{-4} to 4×10^{-4} and 5.2×10^{-4}. The reason for the enhanced optical activity is associated with increased symmetry breaking effect in these highly anisotropic structures, which cause enhanced electronic transition from the longer axis.

$CsPbI_3$ nanocrystals exhibit intense photoluminescence with a peak at 640 nm and a quantum yield of 90%. The absorption and photoluminescence dissymmetry factors of such materials reached 1.1×10^{-2} and 2.3×10^{-2} for absorption and photoluminescence, respectively. Composite films based on such nanostructures were prepared, and it was shown that such materials can be used as optically active filters. The results obtained are of applied importance for the design and fabrication of efficient spin-LED elements and photodetectors based on chiral nanostructured materials.

EXPERIMENTAL OBSERVATION OF EXCEPTIONAL POINTS AND FERMI ARC

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Key words: Fermi arc, exceptional point, Mie resonator, Fano resonance, quasi-normal modes

In this work, we report the first experimental observation of an EP [1] and a Fermi arc [2] in a single dielectric ring, arising from the interaction of radial and azimuthal modes that depend differently on the ring geometrical parameters. To demonstrate EPs related by the Fermi arc, we went into the space of two parameters, such as the height (h) and the width (W) of the ring resonator. Riemann surfaces for the eigenvalues and eigenfunctions of the two interacting modes TE_{012} and TE_{020} were calculated. The three-dimensional representation allowed us to detect two EPs in which both the eigenvalues and eigenfunctions coincide. The calculation showed that the EPs are related by a bulk Fermi arc, along which the frequencies of the two modes coincide and the half-widths vary. The EPs and FA was experimentally demonstrated using 203 experimental images, on which 203 experimental extinction spectra were obtained to cover the entire region of parameters (W, h). Fitting of experimental spectra was performed using pre-calculated spectral parameters of intensity and resonance asymmetry.

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Laser-assisted surface functionalization & related phenomena

LASER FUNCTIONALIZATION OF TITANIUM SURFACES: FOR LABORATORY RESEARCH AND FOR PRACTICAL INDUSTRIAL APPLICATIONS

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Key words: laser functionalization, titanium alloys, laser ablation, biointegration, antimicrobial activity, medical devices

This report presents developed methods and technologies for functionalizing the surface of titanium alloys. The imparting of new and improved functional properties, such as biocompatibility, osseointegration, and antimicrobial activity, is achieved by changing the physical and chemical properties of the surface of the material. Laser surface modification of titanium alloys offers a promising approach to enhance their functional properties and expand their applications in medical devices. Nanosecond laser ablation (NLA) is a particularly versatile technique for modifying titanium alloys surface. It utilizes short, high-intensity laser pulses to ablate material from the surface, creating micro- and nanoscale structures. These structures can promote bone cell adhesion and differentiation, leading to improved osseointegration. The possibilities and new applications of NLA of titanium alloys for improving the biointegration properties of intraosseous implants, such as dental implants and orthopedic implants, will be considered including the examples of actual application. The results of research on the development of NLA-based technology for the post-processing of medical devices manufactured by selective laser melting will be shown. Laser surface modification in this work is also used to impart antimicrobial properties to the surface of medical devices. Laser thermochemical writing is used to form photoactivated antibacterial coatings directly on the surface of titanium alloys. These coatings can effectively inhibit the growth of bacteria and other microorganisms, reducing the risk of infection.

The development of laser-based surface modification techniques has opened up new possibilities for improving the performance and safety of titanium alloys in medical devices. These techniques offer a versatile and effective approach to enhancing the biocompatibility, osseointegration, and antimicrobial properties of titanium implants, paving the way for improved patient outcomes and reduced risk of complications.

The research was supported by ITMO University Research Projects in AI Initiative (RPAII) (project #640114).

NANOSTRUCTURING OF NEAR-SURFACE LAYERS OF TITANIUM AND TITANIUM NICKELIDE AS A RESULT OF PULSED LASER TREATMENT (INVITED)

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Key words: titanium, titanium nickelide, nanostructuring, structure, laser treatment

The report presents the results of experimental studies with analysis of the physical mechanisms of the observed nanostructuring processes of near-surface layers of technically pure titanium and its intermetallic compound with nickel in the initial recrystallized and submicrocrystalline (SMC) states as a result of laser treatment with nanosecond pulses under a layer of water.

The structure and phase composition of the near-surface layers of the materials under study have been studied using transmission and scanning electron microscopy methods, including the use of technology for manufacturing thin foils (lamellae) with an ion beam. It has been established that in the recrystallized state, laser treatment of titanium leads to the formation of a SMC structure, and causes further grinding of the initial SMC structure to a nanostructured state. At the same time, the average size of the elements of the grain-subgrain structure decreases from 160 ± 10 nm to 75 ± 6 nm. A similar treatment of titanium nickelide occurs with amorphization of a thin subsurface layer under which a SMC structure is also formed. Possible mechanisms of the observed effect of nanostructuring of the subsurface layer are discussed. Estimates of the possibility of a sequence of phase transformations $\alpha \rightarrow \omega \rightarrow \alpha$ (phase recrystallization) and the realization of the dynamic recrystallization process under considered conditions are made.

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STUDY OF SHORT-WAVELENGTH-IR PHOTORESPONCE OF SI:AU OBTAINED BY LASER HYPERDOPING

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Key words: laser hyperdoping, Si photodetector, laser melting

Short-wavelength-infrared range includes practically important wavelengths for telecommunications and gas sensing. These practical applications require not only laser sources, but also photodetectors. The existing technologies (InGaAs, HgCdTe), have their limitations due to complicated manufacturing process and limited compatibility with Si platform. In this work we study the possibility of utilization of alternative approach consisting in laser hyperdoping of silicon above the Mott limit for impurity band formation and efficient sub-bandgap light adsorption.

Nominally pure, n-doped and p-doped Si (100) wafers were studied. For laser hyperdoping the samples were covered by gold film with thickness from 5 to 40 nm. The MiniMarker-2 M20 marking system (LTC, Russia) was used for laser melting of the gold film by scanning the sample surface by 100-ns laser pulses at 1064-nm wavelength. Residual gold film was removed by chemical etching in aqua regia and HF aqueous solution. Two Ohmic contacts were created on the irradiated surface by indium soldering for resistivity photoresponse measurements, accompanied by one contact at the bottom surface for photodiode photocurrent measurements. The sample's photoresponse was measured during 1550-nm irradiation using Keithley 6430 sub-femtoamp Remote Source Meter (Keithley, USA).

We have shown that optimization of the laser hyperdoping procedure allows to obtain more than 80% increase of sample conductivity for 1 W irradiation for nominally pure and n-doped substrates. For p-doped substrate the maximum photoresponse was 60%. The photocurrent response of hyperdoped samples was measured and discussed.

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HIGH-RESOLUTION LASER RECORDING ON METAL AND OXIDE FILMS

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Key words: diffraction grating, thin films, direct laser ablation, nonlinear photothermal effect, microstructures

Direct laser recording is a mask-free, highly efficient and cost-effective lithographic tool. Currently, the method is widely used to create various micro- and nanotechnology devices, such as photomasks used in photolithography for manufacturing chips, integrated circuits, micro-optical devices, and various surface microstructures. The process of registration of the microstructure element on the film surface occurs under the action of a focused laser beam. The pattern is formed due to the physical and chemical effects of polymerization, oxidation, and removal (ablation) of the substance. However, the resolution of the production of elements by laser recording is limited by a value of the order of λ/NA (NA is the numerical aperture of the output lens), which determines the diameter of the laser spot (resolution) in the focus area. It follows from the formula that the characteristic parameters of lasers and lenses provide the method with only a micron resolution. Recently, there have been works proposing to increase the resolution of laser recording up to the diffraction limit ($\sim\lambda/2$) and higher based on a new principle called the nonlinear photothermal effect. The approach is based on the assumption of the possibility of nonlinear interaction of the acceptor material with laser radiation having a Gaussian intensity profile. At near threshold values of the radiation power density, the size of the formed elements is significantly reduced compared to the effective diameter of the focal spot. The paper presents the results of research in the field of direct laser recording on films of molybdenum, a number of oxides: MoO_3, TiO_2, ZrO_2 and Cr/ZrO_2 bilayer. Studies have shown that exposure to focused laser radiation with threshold values of power density leads to the formation of tracks and nanodots with a characteristic size several times smaller than the effective spot diameter (which determines the basic resolution of the lithographic installation). It is shown that with sufficiently sharp focusing of the impacting beam, super-diffraction resolution of the track during processing is easily achievable. With continuous laser exposure to molybdenum films, a 3.5-fold reduction in the size of the microstructure element was achieved compared to the effective spot diameter. The best result was achieved in the nanosecond laser exposure mode, in which a 6-fold reduction in the size of the element (nanodots) on the Cr/ZrO_2 bilayer was observed. The possibility of manufacturing diffraction gratings with a meander relief, the period of which is equal to or less than the effective beam diameter, is shown.

LASER SURFACE MODIFICATION OF TITANIUM IN CONFINED CONDITIONS

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Key words: laser surface modification, absorbing layer, thermomechanical effects, material hardening, piezoelectric properties

The physical mechanisms of energy transfer during laser treatment of metals make it possible to significantly change the structure and properties of the surface layer. Usage of ns IR laser radiation to initiate localized heating of a spatially confined absorbing layer is of particular interest, as it allows the effective shock processing of underlying metal. In such conditions, intensive thermomechanical effects occur, which contribute to the formation of nanocrystalline structures and a significant increase in the hardness of the treated area.

This work presents the results of an experimental study of laser treatment parameters aimed at controlling the mechanical properties of the surface layer of titanium samples. The treatment was carried out in spatially confined conditions – the absorbing target was placed between quartz glass and the titanium sample. It was found that when ns IR laser pulses are applied to the target, a localized plume is formed, enabling intensive processing of the metal surface. This leads to significant changes in surface topography and the formation of a nanocrystalline surface layer showing high hardness values.

The proposed method can be adapted based on target. The first approach uses powdered graphite between quartz glass and titanium ("metal-graphite-glass"), forming a nanocrystalline layer (grain size about 50 nm) with hardness up to 2500 HV under nanosecond laser pulses (1.06 μm). The second method employs a graphene layer on polyimide ("metal-graphene-polymer"), achieving up to 900 HV. The third utilizes SrO powder in a "metal– SrO and TiO mixture –glass" configuration, enabling the formation of a surface with piezoelectric properties. These results demonstrate the potential for industrial-scale application of laser surface modification in metalworking and mechanical engineering.

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LASER-INDUCED DEWETTING OF BI-LAYER AU/SI THIN FILMS FOR VARIOUS NANOPHOTONIC APPLICATIONS

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Key words: laser-assisted fabrication, white-light photoluminescence, gold-silicon nanostructures, laser-induced dewetting

The question of exploiting silicon-based devices as efficient white-light sources has been challenging for several decades. Indeed, since Si is an indirect bandgap material, its photon emission is strongly suppressed and originates only from weak phonon-mediated transitions. Together with the presence of non-radiative channels of energy transfer that are usually faster than radiative ones, this leads to extremely low quantum yield for bulk Si (~10^{-7}). A promising strategy to enhance the photoluminescence (PL) efficiency of silicon structures relies on the use of hybrid Au/Si nanoparticles typically produced by femtosecond laser ablation in air or liquid. In such systems, gold nanoinclusions are introduced inside the crystalline silicon matrix to improve light absorption of the system as well as to inject hot carriers into the active material.

Here, we introduce an alternative method for fabricating hybrid Au/Si particles through femtosecond laser-induced dewetting of bilayer gold-silicon thin films. Unlike conventional ablation techniques, our approach enables the direct and high-throughput fabrication of ordered particle-based structures. We identify four distinct fabrication regimes, each resulting in Au/Si microstructures with unique geometries and optical properties. We systematically investigate their PL generation properties and propose several potential applications, including optical anti-counterfeiting and data storage. Furthermore, we focus on individual Au/Si submicroparticles that exhibit strong ultra-broadband PL signal spanning from 450 to 900 nm, with comparatively high quantum efficiencies (~1-3%). We delve into the thermodynamics underlying the formation of their complex sponge-like internal structure and explain how these structural features contribute to the observed intense white-light generation. Altogether, our findings pave the way for the development of silicon-based PL emitters with enhanced radiation efficiencies for various nanophotonic applications.

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LASER GAS AND CENTRIFUGAL ATOMIZATION

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Key words: laser gas atomization, laser centrifugal atomization

A process of laser gas atomization (LGA) has been developed to obtain a spherical metal powder with a particle size of 10 nm-100 μm using laser beams of conical geometry in an conical inert gas flow, into which the material is introduced in the form of a wire. Particle condensation from melt, vapor and erosive plasma is strongly and rapidly quenched by the inert gas flow, resulting in high supersaturation. The surface shielding by the plume of vapor and plasma is suppressed due to plume blow-off by gas flow.

The efficiency of LCA is up to 0.5 kg/kWh at an electric power of 16 kW, while the existing, most efficient methods of plasma and gas atomization provide an efficiency of no better than 0.1-0.25 kg/kWh. The method can be used to obtain powders from various materials - metals, ceramics, plastics.

The highest quality spherical powders are produced by plasma centrifugal atomization. The method has significant disadvantages - high energy costs, the inability to obtain powders smaller than 30 microns. The new method - laser centrifugal atomization (LCA) and systems for its implementation have developed, which allow us to overcome these shortcomings. In the new method, the end of a rotating hollow cylinder with a wall thickness of 4 mm is melted by a system of several lasers, whose focal spots with a diameter of, for example 2 mm are located evenly around the perimeter of the cylinder. When the cylinder rotates, a pulse-periodic mode of action is implemented for each point of the end.

Calculations of the processes of melting and evaporation of the end of a rotating hollow cylinder with a diameter of 5 cm at a speed of 170 rev/s were carried out under the influence of 4 lasers with a power of 10 to 40 kW. Atomization of the melt is carried out in an atmosphere of inert gas. And atomization of an erosion plume or erosion plasma is carried out under conditions of vacuum or reduced pressure.

The results of calculations show that the productivity of obtaining powders from the melt (size 30-200 microns) will be up to 500 kg/h with an efficiency of 0.41 kWh/kg, and nanoparticles from the vapor plume or plasma - up to 150 kg/h with an efficiency of 0.87 kWh/kg. Since the plume of vapor (plasma) is deflected by centrifugal force, the restrictions on the power of laser radiation associated with shielding the target are removed.

LASER-INDUCED INTERFACE CONTROL FOR NANOPHOTONICS (INVITED)

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Key words: nanophotonics, laser-assisted modification, nanofabrication, surface and interfaces control

Nanophotonics is a rapidly growing field of science that studies the interaction between light and matter at the nanoscale. Its basic unit is a resonant nanostructure, in which optical properties are tightly connected with its material, structural and geometric properties. Interface properties, such as those between different crystalline phases within a nanostructure created from a single material, play a crucial role in determining the optical properties of the structure. This becomes even more significant in hybrid nanosystems that combine two or more materials. Considering the wide range of effects that laser irradiation can have, due to the ability to influence different processes in solid materials through the choice of pulse duration, energy density, wavelength, and other parameters, it is a powerful tool for controlling and reconfiguring the properties of interfaces in various types of nanophotonic structures.

In this report a brief overview of laser-assisted engineering of the interface properties and its influence on the optical characteristics of nanoobjects are provided [1-4]. First, we start with the nanosecond pulses providing fabrication of TiO_2 nanocoatings on the surface of a bulk titanium plate. The results of the phase composition control and its effect on the photocatalytic properties of created system are discussed. Then, we demonstrate fs-laser assisted fabrication of complex Au-Si nanostructures on the surface of Au-Si films. The inherent nanoscale randomness alongside with developed interface properties in such systems open up a way to randomization of non-linear optical response. Finally, we have a look deep at the nanoscale and demonstrate how fs-laser assisted precise adjustment of the interface properties in single Au-Si optical nanoantennas is utilized to manipulate non-linear optical response in such complex systems. The represented results demonstrate functionalities, which laser irradiation additionally offer for nanophotonics in terms of interfaces control as well as pave the way to a wide and more flexible application of lasers for optical response engineering. The letter one is very important in fabrication of complex nanophotonic structures and their applications in different fields from quantum nanophotonics to photocatalysis and biosensing.

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UNSTEADY BOILING OF LIQUID ON A HEATING SURFACE MODIFIED BY LASER RADIATION (INVITED)

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Key words: heat transfer enhancement, surface modification, laser

The non-stationary heat exchange between a heated surface with a modified texture and a flowing liquid with a temperature below its saturation point is studied both experimentally and numerically. We use a cylindrical hollow rod with ordered protrusions, created by laser radiation, as the object. We show the mechanism of accelerated bubble condensation in the spaces between the protrusions on the heated surface, which is realized through the inflow of cold liquid from the top of the protrusion after the inertial growth phase ends. We determine the conditions for effective implementation of this phenomenon in non-steady heat transfer between a metal surface with modified texture and flowing subcooled fluid.

PROTECTION OF STEEL SURFACE FROM THE REAL ENVIRONMENT IMPACT BY LASER MODIFICATION

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Key words: laser microstructuring, wetting, corrosion, biofouling, mineral sediments

The operational characteristics of metals are substantially reduced by corrosion and surface pollution, such as mineral and biological fouling. These processes not only degrade the appearance and functionality of products and structures, but also increase the possibility of emergencies, which underlines the relevance of the development of new methods of material protection.

Traditional technologies of cleaning (mechanical, chemical) and anti-corrosion treatment (coatings, alloying) have significant limitations: risk of surface damage, use of toxic reagents, complexity of processing small or geometrically difficult parts. In this regard, laser treatment is especially interesting, as it combines the absence of consumables, non-contact and the possibility of local impact.

This paper proposes to consider the fundamentals and approaches to the development of a method of laser microstructuring of metals for the resistance of steel surface to environmental influences. Laser treatment of steel surface was conducted at normal conditions in air atmosphere using a technological unit based on a pulsed ytterbium fiber laser with a central wavelength of 1064 nm.

Research of the effects of different microgeometries, chemical composition and wetting state allows controlling the deposition rate of surface contaminants. This phenomenon is associated with a decrease in the contact area of the metal with the liquid environment and a decrease in the surface energy of the substrate, as well as with the appearance of anticorrosive oxides and compounds on the metal surface. Reduction of surface energy of steel can be provided by means of exposure in stearic acid or exposure for a long time in air atmosphere. Such bases to the development of the method of laser metal protection allow to achieve the reduction of contamination almost 1.5 times in comparison with contamination on untreated metal.

ART HOLOGRAPHY LABORATORY: CURRENT CHALLENGES AND FUTURE DIRECTIONS

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Key words: art holography, full color holography, photographic emulsion, holographic camera

Art Holography is a visual discipline at the intersection of science, technology, and art. As a technology, it remains the only method capable of reproducing truly lifelike three-dimensional imagery. Its scientific and technological foundations were established in the 1960s and actively developed until 2015. Despite this, the field remains niche and underrecognized. This report examines the key technological barriers impeding its progress and explores promising avenues to overcome them, drawing on research from the Art Holography labs at ITMO University (Saint Petersburg), the "Volonography" (Tomsk), and the "Continuum" (Novosibirsk).

The widespread implementation of art holography is constrained by several critical factors. First, the high cost of recording equipment, which requires highly qualified specialists. The experimental status of most projects makes it difficult to move to mass production. Secondly, there are problems of availability of the assortment of materials for hologram recording. Thirdly, holographic products are not characterized by durability, long-term exposure to intensive light and humidity leads to a decrease in image quality.

To overcome these limitations and fully realize the technology's potential, efforts must focus on three critical areas: first, advancing high-resolution recording media through the development of new silver halide emulsions for color holography and establishing their industrial-scale production; second, conducting in-depth research into photomaterial degradation processes to enhance their durability; and third, implementing practical applied projects.

Despite current technological and economic challenges, art holography retains significant potential. A breakthrough hinges on consolidating efforts among scientific laboratories, industry stakeholders, and artists. Investments in new materials, streamlined replication processes, and interdisciplinary collaborations could transition this technology from experimental research to mass application, opening new horizons for art, education, and historical preservation.

LIBS STUDY OF THE EFFICIENCY OF LASER CLADDING OF TITANIUM CARBIDE POWDER ON CHROMIUM STAINLESS STEEL

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Key words: laser cladding, steel, TiC, LIBS

Pulsed laser cladding of titanium carbide powder on different modes was used in the restoration of steel parts. The process of cladding with changing laser parameters was implemented on laser commercial setup Bulat LRS 50A: laser Nd:YAG (λ=1.06 μm), pulse duration 0.1-20 ms, spot diameter 0.2-2.0 mm, max pulse energy 40 J. The titanium carbide (TiC) powder was deposited over a stainless steel 4Cr13 substrate with graphite paste and BF glue fillers. The research work focuses on study of titanium carbide injection depending on pump voltage, pulse duration and spot diameter. Pulse duration used 0.5 and 0.7 ms, spot diameter 0.5 μm and 1.0 μm, pump voltage changed 275-350 V. The efficiency of titanium powder injection was studied by LIBS-method (laser induced breakdown spectroscopy): Q-switched Nd:YAG-laser (λ=1.06 μm), pulse duration 10 ns, pulse repetition rate 21 Hz, pulse energy ~120 mJ, power density ~1010 W/cm^2 with CCD registration system. The elemental composition of the steel was observed layer-by-layer with the aid of 3 times scanning sampling, the titanium spectral lines behavior was estimated on three depths. It was found out that the glue filler promotes deeper injection than the graphite paste, but less homogeneous. The pulse duration and the laser spot diameter influence more noticeably on injection of titanium carbide than pump voltage. The more the diameter and the longer the pulse the better injection.

DIFFRACTIVE OPTICS WITH 2D-TRANSITION METAL DICHALCOGENIDES (INVITED)

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Key words: laser writing, transition metal dichalcogenides, diffraction gratings

2D transition metal dichalcogenides (TMDs) is a large family of layered van der Waals materials (MX_2, M=transition metal, X=chalcogen) that have attracted significant attention due to their electronic properties. These electronic properties can be tuned by adjusting the number of monolayers in a film and of course by adjusting their composition. Furthermore, TMDs exhibit enormous optical path lengths as compared to the geometrical path as well as very large optical anisotropy, which is associated to their layered nature, suggesting a significant potential for utility in the area of photonics. The photonic aspect of TMDs makes them appropriate materials for the constitution of efficient diffractive structures, which could be, for example, overlaid to optical waveguide photonic arrangements. Here, we present laser-induced/assisted synthesis of MoS_2, WS_2 and their alloys, $Mo_xW_{(1-x)}S_2$, which provides a suitable and convenient route to the production of 1D and 2D diffractive structures that can be applied, in an additive manufacturing fashion, onto a variety of photonic substrates.

This synthesis method utilizes liquid-phase chemical precursors that are spin-coated onto substrates. Laser (or e-beam) irradiation decomposes those precursors to facilitate ultrafine spatially selective synthesis of TMDs (We report the fabrication of 1D and 2D periodic TMD structures with a period as short as ~150 nm). Here we report production of diffractive structures, which are either occurring spontaneously during the laser synthesis process (laser-induced periodic surface structures - LIPSS) or produced intentionally by direct laser writing in sequential (single beam) or interferometric irradiation fashion.

Intentional, direct laser production of diffractive structures (single beam or interferometric) is a more practical approach that provides advanced design flexibility. It is enabled by the ability of the liquid precursors, which are used to synthesise TMDs, to act as photoresists that allows spatially selective, high-resolution patterning and synthesis. 1D and 2D gratings as well as Fresnel lenses, consisting of MoS_2 and WS_2 have been produced in this manner onto silica, sapphire and lithium niobate substrates.

ABLATION-FREE LASER NANOTEXTURING OF THIN Au FILMS: HIGH-RESOLUTION STRUCTURAL COLORING AND METASURFACE PRINTING (INVITED)

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Key words: femtosecond laser pulses, gold films, structural colors, metasurfaces, direct laser nanostructuring

Optically resonant nanostructures made of noble metals are of paramount importance for diverse applications in sensing, filtering, optoelectronic devices and information encryption justifying the need for high-performing single-step and inexpensive approaches for their fabrication over practically relevant scales. In this presentation, we demonstrated direct femtosecond laser nanotexturing of thin noble metal (Au and Ag) films for the fabrication of functional plasmonic nanostructures and their ordered arrays. By exploiting tightly focused laser radiation and the unique ablation-free interaction of sub-threshold pulses with thermally thin films, we achieved highly controllable and reproducible fabrication of plasmonic nanostructures with tunable morphologies—hollow nanobumps, nanojets, and nanoholes—at lateral periodicities down to 250 nm. These nanostructures permanently modify the optical properties of the surface, enabling a template-free, high-resolution structural color printing approach with a superior lateral resolution of up to 50,000 DPI and facile tuning of color tone and saturation. Furthermore, precise orientation control of nanostructures within subwavelength lattices allows modulation of their local plasmonic response, facilitating optical information encryption within colorful images. The hidden data can be retrieved using a simple cross-polarized optical visualization scheme, adding high-resolution encryption, coloring, and security labeling capabilities to the method. We also applied this fabrication approach to produce plasmonic metasurfaces supporting symmetry-protected quasi-bound states in the continuum (QBICs) with a Q-factor up to 40, as confirmed by FTIR spectroscopy and angle-resolved third-harmonic generation experiments. We also proved high applicability of the laser-printed metasurfaces for nonlinear plasmon-mediated light conversion, SERS/SEIRA-based sensing of molecular analytes, controlling emission properties of the attached quantum emitters as well as realization of novel optoelectronic devices.

Laser-induced periodic surface structures

LIPSS-BASED PATTERNING OF THIN FILMS: PECULIARITIES AND APPLICATIONS

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Key words: laser-induced periodic surface structures, laser-material interaction, laser-induced oxidation, thin metal films

Processing of brittle transparent materials (e.g., glasses) presents significant challenges, but several successful laser-based approaches have been developed recently. An overview of these methods is provided in this work, with particular attention for the most promising laser-induced backward transfer (LIBT) and laser-induced periodic surface structures (LIPSS) techniques. Laser-induced periodic surface structures created on glasses are of specific interest due to versatility of their appearance and morphology depending on slight changes in the laser processing parameters and materials characteristics. Close attention is required for the monitoring and prediction the morphology of thermochemical laser-induced periodic surface structures, generating on an auxiliary metal films deposited on glass substrate and oxidating under the laser action in air. Complex of the material parameters and physical-chemical processes directs the thermochemical laser-induced periodic surface structures appearance, but harnessing these processes allows to directly pattern the surfaces of transparent materials on the submicron level, opening the possibilities for demonstrating all kinds of optical effects.

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PEROVSKITE DEVICES WITH LIPSS (INVITED)

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Key words: LIPSS, perovskite thin films, nanostructuring

Nanostructuring of $APbX_3$-based perovskite thin films is a powerful tool to improve the performance of photovoltaic devices based on them, Due to increase of charge extraction or modifying layer and change of light reflection and transparency, it is possible to achieve not only structural coloration, but light trapping effect and better light manipulation. Laser-induced periodic surface structures (LIPSS) have great promise for a plenty of perovskite optoelectronic devices: solar cells and light emitting diodes. However, LIPSS formation on perovskites is a challenging process because of their organic-inorganic chemical composition and might cause perovskite degradation. At the same time, due to the difficulty in exciting plasmon resonance in dielectric and wide bandgap semiconductor materials, the formation of periodic structures becomes challenging without the use of ultrashort pulses.

In our work, we explore the potential of applying a perovskite layer on a pre-structured surface of the transport layer in order to take advantage of the shape effect. We demonstrated direct laser formation of highly-ordered continuous LIPSS on the FTO, TiO_2 and ITO films with the use of UV nanosecond pulses and investigated the influence of processing parameters on the period their uniformity of such gratings. $CsMAFAPbIBr_3$ and $CsPbBr_3$ perovskite thin films on nanostructured TiO_2 substrate demonstrate anisotropy of perovskite luminescence. If the LIPSS forms on ITO the anisotropy of light is not detected experimentally. In addition, these perovskite films show structural coloration from both sides due to light diffraction when they are deposited on LIPSS. We proved that TiO_2 LIPSS improves the charge extraction from perovskite films, which was confirmed by time-resolved photoluminescence. The developed method does not damage or deteriorate the formed perovskite films, unlike direct laser ablation of APbX3 materials, mold imprinting, mechanical scratching with a probe or plasma chemical etching. In addition, LIPSS formation is suitable for scaling up the method due to the high performance of laser processing up to 2.25 cm^2/min and the possibility of uniform nanostructuring of the entire working area.

The work is funded by Russian Science Foundation grant № 24-79-10131.

LASER-INDUCED SURFACE MICRO- NANOCLUSTERS OF DIFFERENT TYPES UNDER COMPETITION OF TOPOLOGICAL AND THERMODINAMICAL PARAMETERS TO PRODUCE BY CONTROLLED WAY THE FUNCTIONAL CHARACTERISTICS (ELECTROPHYSICS AND OPTICS) (INVITED)

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Key words: laser thermodynamics, topological surface dendrites in high entropy alloy, electrophysics

The processes and models of synthesis of surface dendrites structures and defects with controlled micro- and nanotopology during laser ablation of high-entropy alloys are considered. Their stechiometric composition $FeCr_{0.6}Ni_{0.1}Mn_{0.3}CO_3$ corresponded to the structure of the AVX3 type of perovskite with high photoconductivity efficiency.

In the experiment, we used YAG:Nd^{3+} - laser (wavelength 1.06 microns) with a laser radiation power density of up to 106 W/cm^2 with a millisecond pulse duration. The process of local heating due to the absorption of the medium in the laser beam occurred under conditions of surface thermal conductivity in a thin layer. The temperature distribution field was determined by the radius of the light spot on the sample surface and the duration of the laser pulse when it was scanned over the surface in a preset mode.

A universal model is proposed within the framework of laser thermodynamics concepts for the surface synthesis of crystal structures of a high-entropy alloy with dendrites induced as a result of different modes of exposure to a sequence of laser pulses during laser ablation. The entropy of mixing is calculated depending on the number of point defects and configurations of the implemented topology of dendrites. It is found that the high-entropy of mixing of such structures leads to an effective increase in the local electric field on the dendrite sample.

The high electrical conductivity on the surface of a sample with a collection of single dendrites is estimated to be several orders of magnitude higher than its value for a homogeneous surface configuration. Modeling of the Volt-Ampere Characteristics (VAC) of a surface ensemble of dendrites is considered in the framework of island fractal structures of the cluster type. The results of the electrical conductivity measurement depended on the location and transverse dimensions of the micro contacts in the AFM sensing technique when scanning them over the sample surface. In this case, the VAC was determined, firstly, by isolating and estimating the lengths of the electrical conductivity paths for the simulated inhomogeneous film, taking into account the hopping component between discrete islands/clusters. Secondly, – as the sum of the resistances of the conduction paths in the presence of jumps of charge carriers in a specific configuration of the dendrites on the sample surface. Mathematically, to isolate the conduction path between clusters, we considered a weighted graph of possible jumps with vertices in islands and edges with weights equal to the distances between clusters, taking into account the radius of localization of the charged objects/electrons. The effect of thermo-oxidative degradation of a high-entropy alloy of dendrites, which dramatically changes the functional characteristics of the samples, is analyzed.

The considered systems with controlled electro physical and optical characteristics are of considerable interest for nanophotonics and nano- microelectronics in the development of elements and systems based on new physical principles. This is of fundamental importance, among other things, for studying directions and trends for achieving a superconducting state in selected topological configurations created in a controlled manner in different schemes of laser thermodynamics.

SILICON LIPSS WITH MAGNESIUM SILICIDE NANOLAYER FOR ENHANCED POLARIZATION-SENSITIVE INFRARED PHOTODETECTION

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Key words: laser-induced periodic surface structures (LIPSS), femtosecond laser processing, near-infrared photodetectors, polarization sensitivity, magnesium silicide

Silicon (Si) nanostructures offer significant advantages in optoelectronics, particularly for enhancing the performance of silicon-based photodetectors and solar cells. At the same time, inherent limitations of Si restrict its applicability in many applications due to limited spectral response (~1100 nm) constrained by 1.12 eV material bandgap and centrosymmetric crystal structure rendering insensitivity to the incident light polarization. This study addresses these limitations by liquid-assisted femtosecond (fs) laser nanopatterning of monocrystalline Si followed by subsequent deposition of the magnesium silicide (Mg_2Si) nanolayer. Direct fs-laser irradiation of silicon in methanol produces well-ordered laser-induced periodic surface structures (LIPSS) exhibiting significant optical anisotropy, thereby inducing inherent polarization sensitivity.

The use of methanol as the processing liquid precludes Si oxidation, removes ablation products and shrinks down the LIPSS periodicity to subwavelength values demonstrating broadband antireflective performance [1]. Moreover, the fs laser treatment introduces defects within the patterned near-surface layers resulting from ultrafast phase transitions (melting and recrystallization) and enhancing the absorption at near-infrared wavelengths beyond the intrinsic absorption edge. This allowed as to demonstrate LIPSS-patterned vertical p-n junction Si photodetector with sub-band photoresponse and cross-polarized modulation contrast above 400% at low bias voltage [2]. Device performance was further optimized by capping its LIPSS-patterned active areas with a nanolayer of narrow bandgap ($E_g \approx 0.7$ eV) Mg_2Si, which extends the operation range up to 2000 nm. The developed cost-effective CMOS-compatible fabrication route holds promise for production of high-performance, polarization-sensitive Si-based photodetectors for advanced medical imaging and security systems.

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FORMATION OF 2D LASER-INDUCED PERIODIC SURFACE STRUCTURES WITH FEMTOSECOND LASER PULSES

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Key words: LIPSS, GST, femtosecond laser pulses, self-organized structures, surface structuring

Formation of laser-induced periodic surface structures (LIPSS) under the impact of laser radiation is a promising method for surface structuring of a wide range of materials. It is generally accepted that interference between incident light and waves scattered on inhomogeneities of the irradiated surface is a main mechanism of LIPSS formation in the form of grooves in the case of ablative LIPSS or protrusions in the case of thermochemical one at the maxima of intensity modulation. Moreover, LIPSS formation based on a material phase change from amorphous to crystalline or vice versa was demonstrated recently and have gained significant attention in research due to possible applications in all-optical tunable photonics. Using LIPSS, it is possible to create periodic relief not only with one-dimensional (1D), but also with two-dimensional (2D) periodicity providing optical properties anisotropy of the processed surfaces. Here, we present the results of 2D thermochemical LIPSS formation on Ti (30 nm) thin films by fs laser pulses with linear polarization and the central wavelength λ of 1026 nm. The formation of 2D structures was carried out using 2 scans with perpendicular polarization direction and two types of pass orientation relative to each other: parallel and perpendicular. We found that in the case of parallel tracks, square 2D structures are formed, and in the case of orthogonal tracks, hexagonal 2D structures are observed. Scanning with different angles α between the directions of polarization during the first and second passes was also investigated. In addition, performed numerical simulation of thermochemical LIPSS formation is in good agreement with the experimental results. We also demonstrate the formation of similar 2D structures on 200 nm thick film of phase change material ($Ge_2Sb_2Te_5$) despite a different mechanism of LIPSS formation in this case.

The work was supported by the Russian Science Foundation grant (No. 21-72-20162-П).

NUMERICAL SIMULATION OF LASER-INDUCED SURFACE STRUCTURES FORMATION UNDER MULTI-PULSE LASER PROCESSING

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Key words: laser-induced periodic surface structures, thin films, ultrashort laser pulses, surface functionalization

Laser-induced periodic surface structures (LIPSS) are nanoscale to microscale patterns formed on solid surfaces through high-intensity laser irradiation, often resulting from light–matter interactions such as interference and ablation. These structures exhibit remarkable periodicity and orientation, enabling applications in optics, tribology, biomedicine, and energy harvesting and storage. A relatively recently discovered non-ablative type of LIPSS, formed via thermally stimulated oxidation of metals and semiconductors by femtosecond laser pulses and referred to as thermochemical LIPSS (TLIPSS), has attracted significant attention owing to its extremely high uniformity and complex chemical composition. Unlike the commonly obtained ablative LIPSS, which are oriented orthogonally to the laser polarization direction, TLIPSS align parallel to the polarization. As a result, established models that implicitly or explicitly rely on surface electromagnetic waves, such as surface plasmons, are not applicable for explaining TLIPSS formation. Moreover, like other types of LIPSS, TLIPSS generally form and are studied in a multi-pulse exposure regime with scanning, whereas most existing models do not account for multi-pulse processing and scanning effects.

In this work, we demonstrate an algorithm to numerically model the multi-pulse formation of TLIPSS based on dipole-like light scattering from surface roughness. The algorithm involves calculating the intensity distribution on the irradiated surface resulting from interference between scattered and incident fields, followed by simulating changes in surface relief due to localized oxidation after a single laser pulse. These steps are iteratively repeated to simulate the cumulative effect of the specified number of pulses under dynamically changing scattering conditions with arbitrary scanning schemes, laser beam profiles, and linear polarization directions. Using titanium as an example material, the algorithm successfully reproduces experimental results, including the formation of 2D TLIPSS with quadratic and hexagonal periodicities, as well as variations in TLIPSS morphology and uniformity when writing on the cylindrical surface of an optical fiber with different polarization directions.

The work was supported by the Russian Science Foundation grant (No. 21-72-20162-P).

HIGHLY REGULAR LASER-INDUCED PERIODIC SURFACE STRUCTURES FOR PHOTONICS AND FIBER OPTICS (INVITED)

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Key words: LIPSS, D-shaped fiber, GST, reflection spectrum

The micro- and nanostructuring of materials is highly demanding for producing advanced photonics devices with tailored optical and mechanical capabilities. For optical fibers in particular, the fabrication of regular periodic structures on the flat fiber tip, and polished side of D-shaped fibers enables efficient light coupling and the development of advanced fiber sensors. This sensing system exploits resonant effects, such as surface plasmons, to enhance its sensitivity and resolution. Among existing fabrication techniques, femtosecond laser-induced periodic surface structures (LIPSS) emerge as a cost-effective, rapid, and scalable solution for these applications.

Here, we present the results of highly regular LIPSS formation on Ti thin films deposited on the optical fiber tip and polished D-shaped fiber under the impact of IR fs laser pulses with linear polarization. In the first case, light coupling at extremely large angle (~50 degree) with 1D and 2D LIPSS was demonstrated. In the second case, the surface periodic relief of LIPSS enables fundamental mode coupling propagating in opposite directions resulting in a narrow peak (~1 nm) in the reflection spectrum due to the high regularity of the induced thermochemical LIPSS. We also demonstrate the formation of highly regular LIPSS on 100 nm thick film of phase-change material ($Ge_2Sb_2Te_5$) deposited on a polished D-shaped fiber promising for rewritable spectral filters. Moreover, the high regularity of the structures facilitates resonant coupling of incident to the surface plasmon waves on the silver-coated LIPSS providing a large resonance amplitude and Q-factor of 150 with high potential for plasmonic biosensing and nonlinear optics.

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MAGNETIC LIPSS FABRICATION FOR BIOSENSING (INVITED)

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Key words: femtosecond laser pulses, laser-induced periodic surface structures, thin magnetic films, magnetic nanostructures, biosensorics

Magnetic biosensors (MBS) based on a spin valve (SV) are promising components for creating a lab-on-a-chip, due to their compactness, ease of operation and high sensitivity [1]. Promising approaches to manufacturing SV-based MBS are local laser annealing to switch the exchange bias in the SV [2] and laser-induced periodic surface structures (LIPSS) fabrication [3] on MBS for more efficient retention of magnetic nanoparticles (MNP) used as detection markers, due to the relief roughness and enhanced interaction of the MNP magnetic field with the SV [3].

In order to analyze the possibility of modulating the SV structure using LIPSS, as well as laser-induced switching of its exchange bias, we irradiated Si substrates and Si/Ta/NiFe/IrMn/Ta films, representing a layer of SV structure, with femtosecond laser pulses (1250 or 1050 nm; 150 fs, 10 Hz – 80 MHz, up to 125 μJ).

In the first case, LIPSS were formed on Si using femtosecond pulses, and covered by Ta/NiFe/IrMn/Ta film. The LIPSS structure after laser irradiation and after film deposition was monitored by SEM. In the second case, Ta/NiFe/IrMn/Ta film was laser-irradiated in a magnetic field with femtosecond pulses below the ablation threshold. Kerr microscopy revealed that within the laser-structured substrate, the Ta/NiFe/IrMn/Ta film exhibits an out-of-plane magnetic response. Switching of the film magnetization direction after femtosecond laser annealing is demonstrated and formation of magnetic-only LIPSS representing gratings with alternating magnetization on its surface was discovered. The periods of magnetic LIPSS correspond to the laser wavelength used. The obtained results can be used to increase the sensitivity of the MBS based on SV.

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LIPSS-BASED NANOPATTERNING FOR PHOTONIC AND OPTOELECTRONIC APPLICATIONS (INVITED)

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Key words: LIPSS, nanogratings, nonlinear crystals, vanadium dioxide

Multi-pulse laser exposure of material interface can drive self-organization phenomena yield in periodically modulated energy deposition and formation of ripple-like surface morphologies also referred to as laser-induced induced periodic surface structures (LIPSS). LIPSS have appeared to be a universal phenomenon allowing to pattern practically any type of material with subwavelength periodic nanomorphologies. Self-organization can be achieved within large focal spots yielding in regular nanoscale feature size almost unachievable with direct laser patterning justifying practical attractiveness of such technologies for diverse applications. In this presentation, we will summarize our recent effort related to LIPSS formation over the surfaces of diverse materials including several types of promising nonlinear crystals, thin films of titanium and thermochromic vanadium dioxide. We will discuss the origin of LIPSS formation as well as demonstrate applications of such grating-type morphologies for modulation of the optical properties of mentioned materials with the application area in structural coloration, anti-reflection, filtering and optoelectronics.

LIPSS AND DIFFRACTIVE OPTICS (INVITED)

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Key words: laser-induced periodic surface structures, diffractive optics, diffraction grating, laser technology

Laser-induced periodic surface structures (LIPSS) are formed on the surface of a number of film materials (Ti, Cr, Si, and others) under the influence of pulse laser radiation. They have a fairly high order and submicron periods. They can potentially be used in diffraction optics to cost-effectively solve a number of relevant applied problems, for example, such as the formation of diffraction gratings for separating light beams by wavelength, beam splitting of monochromatic beams, increasing the efficiency of solar cells by reducing light reflection and increasing absorption, creating metamaterials operating in the infrared light, manufacturing biosensors and optical sensors, creating anti-reflective coatings, encoding visual information to protect products from counterfeiting. The potential advantages of using LIPSS are one or two (in addition to etching) stages of the forming process, high reproducibility, the ability to work with various materials, flexibility in creating complex structures, miniaturization and integration into micro-optical systems.

In turn, the methods and the element base of diffractive optics can also be useful for the technology of forming LIPSS. This is a fairly new approach based on the use of diffractive optical elements (DOE), which make it possible to control the distribution of intensity, phase, and polarization of laser radiation in the plane of the exposed sample in order to create complex microstructures on the surfaces of materials, as well as improve the performance of laser writing and the uniformity of the formed LIPSS. Optical diffractometry methods developed for the control of DOE are also in high demand for the characterization of LIPSS. Thus, researchers of LIPSS formation methods and specialists in diffractive optics can provide each other with new tools and methods for creating new innovative technologies and component bases of microsystem technology.

Laser chemistry and materials science

LASER-ASSISTED OMCVD IN MATERIAL SCIENCES (INVITED)

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Key words: laser, CVD, organometallic compounds, material sciences

The properties of a body are essentially determined by its surface rather than its volume. The deposition of organometallic compounds via Chemical Vapor Deposition (OMCVD) makes it possible to apply surface coatings even to temperature-sensitive bodies in material sciences or microtechnology. Organometallic chemistry is defined as chemical compounds in which an organic ligand is directly bonded to one or more metal atoms. This chemical modification with organic ligands specifically alters the physicochemical properties such as vapor pressure or sublimation capacity, making such compounds particularly suitable for OMCVD. For surface deposition, energy must be coupled in to specifically cleave the metal-carbon bond and cause the metals to precipitate from the gas phase. Traditionally, heat is used for this purpose. Laser technology is superior to traditional methods like heat in this regard, as it allows coupling in laser photons that exactly match the bond energy of the metal-carbon bond. The combination of laser technology with OMCVD represents a further advance: Here, the coatings can be obtained much more precisely than with conventional thermal OMCVD. The lasers used and their provided energies must be well matched to the chemical organo-metallic compounds used. This makes it possible to produce coatings with metals that are of particular value in materials science or microtechnology, but have previously been difficult or even impossible to obtain.

PHOTOCATALYTIC SELECTIVE OXIDATION OF TOLUENE OVER CHLORINE-COORDINATED MIL-101(Fe) UNDER AMBIENT CONDITIONS (INVITED)

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Key words: photocatalytic selective oxidation, metal-organic framework (MOF), C(sp^3)⁻H bond activation, photocatalytic mechanism

The selective oxidation of C(sp^3)−H bonds under mild conditions is a challenging process. We report a stable chlorine-coordinated metal−organic framework (MOF) photocatalyst, MIL-101(Fe), for efficient visible-light-driven oxidation of toluene to benzaldehyde under ambient conditions. This catalyst achieves a benzaldehyde yield of 3.11 $mmol{\cdot}g^{-1}{\cdot}h^{-1}$ with 92.1% selectivity in 5 hours, outperforming most reported methods. The high catalytic performance is attributed to the activation of the C(sp^3)−H bond via a chlorine radical (Cl) from the coordinated −Cl in the MIL-101(Fe) structure. Additionally, the photocatalyst shows good tolerance to various toluene derivatives, making it versatile for selective oxidation under optimized conditions.

PLASMON-ASSISTED TRANSFORMATIONS OF RADICAL PRECURSORS UNDER IR LIGHT (INVITED)

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Key words: plasmon, nanoparticles, plasmon-assisted transformations

The plasmonic chemistry provides novel opportunities for the initiation of organic reactions under visible or IR-light. One of key direction in the plasmonic chemistry is the selective activation of homolysis processes for the formation of radicals. The report will be dedicated to the fundamentals of C-I and C-O bonds homolysis under plasmon excitation. Moreover, the implementation of alkoxyamines as chemical probe for the mechanistic studies will be discussed.

DEFECT ENGINEERING OF MoS_2 BASED ON PHOTO-DRIVEN FENTON REACTION (INVITED)

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Key words: MoS_2, laser processing, electrocatalysis

Molybdenum disulfide (MoS_2) is a widely studied 2D semiconducting material with promising applications in (photo)catalysis, particularly its monolayer form with a direct bandgap. The Gibbs energy at the edge of MoS_2 is close to zero, which enhances its photocatalytic efficiency. However, further improvement can be achieved by inducing defects and functionalizing MoS_2 with nanoparticles. Herein, we present a green, cost-effective, and rapid method to increase defect density in MoS_2 and deposit nanoparticles. We propose a mechanism in which MoS_2 is etched down to a highly defective monolayer through a photo-driven Fenton reaction. Notably, this process does not require the external supply of Fe^{2+} or H_2O_2, as they are generated in situ by Fe^{3+} and radicals. The resulting structures exhibit enhanced efficiency in electrocatalytic hydrogen evolution reactions. High-defect areas are functionalized by magnetic nanoparticles during the process. Furthermore, we demonstrate that deposition locations can be defined by laser-induced defects, and the deposition area can be optimized by controlling light intensity and illumination time. This approach offers a potentially interesting and scalable method for fabricating predefined patterns of photocatalytically active structures for advanced applications.

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METAL–NITROGEN–CARBON CATALYSTS FOR WATER PHOTOELECTROCATALYSIS (INVITED)

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Key words: nanocarbon, electrocatalysis, CO_2 reduction, catalytic mechanism

Photo-assisted electrocatalytic CO_2 reduction technology significantly enhances CO_2 conversion efficiency and reduces reaction energy consumption by coupling light energy with electrical energy and utilizing the photoelectrochemical synergistic effects of semiconductor materials. The core of this strategy lies in the photoexcitation-generated electron-hole pairs, which optimize the surface charge distribution of electrocatalysts, thereby promoting CO_2 adsorption/activation and lowering the energy barriers for key intermediate formation.

How to effectively reduce CO_2 emissions and develop non-fossil fuel resources is essential to reduce the greenhouse gas CO_2 emissions in the atmosphere and reduce our dependence on non-renewable energy resources. The technology of using renewable energy to generate green electricity, and the technology of electrochemical CO_2 reduction of electric energy to prepare high value-added chemicals of formic acid only needs to be carried out under normal temperature and pressure, and has the advantages of fast reaction rate and high conversion efficiency, which has attracted more and more researchers' attention in recent years. Although traditional bulk metal materials have certain catalytic activity for electrocatalytic CO_2 reduction, they often have the disadvantages of high overpotential, low current density, poor product selectivity, and easy inactivation, which seriously hinder the industrial application of bulk metal materials in electrocatalytic CO_2 reduction. Compared with bulk metal materials, metal single-atom catalysts often exhibit unexpected catalytic activity in some important chemical reactions due to their unique electronic and geometric structures, special size effects, and other characteristics. The project has carried out systematic research on this problem, and has taken the lead in proposing the structural design principle based on key carbon-rich non-precious metal electrode materials in the process of high energy efficiency conversion, and has achieved a series of innovative research results.

LASER SPECTROSCOPY OF CARBON NANOPARTICLES IN CREATION OF MULTIMODAL LUMINESCENT NANOSENSORS (INVITED)

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Key words: carbon dots, multimodal luminescent nanosensors

The relevance of the development of optical nanosensors of environmental parameters is due to the active development of science and industry, where the problem of controlling the content of substances in multicomponent media is becoming increasingly acute.

One of the most promising bases for sensors are carbon dots (CD), which have photoluminescence (PL) that is sensitive to environmental parameters. The objects of our study were CD synthesized by hydrothermal method from citric acid and ethylenediamine. The effect of temperature, pH, ions present in the medium, on CD PL was found. In this study, the mechanisms of pH and temperature influence on CD PL were studied by quantum calculations of the behavior of surface groups at various pH and by the results of analysis of dependences of CD ζ-potentials on the pH. Using the artificial neural networks, CD-based nanosensors were developed that allow measuring the temperature and pH of the environment with an accuracy of 0.67°C and 0.005, respectively. As a result of studying the interactions of CD with metals ions, the sensitivity of CD PL to certain ions was discovered and confirmed by molecular dynamics calculations. Using the Stern-Volmer theory and PL decay kinetics, it was found that the main type of PL extinguishing by ions is a dynamic mechanism. The use of convolutional neural networks made it possible to develop a CD nanosensor that provides the accuracy of the simultaneous determination of Cu^{2+}, Ni^{2+}, Al^{3+}, Co^{2+}, Cr^{3+}, Pb^{2+} and NO_3-in water from 0.21 to 1.00 mM. The obtained errors satisfy the needs of monitoring the composition of waste and process waters.

The results were obtained using laser photoluminescence spectroscopy, time-resolved spectroscopy, laser correlation spectroscopy, IR absorption spectroscopy.

The research was carried out at the expense of the grant of the Russian Science Foundation No. 25-12-68005, https://rscf.ru/en/project/25-12-68005/.

Ru INCORPORATED INTO Se-CONTAINING $CoSe_2$ AS EFFICIENT ELECTROCATALYSTS FOR ALKALINE HYDROGEN EVOLUTION (INVITED)

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Key words: alkaline hydrogen evolution reaction, $CoSe_2$, electrocatalysis, selenium vacancy

In alkaline media, the slow water dissociation leads to poor overall hydrogen evolution performance. However, Ru catalysts have a certain water dissociation performance, thus regulating the Ru-H bond through vacancy engineering can accelerate water dissociation. Herein, an excellent Ru-based electrocatalyst for alkaline HER is developed by incorporating Ru into Se vacancy-containing $CoSe_2$ (Ru-VSe-$CoSe_2$). The results from X-ray photoelectron spectroscopy, kinetic isotope effect, and cyanide poisoning experiments for four catalysts (namely Ru-VSe-$CoSe_2$, Ru-$CoSe_2$, VSe-$CoSe_2$, and $CoSe_2$) reveal that Ru is the main active site in Ru-VSe-$CoSe_2$ and the presence of Se vacancies greatly facilitates the electron transfer from Co to Ru via a bridging Se atom. Thus electron-rich Ru is formed to optimize the adsorption strength between the active site and H*, and ultimately facilitates the whole alkaline HER process. Consequently, Ru-VSe-$CoSe_2$ exhibits an excellent HER activity with an ultrahigh mass activity of 44.2 A•$mgRu^{-1}$ (20% PtC exhibits only 3 A•$mgRu^{-1}$) and a much lower overpotential (29 mV at 10 mA•cm^{-2}) compared to Ru-$CoSe_2$ (75 mV), VSe-$CoSe_2$ (167 mV), $CoSe_2$ (190 mV), and commercial Pt/C (41 mV). In addition, the practical application of Ru-VSe-$CoSe_2$ is illustrated by designing a Zn-H_2O alkaline battery with Ru-VSe-$CoSe_2$ as the cathode catalyst, and this battery shows its potential application with a maximum power density of 4.9 mW•cm^{-2} and can work continuously for over 10 h at 10 mA•cm^{-2} without an obvious decay in voltage.

SYNTHESIS OF PALLADIUM NANOPARTICLES BY LASER-INDUCED FORWARD TRANSFER FOR CATALYSIS APPLICATIONS

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Key words: LIFT, palladium nanoparticles, catalysis, laser ablation, additive manufacturing

One of the main obstacles to increasing the selectivity of heterogeneous catalysts is the insufficient degree of homogeneity of their active centers. There are several fundamental reasons leading to such heterogeneity. For metal catalysts, one of the main reasons is that the active centers may include a different number of surface metal atoms, resulting in significant differences in their adsorption-catalytic characteristics. In this work, a new method for the preparation of catalysts based on palladium particles by laser-induced forward transfer onto various substrates is considered. The influence of laser synthesis parameters and donor film thickness on the characteristics of the obtained nanoparticles was investigated. The investigated technology allows achieving a high degree of homogeneity of active centers, avoiding the participation of multi-atomic centers in the catalytic process and, thus, significantly increasing its selectivity. In addition, due to high scanning speeds of the donor film, the speed of the whole technological process increases; the film consumption is not less than 80%. The size and structure of palladium nanoparticles were investigated by scanning electron microscopy, chemical composition by energy-dispersive X-ray spectroscopy (local measurements or mapping), stability and particle size by dynamic light scattering. The catalysts obtained by this method can find wide application in various fields requiring highly selective catalysts.

DIRECT LASER METALLIZATION FROM DEEP EUTECTIC SOLUTIONS FOR APPLICATIONS IN MICROELECTRONICS (INVITED)

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Key words: laser metallization, deep eutectic solutions, microelectronics, additive manufacturing, sustainable materials processing.

Deep eutectic solvents (DESs) have emerged as sustainable precursors for direct laser metallization, enabling rapid, localized deposition of conductive metals on diverse substrates without vacuum systems or photolithography.

This method leverages DESs—comprising choline chloride, organic acids (e.g., citric, tartaric), and metal salts—to dissolve metal ions, which are thermally reduced via laser irradiation (e.g., 532-nm continuous-wave or pulsed 1064-nm lasers). The technique achieves high-resolution patterning (down to 10 μm) and strong adhesion on industrially relevant substrates, including polyimide, glass, fiberglass, ceramics, ferrites, and PDMS, validated through tape tests and SEM/XRD analysis. Key innovations include enhanced deposition rates >10mm/sec and compatibility with flexible and curved materials. For demonstration we fabricated radio RFID tags, printed circuit boards, and flexible sensors. Process optimization involves tuning laser parameters (power, scanning speed), substrate pre-treatment and DES chemistry (eg., adjusting viscosity). Optimization of these parameters allows us to achieve controlled metallization thickness and morphology. Unlike other template-free methods, such as inkjet printing and laser sintering, the direct laser metallization does not require the synthesis of nanoparticles and the creation of nanocomposite inks, the cost of which is quite high. The synthesis of a deep eutectic solution occurs by simply mixing the powders under heating. Then, various methods can be used to apply the film to the surface of the dielectric (eg. dr blade, spin coating, drop casting).

This approach bridges additive manufacturing and microelectronics, offering a cost-effective pathway for next-generation flexible and 3D-integrated devices. In the future, the technology can combine additive manufacturing and microelectronics, offering scalability and cost-effectiveness.

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DESIGN AND SYNTHESIS OF CONJUGATED COVALENT ORGANIC FRAMEWORKS FOR PHOTOCATALYTIC APPLICATIONS (INVITED)

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Key words: photocatalysis, covalent organic frameworks, porous polymers, conjugated polymers, organic semiconductors

Two-dimensional sp^2c-conjugated covalent organic framework (2D sp^2c-COFs) refer to crystalline organic porous polymer constructed by C = C bonds. The 2D sp^2c-COFs have shown great potential in a wide range of applications from organic semiconductors to catalysis, because of their designable periodic porous structures, high surface area, excellent structural stability, and high charge transfer. This talk will elucidate the research endeavors of our research group concerning 2D sp^2c-COFs. Firstly, the structural design and synthesis methods of 2D sp^2c-COFs are presented. Subsequently, we introduce the preparation strategies for 2D sp^2c-COFs. Moreover, the applications of 2D sp2c-COFs in photocatalysis, uranium extraction and hydrogen production will be discussed. Finally, I will present my perspective on the research of two-dimensional sp^2c-conjugated polymers for photocatalytic applications.

DEEP EUTECTIC SOLVENT - ASSISTED DIRECT LASER WRITING OF METAL STRUCTURES FOR ELECTROCHEMICAL SENSORS

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Key words: deep eutectic solvents, design of experiments, direct laser writing, electrochemical sensor

This work presents an advanced approach to direct laser writing of metal structures using deep eutectic solvents (DES) as a deposition medium. DES, a class of environmentally friendly and easily tunable solvent systems, offer significant advantages for laser-induced metal deposition by enabling more controlled and efficient synthesis under mild conditions. Their unique physicochemical properties, including high thermal stability, low volatility, and the ability to dissolve a wide range of metal precursors, make them ideal candidates for enhancing the capabilities of laser-induced deposition [1]. A comprehensive study was conducted to investigate the influence of key physical and chemical parameters on the efficiency and quality of the resulting metal structures. These parameters include the composition of the DES, the concentration of metal precursors, laser power, scanning speed, and irradiation time. To optimize this complex multifactorial process, the Nelder-Mead design of the experiment method was applied, allowing for systematic exploration and fine-tuning of the reaction conditions. This approach not only minimized reagent consumption and processing time but also maximized the structural integrity and functional properties of the deposited materials [2].

The resulting metal structures demonstrated excellent electrochemical performance, mechanical flexibility, and high surface uniformity, making them promising candidates for a wide range of applications. These include flexible sensors, electrochemical devices, and other components of advanced flexible and wearable electronics. The proposed methodology paves the way for the scalable and sustainable fabrication of high-performance metal structures on flexible substrates, contributing to the development of next-generation electronic devices.

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LASER-ASSISTED FABRICATION OF MATERIALS FOR ELECTROCHEMICAL APPLICATIONS

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Key words: laser fabrication, laser deposition, electrochemical sensor, working electrode

The precise and controlled energy delivery provided by laser-based technologies has been recognized as particularly advantageous for the development of novel materials with optimized properties specifically tailored for electrochemical sensors and supercapacitors.
In this work, various laser-assisted fabrication techniques have been systematically explored for the preparation of advanced materials suitable for electrochemical applications, with particular emphasis on non-enzymatic electrochemical sensors. Special attention has been paid to flexible sensors, which have emerged as a promising category due to their mechanical adaptability and potential integration into wearable electronic devices. Laser-induced chemical processes occurring at the substrate-precursor interface have been thoroughly investigated, resulting in the controlled formation of conductive metallic structures. These metallic structures have subsequently been used as working electrodes within sensor systems, demonstrating considerable potential for the electrochemical detection of various analytes.

Furthermore, the influence of various laser parameters on the structural, morphological and electrochemical properties of the synthesized materials has been extensively investigated. Compared to conventional synthesis methods, laser-assisted fabrication has been shown to offer significant advantages, particularly with respect to precise spatial localization. This capability has facilitated the direct fabrication of electrodes with customized geometries on substrates of arbitrary shape and configuration.

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LASER-DRIVEN CHEMISTRY IN LIQUIDS, SOLIDS, LIQUID/SOLID INTERFACES (INVITED)

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Key words: laser synthesis, nanoparticles, optical phase elements, SERS

Laser-driven chemistry represents a powerful approach that utilize the unique properties of laser light to induce and control chemical reactions in various phases of matter. The interaction between laser radiation and matter can lead to a wide range of phenomena including deposition, nanoparticle synthesis, interfacial reactions, etc. The fundamental advantage of laser-based approaches lies in their exceptional spatial and temporal control, the ability to deliver extremely high energy densities to specific locations, and the capacity to selectively excite particular molecular or electronic transitions thus realizing an idea of 'chemical reactor in laser focus'. These characteristics make laser-assisted chemistry invaluable for applications ranging from materials synthesis to nanofabrication and modifications in bulk of solids benefiting wide range of functionality. The report will demonstrate examples of laser synthesis for various cases – in the liquid phase, solid state and at the interface of their phases. Thanks to laser-induced processes in various regimes (photo-, thermo-chemical), we managed to obtain metallic and composite nanomaterials with plasmonic, electrocatalytic properties [1-4]. In addition, optical phase elements with high refractive index contrast due to laser-induced migration of components in phosphate glasses of various compositions will be demonstrated [5].

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PLASMON-TRIGGERED NEAR-FIELD POLYMERIZATION: NANOSCALE CONTROL, CHIRAL NANOPARTICLE FABRICATION, AND SENSING APPLICATIONS (INVITED)

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Key words: chiral nanoparticle, radical polymerization, circular dichroism, plasmonic, near-field

The development of functional metallic nanostructures based on unique surface chemistry and physics phenomena, including plasmon-induced mechanisms, represents a rapidly advancing field in nanophotonics. This approach holds significant potential for applications in analytical chemistry, photocatalysis, photovoltaics, sensing, and nanomedicine. Of particular interest are technologies for selective deposition of target objects near metallic nanoparticles. Advances in selective deposition enable the creation of complex plasmonic nanostructures, including chiral ones. Chirality, defined by the absence of mirror symmetry, is ubiquitous in both macroscopic and nanoscale systems. Achieving strong and robust chiral responses in plasmonic metasurfaces remains a key goal in modern nanophotonics. While chiral plasmonic nanostructures are often fabricated via top-down methods like electron-beam lithography (EBL), these approaches are costly, labor-intensive, and limited in scalability.

In this study, we propose a novel method for fabrication chiral nanoparticles via plasmon-induced polymerization using divinylbenzene monomers and a tetraphenylporphyrin photoinitiator. Silver nanostructures of varying sizes were fabricated via a two-step process: vapor deposition of silver films on conductive/dielectric substrates, followed by post-thermal treatment in a muffle furnace (200–500°C). Equivalent thicknesses ranged from 5 to 15 nm. To induce circular dichroism (CD), isotropic silver nanostructures were irradiated with circularly polarized light (532 nm and 543 nm) at power densities of 0.1–20 kW/cm^2. SEM imaging revealed the formation of polymeric shells around nanoparticles after irradiation. Increased power density led to polymer-mediated interparticle connections, indicating nanoparticle interactions. CD spectra in the visible range demonstrated optical activity, with irradiation disrupting the racemic balance of enantiochiral moieties, enhancing absorption for probe beam polarization matching that of the polymerization laser.

The resulting chiral nanostructures exhibited high sensitivity to external refractive index (RI) changes: increasing RI from 1 to 1.5 caused a pronounced attenuation of CD signal intensity. This highlights their potential for sensing applications. The proposed method offers a scalable, cost-effective alternative to traditional lithography for fabricating chiral plasmonic systems with tailored optical properties.

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Biomedical laser technologies

NANO- AND MICROSTRUCTURED MATERIALS AND PHOTONICS WORK TOGETHER FOR MEDICINE (INVITED)

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Key words: nano- and microstructured materials, drug delivery sytems, multimodal contrast agents, nanozymes

Nano- and microstructured materials have good prospects for drug delivery systems and sensor devices. Modern drug delivery systems have a number of requirements:

1) encapsulated bioactive substance in the required therapeutic dose;
2) overcoming barriers, such as blood-brain barrier;
3) providing targeted delivery;
4) realizing the possibility of visualization of these systems in vivo, using modern diagnostic methods such as MRI, fluorescence and optoacoustic tomography, etc.;
5) providing sensory function;
6) remote release of the encapsulated substance.

A technology has been developed for the scalable synthesis of magnetic resonance imaging (MRI) contrast agents based on iron oxide nanoparticles, which are less toxic than traditional gadolinium-based contrast agents and have therapeutic potential against tumor cells. Methods that allow the preparation of nanostructured particles include the sequential adsorption method, the induced crystallization adsorption method, and their combination. The possibility of using optical methods for in situ monitoring of ICA has been demonstrated. The presence of inorganic nanoparticles and/or organic dyes within the core-shell and microcapsule structures, allows visualization by the optoacoustic method. The core can be in gaseous, liquid and solid phase. The presence of a liquid or gaseous core provides ultrasonic contrast. The presence of a liquid or gaseous core provides ultrasonic contrast.

It has been established that the optoacoustic signal from microcapsules is determined by the concentration of the substance absorbing laser radiation and its location in the capsule (polymer shell/internal volume of capsules). The presence of iron oxide nanoparticles enables MRI visualization of nanocomposite particles. In addition, the presence of iron oxide nanoparticles within the capsules allows the use of magnetic field for their controlled aggregation and movement. The MRI image contrast of microcapsules containing iron oxide nanoparticles can be modified by varying the average value between iron oxide nanoparticles in the nanocomposite shell, and the capsule shell can be disrupted using ultrasonic exposure. The possibility of combining encapsulated gold nanoparticles (nanozymes) and photodynamic dye to increase the efficiency of PDT has been shown. It was shown that for capsules containing both gold particles and PD dye the efficiency of PDT is 9 times higher compared to capsules containing only PD dye, and 25 times more efficient compared to unencapsulated PD dye. Nano- and microstructured materials together with modern photonics methods, which have already become commonplace for both preclinical and clinical research, can be used to create new drug delivery systems combining functionality such as navigation, visualization, in vivo monitoring of biochemical processes, remotely activated release of bioactive substances in vivo.

ULTRASHORT-PULSE LASER INSCRIPTION IN BULK DIELECTRICS: FUNDAMENTAL PROCESSES AND PROMISING APPLICATIONS (INVITED)

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Key words: dielectrics, ultrashort laser pulses, fundamental mechanisms, bulk inscription, polarizing microoptics, biomedical applications

This talk envisions at the quantitative level the basic non-linear propagation and energy deposition mechanisms for ultrashort laser pulses in bulk dielectrics, using a few enlightening examples. The selected laser inscription regimes were demonstrated to produce embedded micro-optical phase elements based on bulk nanogratings, and local refractive-index variation relevant for ex vivo and in vivo adjustment of intraocular lens characteristics.

LASER ADDITIVE MANUFACTURING FOR BIOMEDICAL APPLICATIONS (INVITED)

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Key words: laser additive manufacturing, 3D computer models, promising biomedical alloys, spectroscopy, machine learning, biocompatibility parameters

The increasing demand for implants for reconstructive medicine, as well as the expansion of their personalization capabilities, requires the improvement of production processes and materials used. Promising alloys, such as superelastic titanium nickelide and magnesium-based alloys, attract the attention of researchers, but their use is still associated with a number of production difficulties, such as control of chemical composition, formation of functional coatings, creation of individual shapes, etc.

The IPLIT-Shatura Department of the Kurchatov Crystallography and Photonics Complex has extensive experience in implementing additive manufacturing for the rapid production of prototypes, models and functional objects, including for biomedical applications, based on their three-dimensional computer models using the layer-by-layer material build-up method. Additive models are widely used in the preparation and planning of surgical interventions in craniomaxillofacial surgery, neck and spine surgery, thoracic surgery, orthopedics and neurosurgery, as well as for the rapid manufacture of implants from biocompatible materials and their preoperative fitting.

The effect of preliminary planning of operations using plastic models is manifested, firstly, in a decrease in the duration of the operation, which is especially important for pediatric patients, whose permissible time under general anesthesia is strictly limited; secondly, quality indicators are improved, which leads to a decrease in the rehabilitation period; thirdly, the cost of the operation is reduced. At the moment, IPLIT is developing a concept for a new approach to the digital production of orthopedic implants from promising metal materials, which would provide the possibility of precise control over the local composition of the material while ensuring an individual geometric shape, as well as the formation of a functional coating in one cycle.

To date, a set of experimental and theoretical works has been carried out aimed at developing the scientific and technological foundations of the approach and ensuring the fundamental possibility of additive manufacturing of objects from superelastic titanium nickelide alloys in the form of wire to obtain the final material for biomedical applications. The stoichiometric composition of the material was selected from the point of view of manufacturability and final biocompatibility, and a set of physical and mathematical models of the processes under consideration was developed and their software implementation was performed. A basic system for the fast recording of spectrometric and pyrometric information from the melt pool and approaches to analyze the obtained data were developed. Spectral features that are "markers" of the chemical composition of the sample were determined. To determine the phase composition, a comparison of the relative intensity of the corresponding spectral lines is carried out using preliminary processing by averaging and filtration methods, subsequent multiple sampling and cross-validation.

Titanium nickelide samples obtained by laser deposition were comprehensively studied to determine their physical, mechanical, structural and biological properties. The possibility of additive manufacturing of NiTi material by the LMD-WP method with a final toxicity of 10% was demonstrated according to data obtained on the 3T3 test cell line of mouse fibroblasts by direct contact with the material.

FUNCTIONALIZATION OF GOLD NANORODS FOR PHOTOTHERMAL THERAPY: ROLE OF LASER MODE AND TARGETING PEPTIDES

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Key words: femtosecond irradiation, nanosecond irradiation, photothermal therapy, gold nanorods, electron-phonon relaxation, photothermal conversion

The photothermal properties of functionalized gold nanorods (Au NRs) under different modes of laser irradiation have been investigated in this study. A comparative analysis of the efficiency of femtosecond (FS, 1030 nm) and nanosecond (NS, 1064 nm) modes in the context of nanoparticle heating and their application in photothermal therapy (PTT) of melanoma was carried out. Numerical simulations based on a two-temperature model showed that FS irradiation leads to more intense local heating (~45°C in 500 s) due to fast electron-phonon interaction. In NS-mode, a more uniform heat distribution is observed, but the efficiency of local heating is limited by the diffusion of heat into the surrounding medium. Experimental studies confirm that under FS irradiation, heating of Au NRs occurs due to non-equilibrium energy distribution between electrons and phonons, resulting in a sharp temperature increase within individual nanostructures. In contrast, NS irradiation, due to the longer pulse duration, is accompanied by a gradual transfer of energy to the environment, which reduces the degree of local thermal effects. Evaluation of photothermal conversion showed its increase with FS-irradiation, which is consistent with the observed therapeutic effects. Additionally, the effect of chemical functionalization of nanoparticles was investigated. Au NRs were modified with Ac-12 (Ac-SYSMEHRWGKPV-NH_2) and GKR (GKRKGSGSSIISHFRWGKPV-$CONH_2$) peptides, which differ in their degree of conjugation and affinity to MC1R receptors of melanoma cells. In vivo studies demonstrated a 1.6-fold increase in intra-tissue accumulation for GKR-functionalized Au NRs, but the maximum therapeutic effect was achieved under FS-irradiation conditions, regardless of the type of peptide modification. Optimization of laser exposure parameters is a key factor in increasing the effectiveness of FS and minimizing the damage to healthy tissues.

STUDY OF METHYLENE BLUE PHOTODYNAMIC ACTIVITY ON ERYTHROCYTE SUSPENSION IN VITRO

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Key words: methylene blue, erythrocytes, hemoglobin deoxygenation, photodynamic therapy

There are conflicting reports that methylene blue (MB), used for photodynamic therapy (PDT), is a type I photosensitiser (PS) and generates reactive oxygen species (ROS) or generates singlet oxygen 1O2.

We investigated MB photodynamic activity and the effect of solvent, MB concentration and binding to erythrocytes on 1O2 production efficiency. To determine the photodynamic activity, the rate of hemoglobin deoxygenation during PDT was measured using the fibre-optic spectrometer LESA-01-Biospec (Biospec, Russia) as described in [1]. Suspensions containing 40% of erythrocyte mass, plasma or physiological solution and 10-100 mg/kg MB were studied. To investigate the binding of MB molecules to erythrocytes, samples were centrifuged (3500 rpm × 5 min) and washed twice. Photosens at 1 mg/kg was used as the reference PS.

The presence of ROS after PDT with MB (660 nm, 50 J/cm^2) was tested on erythrocyte suspensions with physiological solution via the carboxy-H2-DCFDA indicator (25uM, incubation for 30 min in phosphate-buffered saline at 37°C, 5% CO_2). The photodynamic activity of Photosens was two orders of magnitude higher than that of MB. The efficiency of 1O2 generation by MB was low and strongly dependent on concentration. After washing the erythrocyte suspension with 100 mg/kg of MB, the rate of hemoglobin deoxygenation decreased to values typical for 40–60 mg/kg concentrations. We assume that incomplete washing was caused by electrostatic binding of MB to the erythrocytes, leading to ROS formation.

An increase in the luminescence intensity of the ROS sensor was observed on erythrocyte suspensions after PDT with MB compared to control with MB in physiological solution. Therefore, it was shown that MB can act as a type I PS and is promising for PDT of hypoxic tumors.

Study was funded by RSF grant N22-72-10117.

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THEORETICAL AND EXPERIMENTAL STUDY OF THE INFLUENCE OF LASER-INDUCED HEMOGLOBIN TRANSFORMATION ON THE REFLECTION, ABSORPTION, AND TRANSMISSION SPECTRA OF BLOOD

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Key words: diode laser, reflection spectra, transmission spectra, human blood, computer model, methemoglobin

The capabilities of modern optical and laser medical technologies are limited by the small penetration depth of light into biological tissues. In this regard, the study of light reflection, absorption, and transmission processes in biological tissues, with a focus on increasing light penetration depth or, in other words, optical clearing of biological tissues and body liquids, including blood is highly relevant.

Monte Carlo simulations examined the effects of blood oxygenation and methemoglobin concentration on its reflection, absorption, and transmission spectra. When oxyhemoglobin is replaced with deoxyhemoglobin, the most significant spectral changes occur in the 450–520 nm, 590–780 nm, and 780–1100 nm ranges. Replacing deoxyhemoglobin with methemoglobin leads to major changes in the 520–590 nm, 590–780 nm, and 780–1100 nm ranges.

In vitro experiments measuring human blood reflection spectra before and after laser exposure at 450 nm and 980 nm showed the greatest changes around 600 nm, likely due to the laser-induced conversion of oxyhemoglobin into deoxyhemoglobin. In vivo experiments measuring the reflection spectra of animal's skin (rabbit ear) before and after laser exposure at 450 nm and 980 nm demonstrated that immediately after laser exposure with a 150 ms pulse, the reflection of the animal's skin in the 400–800 nm range increases. The most significant spectral changes at 600±10 nm were recorded under dual-wavelength laser exposure first with 980 nm radiation, followed immediately by 450 nm radiation. Optical computer modeling of the skin established that this effect can be explained to a decrease in blood oxygen saturation.

The results of this study can be valuable for the development of laser-based dermatological technologies and systems, including feedback-controlled systems.

ADVANCEMENTS IN SUPER-RESOLUTION TERAHERTZ SOLID IMMERSION MICROSCOPY FOR BIOPHOTONICS (INVITED)

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Key words: terahertz technology, terahertz superresolution microscopy, solid immersion lens, biophotonics, medical diagnosis

Terahertz (THz) technologies are increasingly being utilized in the fields of biophotonics and medical diagnostics. Despite their potential, THz optical systems face challenges such as limited spatial resolution and the absence of effective endoscopes. Our research focuses on developing super-resolution THz microscopy techniques that utilize the solid immersion (SI) effect. This method enables us to surpass the Abbe diffraction limit by focusing an electromagnetic beam at a short distance behind a high-index SI lens. The SI optical system can achieve resolution as fine as 0.15λ (where λ represents the free-space wavelength) with a high-resistivity silicon SI lens, and even down to 0.06λ when using a rutile SI lens. We have successfully employed the THz SI microscope to investigate dielectric materials and various healthy and diseased biological tissues ex vivo. Additionally, the microscope, in conjunction with a linear polarizer and analyzer, has been utilized to examine the optical anisotropy of rat brain tissues ex vivo. We also have developed a reflection-mode THz pulsed SI microscope, which combine the superresolution capabilities of SI optics and the advanced information content offered by THz pulsed imaging. Our research also introduces THz waveguides and endoscopes based on sapphire-shaped crystals, which exhibit low dispersion and minimal radiation loss. These sapphire waveguides, utilizing photonic crystal or antiresonant radiation transfer mechanisms, were produced through the edge-defined film-fed growth (EFG) technique without the need for polishing or drilling. Furthermore, we have created a THz endoscope that incorporates an antiresonant hollow-core sapphire waveguide paired with a sapphire SI lens, achieving an experimentally verified focal spot diameter of 0.2λ.

EFFECT OF SILICON NANOPARTICLES ON THE PROTEIN SOLUTION PROPERTIES UNDER OPTICAL BREAKDOWN

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Key words: protein, nanoparticles, dynamic light scattering, laser surgery, optical breakdown

At present, laser radiation is widely used in medicine, both therapeutic and diagnostic as well as in surgery. The processes of interaction of laser radiation with biological tissues have been studied quite well. However, the interaction processes at the molecular level have not been studied enough.

This paper presents the results of strong laser radiation on the structure of proteins in the presence of silicon nanoparticles. The presence of various nanoparticles in the human body is well known. Some of the most common nanoparticles are silicon and silicon oxide. In this work we have investigated the interaction of Nd:YAG laser radiation with protein-Si nanoparticles water solutions. The wavelength of the laser was 1064 nm and the pulse energy 8mJ. This mode leads to optical breakdown in the solution, which is typical for laser surgery. Bovine serum albumin (BSA) was used as a model protein. Si NPs were synthesized by laser ablation in water. Firstly, the pure protein solutions were irradiated, than solutions, containing both proteins and nanoparticles were exposed. The protein solutions were irradiated for 30 min. It has been shown, that after 30-min irradiation there is partial denaturation, aggregation and fragmentation of the protein molecules. The hydrodynamic diameter of colloids decreased from ~10 nm to ~8 nm. The absorption peak detected at 260-340 nm increased, and the fluorescence peak was found to decrease by about 8%. After the addition of Si nanoparticles, the absorption maxima corresponding to amino acid residues decreased, hydrodynamic diameter changes were more complex due to protein-nanoparticle interaction. The peak intensity decreased even more – by ~18%. So, it can be concluded that in the presence of Si nanoparticles, the protein structure can change more radically.

The obtained results may be of interest in laser medicine because changes in protein conformation influence cellular immunity.

STUDY OF THE INFLUENCE OF GLYCATION OF BIOLOGICAL MOLECULES ON THEIR BONDING WITH WATER MOLECULES (INVITED)

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Key words: glycation of biological tissues, modeling, phospholipids, diabetes

The incidence of diabetes is growing annually, and experts believe that if the situation continues to develop at the same rate, the number of patients with diabetes will double by 2025, and in 2030 this disease will become the seventh cause of death worldwide. Diabetes mellitus is a disease associated with a violation of carbohydrate metabolism, characterized by high glucose levels in the blood. There are diabetes mellitus types 1 and 2. Despite the different mechanisms of pathogenesis, both types of the disease are accompanied by hyperglycemia, which causes serious complications, since glycation of biological molecules occurs throughout the body, including vital organs, then by studying the structural and chemical changes associated with prolonged hyperglycemia in the body, it is possible to obtain information about the degree of glycation of not only hemoglobin, but also various tissues, which should directly indicate the risks of serious complications in the development of diabetes.

Not only amino acid residues of proteins, lipoproteins as lipid-carrying protein macromolecules, but also lipids are subject to glycation. Aminophospholipids directly react with glucose, forming the end products of glycolysis, which are then oxidized by active oxygen species. Using the density functional method, molecular models of phosphatidylethanolamine in the normal and glycated states were constructed, and the effect of glycation on the first hydration shell was studied. Data on the optical properties of tissues in combination with modeling provide information on structural changes occurring with biological tissues and their components, which must be taken into account in diagnostics. This experimental study shows significant differences in the optical parameters of abdominal adipose tissue in healthy and diabetic animals due to the increased water content in pathological tissues.

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ADVANCED LASER AND BIO TECHNOLOGIES FOR NUCLEAR MEDICINE (INVITED)

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Key words: laser technologies, nuclear medicine, nanoparticles, proton therapy, radiosensitizers

We propose different types of nanoparticles (NPs) synthesized by promising laser-based approaches as a NPs for nanotheranostics. The field of nuclear medicine can be significantly expanded by integrating with nanomedicine, which utilizes advanced nano- and biomaterials as carriers of radionuclides or as radiosensitizers for radiation therapy and/or active agents for imaging. We demonstrate the possibility for fast PEGylation and conjugation of laser-synthesized Si*NPs with Rhenium-188 (188Re) radionuclide. The proposed biodegradable complex promises a major advancement of nuclear nanomedicine: our tests on rat survival demonstrate excellent therapeutic effect (72% survival compared to 0% of the control group). Technologies of targeted proton therapy and boron-nutron capture therapy using promising nanoparticles and targeting systems based on them as therapy sensitizers and active agents for diagnostics are considered. The introduction of non-radioactive materials that can be activated from the outside using various external sources of nuclear particles to produce radioactivity in situ is one of the new directions of activation of nano-drugs at the site of a cancerous tumor, which can be considered as in situ production of radiopharmaceuticals. Such binary radiotherapy technologies become especially efficient when one can achieve a high tumor/non-tumor action contrast, which enables to minimize side effects related to the irradiation of healthy issues.

ULTRAFAST LASER SYNTHESIS OF PLASMONIC IV GROUP SEMICONDUCTOR NANOCOMPOSITES (INVITED)

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Key words: laser ablation, composite nanoparticles, biomedical applications, plasmonic nanoparticles, nanocomposites, silicon/gold nanoparticles

Different semiconductor nanoparticles (NPs) have a great potential for various healthcare applications, e.g., for visualization of cancer cells localization [1] or their destruction by radiofrequency-induced hyperthermia [2]. Nevertheless, their performance is still limited requiring use of other elements, e.g., metallic ones, in order to solve several biomedical tasks.

However, it can lead to unpredictable side-effects that can be crucial for living organisms. To avoid them, recent advances of the pulsed laser ablation in liquids (PLAL) method can be used. Firstly, it allows synthesis of different nanostructures in chemically pure conditions due to the use of chemically pure targets and liquids. Secondly, it also allows merging different elements in one nanocomposite with finely controlled chemical composition. As a result, performance of the laser-synthesized nanocomposites can be tiny tuned depending on application task needs. n this research, laser ablation synthesis of different IV group semiconductor nanoparticles (NPs) and their further laser-induced structural modification were performed. Firstly, semiconductor NPs (Si, SiC, Ge) were formed by direct laser ablation of corresponding targets immersed in deionized water. Secondly, chemically stable colloidal solutions of composite NPs were produced by merging of semiconductor NPs with a metallic element either via direct laser ablation (LA) or laser co-fragmentation (LcF) approaches [3].

All semiconductor- based nanocomposites (NCs) revealed strong plasmonic properties accompanied with effective violet photoluminescence [3]. Here, the LcF approach led to formation of smaller NPs having a larger content of semiconductor elements compared to that prepared by LA [3]. Larger contribution of gold in the NCs resulted in stronger plasmonic properties favourable for identification of different bioanalytes [4]. Besides, all plasmonic NCs demonstrated strong ability for photothermal therapy applications due to effective laser-induced heating (~12 °C for 600 s irradiation) of colloidal solutions [3]. Moreover, silicon-gold NPs also have low cytotoxicity making them promising candidates for diagnostic and therapeutic purposes. These achievements show prospects of laser-synthesized semiconductor-metallic nanostructures for multimodal applications such as bioimaging, biosensing, optical labelling or mild hyperthermia.

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LASERS IN MODERN DENTISTRY: MAIN PRINCIPLES AND TECHNOLOGIES (INVITED)

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Key words: dental laser, fractional treatment, diode laser, dentistry

Innovative technologies are constantly being introduced in dental practice, with laser use holding a special place. Laser technologies are rapidly evolving and finding widespread application in modern dentistry. They are used in surgery, therapeutic treatment, endodontics, periodontology, implantology, and aesthetic dentistry. Lasers enable painless and minimally invasive procedures, significantly enhancing patient comfort. There are numerous areas in dentistry where lasers can greatly improve treatment quality. One example is cavity treatment by laser without the use of a dental drill. The laser gently removes affected tissues, reducing pain and the need for anesthesia. In oral surgery, lasers are used for coagulation and tissue incision without bleeding, which is particularly important in gingivectomy, tumors removal, and implantation. In endodontics, laser treatment of root canals improves sterility and reduces the risk of complications. In periodontology, lasers contribute to the effective treatment of inflammatory diseases, while in prosthodontics, they assist in tissue preparation for prosthetics. In aesthetic dentistry, lasers are used for teeth whitening, gum pigmentation removal, and hypersensitivity treatment. A very popular application is the use of lasers for veneer removal.

Despite their advantages, laser technologies have certain limitations. Currently, lasers have not become the gold standard in dental practice. There are several reasons for this, including the high cost of equipment and insufficient awareness among dentists about the potential of laser treatment.

To increase demand for lasers in dentistry, new areas of application must be explored. One such area is fractional laser treatment. Studies have demonstrated the effectiveness of this technique on the oral mucosa. Fractional laser treatment can be used to address scar tissue changes in the mucosa and treat certain types of gum recession. The introduction of these technologies helps minimize pain, accelerate healing, and improve the quality of dental treatment.

EVALUATION OF THE HEMOGLOBIN OXYGEN SATURATION DETERMINATION ACCURACY DEPENDING ON THE OPTICAL PARAMETERS OF THE TRACHEAL WALL LAYERS

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Key words: diffuse reflection spectroscopy, oxygen saturation, trachea

Intraoperative determination of the biological tissues state using methods that provide numerical values can reduce the influence of the human factor on the surgical outcome and reduce the risk of postoperative complications. According to publicly available data, the state of the tracheal wall during the surgical procedure is currently determined only by visual inspection. This work is devoted to the developed method of assessing the state of biological tissues by the degree of their blood supply, which is determined by the values of local oxygen saturation. The method is based on diffuse reflection spectroscopy and provides a numerical parameter, which allows increasing the objectivity of assessing the viability of tracheal tissues. The spectra are recorded using a setup based on the «LESA-01-BIOSPEC» spectrometer. For a preliminary evaluation of the possibility of applying this method in clinical conditions, the propagation of light in tracheal tissues was simulated using the Monte Carlo method, taking into account the division of the wall of this organ into four layers with different optical properties.

The technique was applied to 12 patients who underwent circular tracheal resection. Intraoperative measurements were performed at three stages: before tracheal intersection, after intersection, and after anastomosis (tissue suturing). Based on the modeling results, the spectra recorded from the external side of the organ provide information on the state of the adventitial and fibrocartilaginous layers. While measurements from the lumen allow assessing the state of the mucosal and submucosal membranes. Based on these results, clinical saturation assessment at the second stage was performed on both sides of the tracheal wall. Measurements from the lumen cannot be performed at the first and third stages, but the state of the fibrocartilaginous layer of the trachea is decisive in evaluating the state of this organ, which allows judging the viability of the tissues based on the data recorded from the external side. Among the patients who participated in the study, serious postoperative complication (anastomotic failure) weas observed in only one case and was caused by mechanical damage. The obtained results indicate the possibility of applying the developed technique in clinical conditions during tracheal resection to improve the objectivity of assessing the viability of biological tissues and reduce the risk of postoperative complications.

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HYBRID NANOMATERIALS FOR OPTICAL HEATING AND TEMPERATURE MONITORING IN BIOLOGICAL OBJECTS

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Key words: nanothermometry, optical heating, drug delivery, nanoparticles

Nanothermometry is a cutting-edge technique for measuring temperature at the nanoscale, playing a crucial role in understanding micro- and nanoscale thermal physics. It is an important tool for characterizing the thermal properties of nanosized materials, which can be further applied in biomedicine for diagnostic and therapeutic purposes. Temperature changes strongly affect the mechanisms of cell death, including apoptosis and necrosis, and other cellular functions such as gene expression, metabolism, growth factor activity, cell division, and protein activity. However, the lack of accurate thermal control significantly limits the translation of optical and laser techniques into nanomedicine. Therefore, during optical heating it is crucial to perform real-time temperature monitoring.

This report presents innovative multifunctional hybrid materials for accurate temperature measurements in biological objects during laser-induced heating. This report covers the application of polymeric capsules, modified with nanodiamonds with nitrogen-vacancy centers (NV centers) and gold nanoparticles, for photoinduced delivery of bioactive compounds inside living cells with simultaneous temperature control using optically-detected magnetic resonance (ODMR). The findings reveal that the efficiency of optical heating depends significantly on the location and concentration of gold nanoparticles within the carriers, and the temperature of capsule decomposition was successfully measured in living cells. In another study, it was demonstrated that gold-coated nanodiamonds (NV-centers) can be used for photothermal therapy in laboratory animals due to their ability to inhibit tumor growth. These nanostructures also enable precise measurement of tissue heating temperatures using the ODMR technique. Additionally, it was studied the integration of plasmonic and all-dielectric nanostructures to develop advanced hybrid nanomaterials, facilitating simultaneous optical heating and temperature monitoring through the Stokes shift in Raman scattering.

In conclusion, this report highlights a promising pathway for advancing precise thermal control during nanomedicine procedure. In the future these results allow to avoid side effects during therapy related to overheating.

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ANTIMICROBIAL EFFICACY OF LASER-TRANSFERRED SILVER AND COPPER NANOPARTICLES IN WOUND INFECTION TREATMENT

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Key words: *Cu NPs, Ag NPs, LIFT, wound therapy*

This study evaluated the effectiveness of laser-induced forward transfer (LIFT) of metallic films in the form of silver and copper nanoparticles for the treatment of wound infections caused by the gram-negative bacterium P. aeruginosa and the gram-positive bacterium S. aureus. The model used was BALB/c mice, in which surgical wounds were created and subsequently infected with bacterial suspensions. Experimental groups of animals were treated once with nanoparticles using laser exposure, while the control group received no treatment.

The results of the study showed that the application of silver and copper nanoparticles significantly reduced bacterial colonization of the wound as early as the second to third day of observation, as evidenced by a decrease in the number of colony-forming units (CFU) in wound washes. In the control group, a similar effect was observed only on the fifth to sixth day. Additionally, mortality was recorded in the control group, while the condition of the mice in the experimental groups remained satisfactory, with no signs of edema or wound exudate. This highlights the treatment's rapid therapeutic efficacy. The conducted experiments confirmed that a single laser application of nanoparticles effectively suppresses bacterial activity, indicating a clinically significant impact. An important aspect is the absence of signs of bacterial resistance to nanoparticles after a single application. The obtained data demonstrate the potential of using silver and copper nanoparticles for the treatment of wound infections caused by both gram-negative and gram-positive bacteria, and may serve as a basis for the development of new methods of antimicrobial therapy.

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HARNESSING MICROWAVE RADIATION FOR REMOTE AND OBSCURED BIO-SENSING (INVITED)

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Key words: microwave, radar, speckle, bio-sensing, vital bio-signs

Non-invasive measurement and sensing of vital bio-signs, such as respiration and cardio-pulmonary parameters, have become essential tools in the evaluation process of a subject physiological condition. The demand for new enabling technologies that facilitate remote and non-invasive techniques for such measurements continues to grow. While previous research has made strides in continuous monitoring of vital bio-signs using laser, in this presentation we introduce a novel technique for remote non-contact measurements based on radio frequency. We utilize microwave radiation at e.g. 18GHz to measure the vital bio-signs of the illuminated subjects by analysing the changes in the generated back reflected microwave speckles.

Unlike laser-based methods, this innovative approach offers the advantage of penetrating through walls and tissues, enabling the measurement of respiration and heart rate. Diverging from traditional radar systems, our method introduces a unique sensing concept that enables the detection of micro-movements in all directions, including those parallel to the antenna surface. The ability to penetrate barriers such as walls and tissues opens new possibilities for remote monitoring in various settings, including home healthcare, hospital environments, and even search and rescue operations.

PHOTOPHYSICAL PROPERTIES OF PHOTOSENSITIZERS BASED ON POLYCATIONIC PHTHALOCYANINES AND THEIR PHOTOTOXICITY AGAINST LUNG CANCER CELLS

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Key words: polycationic photosensitizers, A549 lung carcinoma, photodynamic therapy

Lung cancer is the most common malignancy and one of the greatest causes of death in the recent years. Polycationic photosensitizers (PS) demonstrated high in vitro efficiency against lung cancer cells. We studied photophysical properties of PSs based on polycationic phthalocyanine derivatives of different chemical structure with strong absorption in the long wavelength region (680–690 nm). The possible aggregation of PSs in aqueous solutions was investigated by absorption and fluorescence spectroscopy. Their photodynamic effectiveness against A549 lung carcinoma cells in vitro was assessed for phototoxicity at 10 and 30 J/cm^2 with MTT. The studied PSs proved to be very effective for photodynamic therapy against A549 lung carcinoma cells, and exhibited complete photodestruction of the cells at low concentrations. ZnPcChol8 showed the highest effectivity with IC50 of 160 nm for 10 J/cm^2 (60 nm for 30 J/cm^2), with 4αZnPc^{4+} at 190 nm for 10 J/cm^2 and 110 nm for 30 J/cm^2, and 4αβZnPc^{4+} at 330 nm at 10 J/cm^2 and 250 nm at 30 J/cm^2. In all experiments, cytotoxicity was very low, IC50 values for dark control were not reached even at concentrations of 100 μm, which allows these photosensitizers to be classified as non-toxic drugs.

Increasing light dose density results in an increase in phototoxicity, but this increase is not proportional to the light dose density. In our studies, it appeared that the symmetric derivative of 4αZnPc^{4+} was more effective than the asymmetric derivative of 4αβZnPc^{4+} (at least in terms of IC50 values).

This work was funded by Russian Science Foundation and National Natural Science Foundation of China according to the bilateral Russian–Chinese project (RSF grant No. 24-45-00020, NSFC grant No. 22361132541).

NANO GREEN PRINTING OF SMART SENSING DEVICES (INVITED)

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Key words: printing, self-assembly, micro/nanostructures, sensing, biological detection

The development of micro and nanomanufacturing technology is a core issue in the scale-up manufacturing and application of nanomaterials to devices. We utilize the printing templates to precisely control droplet formation, assembly, and patterning of functional materials, achieving high-precision three-dimensional micro and nano structures with an accuracy of 100 nm. By introducing a droplet self-shaping strategy driven by minimizing surface energy into the printing, we have developed a structure-function integrated printing method to fabricate wearable electronics and smart optoelectronics. We have printed photonic resonance structures with single-nanoparticle precision, and verified the critical size for the scattering-diffraction transition in micro/nano structures. When viruses and other biological particles are recognized on the surface of structure, scattering resonance occurs with near-field enhancement, which significantly changes the color of scattered light. This enables rapid identification of target viruses directly from serum or sputum within 15 minutes.

LASER CATARACT EXTRACTION USING THE RADIATION OF 1.54 μm Yb,Er:GLASS LASER: RETROSPECTIVE, CURRENT STATE AND DEVELOPMENT PATHS

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Key words: laser cataract extraction, Yb,Er:Glass-laser, microsecond pulses, laser-induced cavitation, optical fiber, ablation efficiency

Cataract is one of the most common eye diseases, which manifests itself in the clouding of the lens. Treatment of cataract is surgical and involves removal (extraction) of the cloudy lens and replacing it with an artificial one. Currently, several methods are used to destroy cataract lens: manual fragmentation of the cloudy lens, cryodestruction, ultrasonic phacoemulsification, ultrasonic phacoemulsification accompanied by the action of femtosecond laser pulses and laser cataract extraction (LCE) without manual and ultrasound supplementation. The latter method is the least invasive, and as a result, has the least postoperative complications, and is also applicable at any stage of cataracts and has significantly fewer contraindications than other methods due to the high selectivity of laser exposure and the lack of need for contact between the working instrument and the lens.

To this day, the laser system based on Nd:YAG laser with a lasing wavelength of 1.44 μm is successfully used for LCE [1]. Prospects for the development of LEC technology are associated with the development and introduction into clinical practice of a new of a small-sized and efficient microsecond ytterbium erbium glass laser with diode pumping and a lasing wavelength of 1.54 μm [2]. This report covers the stages of the development of devices for LCE, the physical aspects of LCE, the current state of the creation of a 1.54 μm laser system for LCE and possible ways of its further development.

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FUNCTIONAL LIGHT-SENSITIVE NANOMATERIALS FOR TEMPERATURE SENSING AND THERAPY (INVITED)

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Key words: functional nanomaterials, therapy, nanothermometry, optical heating, photothermal therapy

Light-sensitive functional nanomaterials offer a powerful platform for biomedical applications, particularly in therapy and intracellular temperature sensing. These nanomaterials, engineered with responsive optical properties, enable precise control of therapeutic effects, such as photothermal therapy and photodynamic therapy, while simultaneously providing real-time temperature feedback at the cellular level. This dual functionality is crucial for enhancing therapeutic efficacy and minimizing damage to healthy tissues. In this work, we explore the design, synthesis, and application of nanoscale materials capable of responding to specific wavelengths of light, facilitating targeted treatment and high-resolution intracellular thermometry. We discuss recent advances in material fabrication, mechanisms of light-induced responses, and integration strategies for in vitro and in vivo applications. Our findings highlight the potential of these nanomaterials to revolutionize personalized medicine by enabling spatiotemporally controlled therapies with built-in diagnostics.

This work was supported by the Russian Science Foundation (24-75-10006).

CHEMICAL ENGINEERING OF ULTRA-BRIGHT FLUORESCENT NANOCRYSTALS FOR BIOMEDICAL APPLICATIONS

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Key words: fluorescence, nanocrystals, quantum dots, core-shell, chemical engineering

Fluorescent semiconductor quantum dots (QDs) have become ubiquitous in modern science and technology as efficient fluorescent labels and optoelectronic components. Their optical performance strongly depends on the structure of the complex core-shell nanocrystal (NC) and its uniformity throughout the ensemble. Although recent progress in colloidal synthesis made 100%-emissive and non-blinking QDs available, there is still a challenge in reproducible synthesis of these nanomaterials. Here we demonstrate an advanced approach to layer-by-layer deposition of conformal passivating shells on top of fluorescent nanocrystal cores with high degree of control over shell thickness and composition. The essence of our method is in atomistic modeling of nanocrystal growth starting from a single monomer, and collecting of detailed data on NC structural parameters and composition on every growth stage. By this way we obtain extensive data that is further used for planning and conduction of epitaxial shell growth. Unlike known methods for planning of such syntheses, relying on simple geometry models (spheres, cylinders, etc.), we propose tabulated data sets that are readily available for selected type of nanocrystals. Using this approach, we demonstrate precision synthesis of series of CdSe/ZnS/CdS/ZnS core-multishell QDs, ultrasmall CdSe/ZnS QDs and QDs with gradient shell composition which demonstrate outstanding performance as optical reporters and emissive materials for LED fabrication. The developed procedure can be easily extended to other nanocrystal morphologies such as nanorods and nanoplatelets to obtain highly-fluorescent nanomaterials for biomedical applications and optoelectronics.

Light sources & optical solutions for laser technologies

OPTICAL SOLUTIONS FOR LASER TECHNOLOGIES AND ITS INFLUENCE FOR PROCESS PERFORMANCE (INVITED)

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Key words: laser beam size, laser micromachining, achromatic scan lens, telecentricity error, galvanometric scanner, 3D laser processing

The main factors determining the quality of laser technological processes were analyzed. As applied to micromachining, these are the laser beam size in the process zone, diffraction focusing quality over the entire processing field, nonlinearity of the scanner and distortion of the focusing lens, the lens telecentricity error, as well as the accuracy of initial positioning and reproduction of the programmed trajectories during the process. It is stated that the optimal commercial solution for micromachining is a system including a two-mirror galvanometric scanner and a telecentric achromatic focusing lens with the organization of machine vision directly through the scanner optics. In presence in the system of additional linear movements of any components aimed at increasing the total 2D processing field or allowing 3D processing, it is necessary to eliminate their influence on the characteristics of galvanic fields. The existence of dependence of 3D structures micro-fabrication accuracy on the same laser fluence delivery dynamics to the processing object has been experimentally found. For laser cutting, welding and cleaning systems operating with significantly higher laser powers, the problems of laser-induced damage thresholds as well as laser-induced changes in characteristics of passive optical components arise. Additional optimization complexity is compounded by the need to eliminate the focused ghost reflected from the lens surfaces into the space of the scanner and the laser source. The general rule for the high power optics optimization is to reduce the number of passive optical components and to minimize the total axial thickness of the glass. Increasing the complexity of an optical system in order to obtain some unique properties of the beam usually does not result in a reliable commercial improvement of its performance.

GAS FIBER LASERS – A VERSATILE TOOL FOR LASER TECHNOLOGIES (INVITED)

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Key words: hollow-core fiber, fiber laser, gas laser, mid-infrared

Hollow-core fibers (HCFs) have enabled many exciting opportunities in gas-based photonics. In particular, a new type of lasers – gas fiber lasers (GFLs) – have emerged as efficient sources of laser radiation at various wavelength spanning from UV to mid-IR. By using gas-filled HCFs as an active medium, GFLs have not only enriched the wavelength range of fiber lasers, but also paved the way to achieving high intensity radiation that exceeds the damage threshold of any solid-core fibers.

The most of GFLs demonstrated so far can be considered as optical converters of near-IR pump laser radiation to other wavelengths. Such GFLs make use of various optical nonlinear phenomena. For example, dispersive wave generation in noble gases is used to convert the ultrashort pump pulses from the near-IR pump to deep UV with output pulse energy at μJ-level [1]. Alternatively, stimulated Raman scattering helps transferring the intense pump pulses to longer wavelengths, thus providing a convenient way of generating ultrashort pulses in the mid-IR [2] and allowing mid-IR supercontinuum generation [3]. Another GFLs, which are based on population inversion, appeared to be convenient for continuous-wave operation. This type of GFLs have demonstrated the output powers as high as 8 W at the wavelength of 3.1 μm [4].

Recently, a new type of GFLs – gas-discharge fiber lasers (GDFLs) – has been demonstrated [5-7]. Without the need for any optical radiation as a pump, the GDFLs generate laser radiation due to a gas discharge that is maintained inside the HCF by a 2.45-GHz microwave pump. These results open up new opportunities for laser generation at various wavelengths from ultraviolet to mid-infrared that are hardly accessible by other methods.

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SIMPLE SCHEME FOR GENERATION OF RADIALLY AND AZIMUTHALLY VECTOR OPTICAL FIELDS BASED ON SPIRAL VARYING RETARDER FABRICATED ON ICELAND SPAR PLATE BY LASER-INDUCED MICROPLASMA USING PYROGRAPHITE TARGET

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Key words: vector optical fields, laser-induced microplasma, Iceland spar, spiral varying retarder

Recently, special attention is paid to the formation of vector optical fields with cylindrical symmetry, which are effective for various applications related to energy concentration and manipulation of materials at the microscopic level due to their unique properties. Such fields are characterized by a non-uniform state of polarization across the beam cross section. At the same time, the most studied and widely used in various fields of science and technology are vector fields with radial and azimuthal distribution of the polarization vector. For their generation, spatial light modulators are mainly used, which have a number of limitations when working with high-power laser sources, and complex interference schemes with low energy conversion efficiency.

One of the promising directions for converting a linearly polarized Gaussian beam into radially and azimuthally polarized beams is the use of a spiral varying retarder (SVR) made on a crystalline birefringent plate in combination with two l/4 plates. Previously, to generate an azimuthally polarized beam, an additional specifically oriented l/2 plate was inserted into an optical scheme or the l/4 plates were rotated. Using a matrix calculation, we have shown that the SVR should be inserted in the optical scheme with the fast axis orientation directed along the X axis between two l/4 plates with orthogonal fast axes directed at angles of –45° and 45° to the X axis, respectively. In this case, with a horizontally polarized incoming beam, a radially polarized vector field is formed, and with a vertically polarized beam, an azimuthally polarized one.

The fabrication of the 8-sector SVR with the diameter of 10 mm for operation at the wavelength of 530 nm was performed on an Iceland spar plate (Extra grade) using laser-induced microplasma generated by laser ablation of a pyrographite target. The SVR was tested in the scheme with l/4 plates with the analyzer. Without an analyzer in the test scheme, a ring-shaped intensity distribution was observed in the far field; when the analyzer was inserted into the scheme, two uniform lobes appeared in the far field, rotating with the rotation of the analyzer; the energy efficiency of the Gaussian beam conversion was ~ 75%. Thus, the scheme for using the SVR in combination with two l/4 plates was both theoretically proven and experimentally demonstrated.

SPATIAL-LIGHT-MODULATOR-ASSISTED LASER PATTERNING OF AZOPOLYMER THIN FILMS

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Key words: azopolymer thin films, polarization, spatial light modulator, laser processing, projection lithography

Currently, research on the laser processing of polarization-sensitive materials (such as azopolymers) using structured laser radiation with specific distributions of amplitude, phase, or polarization is being actively conducted worldwide. Among these methods, those utilizing spatial light modulators (SLMs) are gaining particular popularity. These devices enable simultaneous control over various characteristics of the incident radiation, contributing to which they have earned great popularity. In this work, we present an approach for the realization of controlled spiral-shaped mass transfer in azopolymer thin films and the fabrication of spiral microreliefs. For such laser processing, we propose to use light fields with structured polarization distributions generated by a SLMs. The projection lithography approach is utilized, transferring the pattern directly to the surface of azopolymer thin films. In addition, we investigate phase-polarization interactions of structured laser beams in projection lithography setup and show that masks with a radial dependence of the modulation level in polar coordinates can be used to simultaneously modulate the phase distribution and polarization of the input linearly polarized Gaussian laser beam. This modulation results in the formation of the spiral-shaped longitudinal component of the light fields that can be used to fabricate spiral microaxicons. Moreover, we show the possibility to control the parameters of the surface relief gratings (SRGs) written in thin films using polarization lithography method implemented using a transmissive SLM. It is possible to modify the period, fill-factor, and profile of the SRGs.

STUDY OF HETERODYNE DEMODULATION SCHEME FOR SEISMO-ACOUSTIC MONITORING APPLICATION

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Key words: fiber optic interferometric sensor, heterodyne demodulation, phase sensitivity, vibration sensing

Fiber optic interferometric sensors (FOIS) are widely used for their high sensitivity and multiplexing capability. In specific applications, such as seismic exploration, where FOIS systems are required to process high-amplitude signals generated by powerful acoustic sources, dynamic range represents a critical constraint on signal detection, tightly associated with the signal demodulation schemes and algorithms. Heterodyne demodulation offers advantages over phase-generated carrier (PGC) demodulation, avoiding external phase modulation and harmonics of the modulation frequency which can bring the problem of signal aliasing, especially in the detection of signals with large amplitude. However, the effects of heterodyne frequency and digital quadrature demodulation algorithms on dynamic range remain underexplored. To investigate the dynamic range, a mathematical model of the digital IQ scheme was developed in the MATLAB environment. The input signal was multiplied by two orthogonal signals at the heterodyne frequency.

The time-varying phase under vibration can be obtained by applying the arctangent function after dividing and filtering the signals. Simulations were performed for acoustic signals with frequencies from 0 to 500 Hz. A Michelson interferometer-based fiber-optic acoustic sensor using differential delay heterodyne demodulation system was implemented for performance evaluation. The system features a Mach-Zehnder interferometer with two acousto-optic modulators in arms at 150 and 149.5 MHz. The difference between the arms of the unbalanced Mach-Zehnder interferometer results in the overlap of the optical pulses propagating along the reference and the sensitive arms of the interferometer, which contain the information about the impact of the acoustic signal of interest.

Study of heterodyne demodulation shows that the maximum amplitude of the output signal has an inversely proportional dependence on the frequency of the measured phase signal. Results of simulation and experiment demonstrate that at the same sampling rate compared to homodyne demodulation it provides a 5-fold gain in the linear dynamic range.

HIGH POWER FEMTOSECOND LASER SYSTEMS FOR INDUSTRIAL AND BIOMEDICAL APPLICATIONS (INVITED)

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Key words: *femtosecond lasers, Yb:doped laser media, high peak and average power, diamond treatment, cosmetology*

In this presentation we report on our investigations in the development of femtosecond (100-1000 fs) MOPA - CPA Yb:KGW and hybrid Yb:fiber – Yb:thin rod laser systems with high average power (10-100 W) and high pulse repetition rate (50 kHz-2 MHz). And we report the industrial applications of our femtosecond laser systems, for example, making a very small hole on a diamond and for medical cosmetology.

CURRENT AND PROSPECTIVE FEMTOSECOND LASER SOURCES AND THEIR INDUSTRIAL AND SCIENTIFIC APPLICATIONS (INVITED)

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Key words: femtosecond laser, micromachining, ultrashort pulse laser

The report will cover the current variety of commercial femtosecond laser sources and directions of ongoing global R&D efforts, as well as hot USP laser applications in industry and science.

ELECTRO-OPTICAL DEFLECTOR BASED ON CASCADED FERROELECTRIC DOMAIN STRUCTURE IN PMN-PT CRYSTAL

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Key words: optical phased array, beam steering, electro-optic effect, ferroelectrics, domain engineering, PMN-PT

A recent advancement in electro-optical beam deflection involved the design and implementation of a cascaded domain-engineered optical phased array (OPA) in a congruent lithium niobate (CLN) single crystal. The demonstrated beam steering capabilities at frequencies up to 3 MHz highlights the potential of cascaded domain engineering for optical phased arrays.

Here, we proposed the fabrication of cascade OPA in multiaxial relaxor ferroelectric [001]-cut PMN-PT crystal with tetragonal symmetry which possesses a high electro-optic coefficient. Using a novel surface fixation technique, we fabricated a five-layer OPA featuring a stable cascaded pattern of 180-degree domains with minimal concentration of undesired ferroelectric-ferroelastic domains. The created cascaded domain structure allowed it to achieve a steering ability of 0.32 deg/V/μm corresponding to electro-optic coefficient r_{33} = 134 pm/V. The obtained steering ability is comparable to the highest reported value of 0.50 deg/V/μm in six-layer CLN OPA. Our findings indicate that further optimization of domain engineering techniques for PMN-PT crystals with control of the domain pattern in the bulk could significantly enhance the performance of electro-optical deflectors.

The research was made possible by Russian Science Foundation (Project № 24-12-00302) and the National Key R&D Program of China (grant no. 2021YFE0115000). The work was performed using the equipment of the Ural Center for Shared Use "Modern Nanotechnologies" UrFU (reg. No. 2968).

SPATIAL LIGHT MODULATOR-BASED INSCRIPTION OF REFRACTIVE INDEX STRUCTURES WITH ARBITRARY TRANSVERSE GEOMETRY WITHIN A STATIC FIBER BY FEMTOSECOND LASER RADIATION

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Key words: femtosecond laser modification, spatial light modulator, fiber Bragg grating, Rayleigh backscattering structure

Ultrafast femtosecond lasers have proven to be a useful tool for transparent material processing and microstructuring. In particular, femtosecond laser inscription technique enables to modify the refractive index within different fibers types (single-mode, multimode, multicore, etc.) that enables to create various reflective refractive index structures such as fiber Bragg grating (FBG), composite periodic structures, Rayleigh backscattering random structure. For various applications such as fiber lasers, sensors, spectral filters, the inscription of three-dimensional complex structures in non-photosensitive multimode and multicore fibers is resulted from a localized refractive index change due to a nonlinear absorption of fs laser pulses reported to be durable at high temperatures (up to 1000 ˚C). Using spatial light modulator (SLM) expands the capabilities of femtosecond laser inscription technique by modulating a phase of fs laser radiation incident on SLM that leads to scanning a focal spot within a static fiber core. We demonstrate SLM-based point-by-point femtosecond laser inscription technique of both regular and random reflective refractive index structures in single-mode, multimode, multicore fibers. Uniform and apodized FBGs are shown to be inscribed by SLM in single-mode fiber. Moreover, high-precision fs laser microfabrication process based on SLM is shown for the three-dimensional inscription of Rayleigh backscattering random structure with ring-shaped cross-section geometry for higher order mode selection of the output laser beam in a fiber Raman laser. Additionally, we demonstrate a SLM capability that allows us to inscribe two FBGs spatially shifted along a twin-core fiber with a high spatial precision along the fiber axis leading to the formation of Michelson-type interferometer for a fiber laser application.

The work was supported by the Russian Science Foundation (№21–72–30024-п).

PORTABLE OPTICAL SOURCES FOR THE STUDY OF PHOTOCONDUCTIVITY PROCESSES HTTP DIAMONDS

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Key words: portable optical sources, laser, photoconductivity of diamonds

Investigation of composition and properties of modern semiconductor materials requires sophisticated experimental equipment including vacuum chambers, cryostats, and high-precision detection systems. One of the key techniques involves sample irradiation with high-power-density light. Previously used optical radiation sources (mercury lamps, gas lasers) were characterized by large dimensions, high power consumption, requirement for stationary power supply, and significant cost, which either limited the feasibility of complex experiments or substantially increased experimental duration. The emergence of a new generation of compact portable narrowband lasers and broadband LED-based light sources capable of generating high-power radiation with relatively compact power supply units has addressed these technical challenges. This study presents implemented methodologies for analyzing HPHT diamond composition and photoconductivity effects. We provide detailed characteristics of the employed optical sources, including:

- Available generation modes with portable power supply
- Achievable radiation power density ranges
- Emission spectra with their specific features
- Frequency selection and tuning capabilities
- Radiation stability parameters. The implemented optical sources meet all requirements regarding spectral composition and power levels.

The spectral coverage includes:

- UV range (200-400 nm) for exciting deep energy levels;
- Visible range (400-700 nm);
- IR range (700-1100 nm) for studying impurity conductivity (e.g., boron and nitrogen).

The generated radiation power is sufficient for photoconductivity detection (typically 10-100 mW/cm²) in continuous-wave mode. We also examined portable sources with pulsed operation mode, which enables increased peak power density without raising average radiation power, thereby eliminating thermal effects on samples and preventing thermionic emission artifacts. Additionally, the influence of non-coherent broadband radiation sources was investigated.

The results obtained demonstrate numerous opportunities enabled by the new generation of compact portable narrowband lasers and broadband LED-based light sources.

Nano- and molecular systems for optical and biomedical applications

CHEMILUMINESCENCE-BASED BIOSENSORS ENHANCED BY NANOSTRUCTURES (INVITED)

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Key words: chemiluminescence, localized plasmon resonance, microfluidics, luminol, silver nanoparticles

Chemiluminescence is of considerable current use in biomedical applications. It serves as a transduction mechanism that signals the appearance of reactive oxygen species by visible light flashes. Concentration of reactive oxygen species being an important characteristic of the living body and its organs conditions by itself, is even more widely used as indirect but highly selective evidence of the presence of various analytes. Although chemiluminescent assays are characterized by many attractive features like no need of any external light source, background-free signals and high selectivity, to be used for “point of care testing” chemiluminescence devices need further development.

In this study we have pursued several ways to develop a highly sensitive and user-friendly analytical device based on chemiluminescence of luminol. First, a microfluidic system has been designed that provides for even and thorough mixing of luminol solution with the oxidizer that serves as an analyte. Additionally, the microfluidic device provides for a convenient control of the analyte expense. Second, we used metal nanoparticles for chemiluminescence quantum yield enhancement, which is known to be rather low due to the unfavorable competition of radiative and nonradiative transitions from the electronically excited state of the luminol oxidation product to its ground state. Silver nanoparticles obtained via laser ablation in water was found to double intensity of luminol chemiluminescent provided the laser parameters used during the ablation process were optimized for the best overlap of the luminol chemiluminescence band with the localized surface plasmon band of silver nanoparticles. Third, we developed a new method of drop-wise luminol and analyte mixing that further reduces the analyte volume necessary for the test. The fourth, several metasurface designs with protrusions and wells were tested as a means of enhancing chemiluminescence.

This study was supported by a grant from the Russian Science Foundation (Project 23-72-00045 https://rscf.ru/project/23-72-00045/).

LIGAND-FREE NANOPARTICLES SYNTHESIZED VIA FEMTOSECOND ABLATION: SERS AND PHOTOTHERMAL APPLICATIONS

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Key words: transition metal dichalcogenides, nanoparticles, photothermal conversion, optical absorption, SERS

Ligand-free nanoparticles synthesized via femtosecond ablation: SERS and photothermal applications. Transition metal dichalcogenides (TMDCs) are in the focus of the modern material science, photonics and electronics due to their outstanding properties coming from a unique layered crystalline structure. Naturally forming a stable form of 2D stacked layers, their transformation into other nanoscale shapes is a challenging task, which is usually solved by using additional chemical precursors and ligands during "wet" synthesis methods. However, the presence of ligands might limit the application range due to effective screening of TMDC nanostructures surface from embedding medium. We demonstrate the ultrashort laser-assisted ablation approach for rapid, highly-tunable, ligand- and substrate-free fabrication of TMDC nanoparticles with sizes 10-150 nm [1].

Crystalline nanoparticles conserve high refractive index, excitons in visible-NIR range, interplanar distances of the bulk counterpart. Nanoparticles might have the onion-like structure prospective for optical nanoresonators. The colloidal solutions are stable for at least a month despite the absence of ligands due to the high zeta-potential. This fact, in its turn, unblocks the NPs use as plasmon-free SERS substrates.

We present experimental SERS results including limits of detection and enhancement factors, theoretically and experimentally demonstrate a high photothermal conversion coefficient of the tungsten diselenide, more than 4 times higher of conventional Si NPs [2], and palladium diselenide, which is comparable with the record-high values of MXenes. The enhanced NPs heating, confirmed by the temperature-dependent Raman spectroscopy, paves the way towards advanced medical applications in theranostics. In addition, we demonstrate the experiment method possibility to yield both crystalline and amorphous kinds of nanoparticles, which due to the enhanced concentration of surface defects are perfect candidates for plasmon-free SERS sensors.

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OPTICAL SENSORS BASED ON MOLECULAR-PLASMON HYBRID NANOPARTICLES (INVITED)

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Key words: optical sensor, hybrid nanoparticle, pH, oxygen, temperature, luminescence

Optical sensors have a number of advantages over sensors based on other physical and chemical principles: remote signal recording, low invasiveness, biocompatibility, locality up to intracellular measurements, etc. The most convenient optical signal in this case is fluorescence, since it can be registered even at a low concentration of emission centers. The absolute value of the recorded fluorescence intensity has no physical meaning and cannot be used as an analytical signal. However, if the phosphor has several luminescence bands, then a ratiometric method based on measuring the ratio of the intensities of two radiative transitions can be used. In this work, the fluorescence intensity ratio and the lifetime of excited states, which are sensitive to various conditions such as temperature, acidity and triplet oxygen concentration, were used as the analytical signal. Hybrid nanostructures are formed on the basis of a metal core, a dielectric shell and porphyrin derivatives. The core was made by laser ablation in liquid from copper, silver, gold and their alloys to control plasmonic resonance. Porphyrins, their derivatives and porphyrin dyads have been used as molecular fluorophores. The silicon dioxide shell is designed to solve several problems: creating a buffer layer between the surface of the plasmonic nanoparticle and the fluorophore, encapsulating the fluorophore and stabilizing the nanoparticles. Calibration curves of the dependence of the relative fluorescence intensity and the excited states lifetime were obtained for thermometry, acidity measurement and determination of the concentration of molecular oxygen in solutions.

DRUG-LOADED POROUS SILICON NANOPARTICLES AS MULTIMODAL AGENTS FOR BIOPHOTONIC APPLICATIONS (INVITED)

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Key words: porous silicon nanoparticles, biophotonics, drug delivery

In recent years, nanoparticles (NPs) have been extensively studied as potential active agents for biomedical applications, including bioimaging, antibacterial and antiviral treatments as well as anticancer therapies. One of the most promising biomedical applications of NPs consists of their use as nanocontainers (NCs) for drug delivery.

There are several principles underlying a high potential of NP-based drug delivery systems [1-3], e.g. (i) passive accumulation of NPs based on the enhanced permeability and retention (EPR) effect; (ii) active accumulation of NPs and NCs conjugated with specific bioactive substances vectors; (iii) activation of controlled drug release from NCs under certain stimulus and conditions; (iv) realization of theranostics (therapy and diagnostics) modality. The latter can be based on luminescent bioimaging with NPs as labels in combination with their therapeutic capabilities [4,5]. Biodegradable porous silicon (PSi) NPs are found to be very promising for both biophotonic diagnostics and therapy [4-7]. It was established that PSi-NPs with various surface modifications could penetrate inside living cells with practically no cytotoxic effect, while various modalities for biomedical diagnostics can be realized [6,7].

The porous structure of PSi-NP allows a high degree of NCs' loading as it was demonstrated for various peptides [9], hydrophilic and hydrophobic drugs [10]. The biophotonic properties of PSi-NPs are determined both the intrinsic photoluminescence of silicon nanocrystals, which consist of those NPs, and exogenic fluorescence of molecular loading, e.g. doxorubicin [4,6], methylene blue [10] etc. Immobilization of drug in NCs and PSi-NPs can be used for increasing the bioavailability of the former, improving solubility, and ensuring overcoming various barriers, for example, the blood-brain barrier, reducing the effect on the body as a whole, targeting the damaged area. An important advantage of PSi-NPs as NCs is based on possibilities of creating new drugs with prolonged therapeutic action as well as fluorescent drugs immobilized in PSi-NPs, that opens new prospects for biophotonic monitoring of anticancer and antibacterial treatments.

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LASER-ASSISTED FABRICATION OF MAGNETIC NANOPARTICLES FOR BIOSENSORICS USING THIN Co AND Fe FILMS (INVITED)

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Key words: pulsed laser ablation in liquids, magnetic nanoparticles, thin metal films, magnetic biosensors

Designing magnetic biosensors requires technologies to fabricate chemically pure magnetic nanoparticles (MNPs) with desirable sizes and properties. Pulsed laser ablation in liquids (PLAL) is a promising tool in this field. In our work, we employed PLAL to fabricate MNPs using thin Co and Fe films as targets for ablation instead of commonly used bulk targets.

PLAL was performed with a picosecond laser EKSPLA PL 2143A (1064 nm, 34 ps, E = 5 mJ, 10 Hz). Ablation of thin cobalt films (5–500 nm) were carried out in distilled water, iron films (250 nm) – in acetone. All nanoparticles obtained exhibit magnetic response at applying an external magnetic field.

The average size of MNPs obtained using Co targets non-monotonically depends on the film thickness and varies in the range of 70–1000 nm according to scanning electron microscopy and dynamic light scattering data. The minimum relative standard deviation of the size distribution obtained is about 20% for the films with the thickness of 5–35 nm used in PLAL. The ablation threshold value and ablation craters profile were found to be dependent on the thickness of the Co film too. These characteristics for thicknesses less than 35 nm are typical for the phase explosion. At larger thicknesses the spallative ablation most likely occurs. These peculiarities are connected to changing the ablation mechanism near the skin layer depth that was estimated as 38 nm. PLAL of the iron films also made it possible to fabricate colloids of MNPs (~90 nm) with an iron core with an oxide shell in the form of FeO according to Raman and Mössbauer spectroscopy data.

The studied MNPs might be used as labels in magnetic biosensorics at conjugation with requirable biomarkers or penetration into cells.

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EXPLORING PHOTOCATALYTIC PROPERTIES OF AMORPHOUS LITHIUM NIOBATE NANOPARTICLES SYNTHESIZED VIA LASER FRAGMENTATION (INVITED)

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Key words: amorphous lithium niobate nanoparticles, photocatalytic activity, laser fragmentation in liquid

The photocatalytic activity of the synthesized nanoparticles was studied during the decomposition of the methylene blue dye under the influence of light from a xenon lamp with an emission spectrum of 200-2500 nm and a power of 200 W. The dye concentration was monitored by periodically measuring UV-Vis spectra. Intensity of the methylene blue absorption band decreases monotonically with increasing light exposure time. It should be noted that dye solutions in the presence of catalysts were mixed in the dark to achieve adsorption equilibrium, resulting in a 5% decrease in the particle concentration of methylene blue in the presence of amorphous nanoparticles, while no change occurred when crystalline powder was added. To consider kinetic relationships, they were constructed in first-order coordinates. Thus, it can be clearly seen that the synthesized particles are more active than the crystalline powder, and their rate constant is almost 2 times higher than that of the initial material, at 0.062 and 0.036 min^{-1}, respectively.

Amorphous lithium niobate nanoparticles were synthesised by laser fragmentation in a liquid of 30-100 nm in size. Amorphous lithium niobate nanoparticles were found to exhibit photocatalytic activity. It is shown that the structure of amorphous $LiNbO_3$ nanoparticles contains O_6 oxygen octahedra with Li^+ and Nb^{5+} ions arranged in them. That is, the nanoparticles retain to some extent the structure (and consequently) the properties of ordinary crystalline ferroelectric $LiNbO_3$. This fact may allow to obtain new materials by introducing amorphous nanoparticles into various matrices. However, the structure of the obtained amorphous nanoparticles is significantly disordered compared to the structure of crystalline powders. In particular, it is possible (due to disordered structure) that the structure of nanoparticles may acquire a center of symmetry.

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TUNABLE NIR-OPTICAL PROPERTIES OF TMDC-NOBLE METAL NANOHYBRIDS BY MULTI-STEP FEMTOSECOND LASER ABLATION IN LIQUIDS

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Key words: laser ablation in liquids, molybdenum disulfide oxidation, core–shell–satellite, near-infrared, photothermal conversion

Molybdenum disulfide (MoS_2) has gained significant attention in the field of optoelectronics and photonics due to its unique electronic and optical properties. The integration of MoS_2 with plasmonic materials allows to tailor the optical response and offers significant advantages for photonic applications. This study presents a novel approach to synthesize MoS_2-Au nanocomposites utilizing femtosecond laser ablation in liquid to achieve tunable optical properties in the near-infrared (NIR) region. Utilizing one-, two-, and three-step synthesis methodologies, we successfully fabricated various core–shell and core–shell–satellite nanoparticle composites, such as MoS_2/MoS_xO_y, MoS_xO_y/Au, and MoS_2/MoS_xO_y/Au. These composite particles are meticulously characterized using electron microscopy, Raman spectroscopy, energy-dispersive X-ray spectroscopy, and optical absorption spectroscopy. In obtained NPs, the emergence of MoS_xO_y is attributed to the inherent susceptibility of MoS_2 to oxidation under laser irradiation. UV-visible absorption spectroscopy unveils considerable changes in the optical response of the particles depending on the fabrication regime due to structural modifications. The presence of defects within molybdenum oxides and sulfoxides significantly enhances the NPs' absorption in the NIR range. Hybrid nanoparticles exhibit enhanced photothermal properties when subjected to NIR-I laser irradiation, demonstrating potential benefits for selective photothermal therapy. Our findings underscore that the engineered nanocomposites not only facilitate green synthesis but also pave the way for tailored therapeutic applications, highlighting their role as promising candidates in the field of nanophotonics and cancer treatment. Remarkably, the optimal configurations, specifically "MoS_2 in Au" and "MoS_2:Au co-fragmented", achieved photothermal conversion efficiency exceeding 46% under 830 nm laser excitation within the NIR-I window, underscoring their substantial potential for selective photothermal therapy.

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SPECTRAL-KINETIC CHARACTERIZATION OF CEF3/CEO2 COMPOSITE STRUCTURES ACTIVATED BY THE ND^{3+}/YB^{3+} ION PAIR FOR TEMPERATURE SENSING APPLICATIONS

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Key words: luminescent thermometry, optical temperature sensing, Nd^{3+}/Yb^{3+}, CeF_3, CeO_2

In this work, we study the possibility of the use of Nd^{3+}, Yb^{3+}:CeF_3/CeO_2 nanoparticles in ratiometric luminescence thermometry. In order to explain the mechanism of the luminescence temperature sensitivity, we physically characterized the samples by means of transmission electron microscopy (TEM), X-ray diffraction (XRD), laser spectroscopy, and electron paramagnetic resonance (EPR). In particular, Nd^{3+}, Yb^{3+}:CeF_3 nanoparticles were synthesized via co-precipitation method and annealed in air at 600 °C for 0, 15, 30, 60, and 120 min to obtain double-phase Nd^{3+}, Yb^{3+}:CeF_3/CeO_2 nanoparticles as well as single-phase Nd^{3+}, Yb^{3+}:CeO_2 ones (at 120 min). The physical diameter of the samples gradually increases from 19 ± 2 (doped CeF_3) to 409 ± 18 nm (doped CeO_2). It was suggested that the double-phase samples consist of sintered doped CeF_3 and CeO_2 nanoparticles having average grain diameter around 65 nm. The single-phase CeO_2 sample also consists of sintered CeO_2 nanoparticles, suggestively. The luminescence intensity ratio (LIR) was analyzed in the 80–320 K range (LIR = INd/IYb, where 848–925 nm ($4F_{3/2}$ – $4I_{9/2}$) Nd^{3+} and 925–1048 nm ($2F_{5/2}$ – $2F_{7/2}$) Yb^{3+}). The maximal relative temperature sensitivity was achieved for Nd^{3+}, Yb^{3+}:CeO_2 sample (~0.2 %/K), which is a very competitive value. The LIR function has a simple linear temperature dependency in the broad 80–320 K which allows uniquely identifying the temperature at least in the studied broad temperature range. The mechanism of temperature sensitivity was suggested.

ACHROMATIC METALENSES FOR MINIATURIZED SINGLE-MOLECULE DETECTION PLATFORMS (INVITED)

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Key words: single-molecule spectroscopy; metalenses, portable diagnostic devices, on-chip lens, diagnostics

Single-molecule fluorescence microscopy is paramount for molecular biophysics research. Currently, dynamic single-molecule platforms show promising properties for diagnostics thanks to the ability to sense ultralow number of biomarker molecules, to monitor intermolecular interactions, or to enable real-time sequencing. Given that, there is a global demand to create miniaturized single-molecule platforms to apply the technology toward applied point-of-care testing settings outside a lab. Metalenses composed of nanoscale dielectric elements of micrometer-size height represent a promising miniaturized optical device that can mimic part of properties of bulky and costly objective lenses that are key optical elements for single-molecule sensing.

However, the requirements to lens properties for single-molecule fluorescence sensing typically include high numerical aperture (NA), high collection efficiency of fluorescence photons, and achromatic operation. We present a transmissive metalens made of nanofins of amorphous silicon, which has high numerical aperture and focusing power [1] with well-matched focal volumes at wavelengths of excitation and emission of Alexa Fluor 647 fluorophore. Our metalens is capable of detecting single fluorescent Alexa Fluor 647 molecules using fluorescence correlation spectroscopy. Moreover, we show capability of determining the size of fluorescently-tagged polystyrene nanoparticles with nanometer accuracy. Moreover, we numerically demonstrate that metalens can be integrated on a waveguide that can provide achromatic operation in aqueous solution at two wavelengths with high NA. Such a platform introduces an ultimately miniaturized on-chip single molecule analysis device for fluorophores in the visible spectrum range [2]. The proposed nanophotonic platforms could make it possible to create compact and portable fluorescent biosensors for medicine and screening of environmental pollution by nanoplastic.

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LASER SYNTHESIS OF LINEAR CARBON FOR NANOPHOTONICS (INVITED)

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Key words: linear carbon, laser fragmentation, nanophotonics

Carbon is one of the widespread materials having multiple allotropic forms. Carbon-based nanostructures include nanotubes, fullerenes, onion-structures, linear chains of carbon etc. The variety of nanostructured forms of carbon opens an opportunity to tailor electronic and optical properties of carbon-based devices for a variety of perspective applications. However, the mass production of nanostructured carbon for industrial applications would require technologies of controllable synthesis of large volumes of specific carbon allotropes characterised by a high stability.

In this work, we synthesized and studied the optical properties of ultimately thin carbon chains. When these chains are terminated by gold clusters, they become highly aligned with absorption strongly dependent on the angle between the chains and the polarization plane of the excitation. The luminescence from gold terminated chains is much stronger than that from the pure carbon structures which have quadratic dependence of photoluminescence intensity on the pumping power. When gold-terminated chains are illuminated by a laser with a frequency close to the plasma frequency of gold clusters, there is a weak blue-shifted luminescence observed. All these effects can be described by a model of finite-length chain interlevel transitions broadened by the exchange of carriers between the carbon chains and gold clusters. The presence of blue-shifted luminescence allows us to estimate the minimum length of the chains. The strong polarization dependence of the luminescence intensity of gold-terminated carbon chain arrays makes them promising candidates for nanoscale logic elements in emerging light controlled quantum devices.

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POROUS SILICON-BASED OPTICAL MICROCAVITIES: COUPLING OF BIOSENSING WITH THE ABILITY TO CONTROL REDOX REACTIONS

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Key words: cytochrome C, porous silicon microcavities, Raman scattering, light-matter coupling

Functionalized optical microcavities are the basic elements of novel highly sensitive and highly selective sensor technologies. By combining classical optical microresonators and new materials, such sensors offer exceptional sensitivity and have high potential for improving medical diagnostics, analytical chemistry, and environmental monitoring. New research directions in this field include the use of advanced hybrid materials. Porous silicon-based microcavities are characterized by high surface area and can amplify the intensity of the electromagnetic field in their cavity by orders of magnitude, which accounts for the high sensitivity of their optical properties to the changes in the environment. In this study, we present approaches to “on-demand” fabrication of porous silicon-based microresonators operating in the regime of weak light-matter coupling. It is shown for the first time that such microcavities can provide not only fluorescence enhancement, but also control of the vibrational states of compounds placed inside them. In addition, the specific photocatalytic properties of porous silicon in such microcavities allow the modification of the redox properties of biological molecules placed inside the cavity. The latter was demonstrated on the example of the heme-containing protein cytochrome C, which acts as an electron carrier in the mitochondrial respiratory chain and is a clinically important marker of mitochondrial and cellular damage. Our results show that microcavities based on porous silicon are of interest not only as sensor systems, but are also capable of controlling chemical reactions, which may find interesting practical applications in photonics and biomedicine.

LASER-STIMULATED RELEASE OF METHYLENE BLUE FROM POROUS SILICON NANOCONTAINERS FOR COMBINED CANCER THERAPY (INVITED)

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Key words: porous silicon, nanoparticles, nanocontainers, Methylene blue, laser irradiation, photoheating

Nanocontainers of porous silicon (PSi) loading Methylene blue (MB) dye were investigated by means of the optical spectroscopy and infrared thermometry under laser irradiation. The photothermal conversion efficiency and kinetics of the MB release from nanocontainers based on PSi were analyzed under CW laser irradiation at 660 nm. The spectroscopical study showed that the loaded nanocontainers had a strong absorption band of MB at 600–700 nm, indicating a high degree of the MB loading for NPs. The MB release from nanocontainers in an aqueous medium was monitored by measuring the MB photoluminescence in the spectral region of 700–800 nm when excited by a continuous wave laser at a wavelength of 660 nm. Also, the polarizing memory method was considered to make a conclusion about the state of MB (inside NPs or free MB in aqueous solution. The MB release from the nanocontainer based on PSi NPs was found to be significantly promoted by nanosecond laser irradiation at 532 nm because of the local laser-induced heating of PSi NPs. The local heating was assessed by the Raman scattering method. The temperature of NPs increase was 30-50 degrees. In vitro experiments with Paramecium caudatum unicellular organisms confirmed the possibility of spatially localized photoheating and enhanced MB release under laser irradiation. The obtained results highlight the prospects of PSi nanocontainers for biomedical applications, including antibacterial therapy and combination cancer treatment, due to their controlled drug release capabilities and photothermal effects.

POLYSTYRENE MICROSPHERE-BASED WHISPERING-GALLERY MODE RESONATORS FOR PHOTONICS AND BIOSENSING (INVITED)

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Key words: whispering-gallery modes, polystyrene microsphere, carbon dots, biosensing

Recent advances in polymer microspheres as whispering-gallery mode (WGM) resonators highlight their versatility in photonics and biomedicine, yet their applications demand materials with biocompatibility, stable emission, and tunable optical properties. We demonstrate the inherent luminescence of undoped polystyrene (PS) microspheres (5.3 μm diameter) synthesized via seeded copolymerization. These microspheres exhibit broad emission (400–650 nm under 405 nm excitation) originating from photochemical oxidation-induced carbonyl defects, alongside narrow WGM resonance peaks (Q-factor ~3.9×10^3). Their biocompatibility is confirmed via high cell viability (>90%) post-encapsulation, positioning them as standalone, label-free WGM sensors. Building on this foundation, we integrate carbon dots (CDs) into PS microspheres to enhance sensing performance. CDs, synthesized solvothermally from citric acid and urea, offer tunable emission, photostability, and biocompatibility. Decoration of PS spheres via impregnation yields composite resonators with preserved WGM properties (Q-factor ~2.8×10^3) and amplified CD fluorescence. These hybrid resonators enable ultrasensitive, label-free detection of bovine serum albumin (BSA) via WGM spectral shifts, achieving a detection limit of 10^{-16} m and a dynamic range spanning four orders of magnitude. The refractive-index-dependent WGM shifts correlate with BSA concentration, while reduced Q-factors upon analyte binding reflect energy dissipation from surface interactions. By combining the intrinsic advantages of PS microspheres (monodispersity, biocompatibility, and defect-driven luminescence) with CD-enhanced optical properties, we establish a versatile platform for in vivo-compatible biosensing.

THE NATURE OF SOLUBILITY OF SHUNGITE CARBON NANOPARTICLES IN WATER AS THE BASIS OF THEIR BIOLOGICAL ACTIVITY (INVITED)

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Key words: shungite carbon nanoparticles, water dispersion, hydrogen bond network

Sustainable technological development requires the creation of new materials with specified characteristics, and green technologies for their production, including biosimilar ones, are welcomed. Aqueous dispersions of carbon nanoparticles are of the greatest interest. The main task here is to develop approaches that allow obtaining thermodynamically and kinetically stable dispersions. One of such materials are shungite carbon (ShC) nanoparticles, aqueous dispersions of which have been developed. The nature of their solubility is molecular-cluster, like that of globular proteins, which makes these dispersions marginally stable. Small deviations from the developed modes of their production in temperature, concentration etc. will lead to obtaining solid phase condensates or films with different structures. This variability allows obtaining a wide range of materials with different properties contrary the desired parameters are not always reproduced. Proteins are also known for their crystalline polymorphism. The methods of DLS, Raman scattering, EPR of spin probes were used to study the cluster organization of aqueous dispersions of ShC and serum albumin in the temperature range of 230-300 K, as well as their hybrid system. In the protein + ShC system colloidal stability is provided with the formation of a protein crown around the nanoparticles. The basic role of the hydrogen bonds of water in the occurrence of supramolecular organization in the studied dispersions was established. Possible reasons for the weak stability of aqueous carbon and protein dispersions with decreasing temperature are discussed, based on the structural and dynamic properties of water. The phase transition was also detected in the albumin dispersion. At least two low-temperature phases were detected in the ShC dispersion by electron diffraction and TEM of solid phase samples obtained by condensing the dispersion at temperatures slightly above zero °C. This indicates destabilization of the dispersion with decreasing temperature.

PORTABLE MICROFLUIDIC SYSTEM FOR DETECTING ANTIBIOTIC-RESISTANT BACTERIA

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Key words: nosocomial infections, antibiotic-resistant bacteria, microfluidic device, isothermal amplification, fluorescent DNA sensors

Nosocomial infections still remain a critical problem in global healthcare, affecting millions annually — 3.2 million in Europe and up to 2.5 million in Russia. One primary bacterial pathogen responsible for these infections is Shigella sonnei, which is characterized by severe symptoms and high contagiousness. Rapid and accurate detection of this pathogen is crucial for timely diagnosis and treatment, especially in healthcare settings with increased outbreak risks. While molecular detection methods like polymerase chain reaction are widely used, their application is limited due to the need for expensive equipment and complex cycling protocols.

We propose an innovative detection system that integrates isothermal amplification and immobilized DNA sensors within a microfluidic device, which is adapted to the fluorescence reading in a spectrofluorometer. The isothermal amplification increases the number of copies of the target sequence containing single nucleotide variations (SNVs) at a constant temperature, eliminating the need for expensive thermal cyclers. Highly specific fluorescent DNA constructs, immobilized on the chip surface, detect SNVs in antibiotic-resistant bacterial strains. These “molecular anchors” assemble and fix signaling fluorescent dye molecules when there is an exact match with the target amplified DNA sequence. In cases of mismatch, the unbound portion of the DNA construct is washed away with a buffer, resulting in a very low background signal. The use of microfluidics significantly simplifies the diagnostic process and makes it more stable. Unlike traditional test systems that use separate tubes for each stage, microfluidic technology integrates all stages of analysis on a single device. This simplification reduces reagent consumption and minimizes human error.

The expected sensitivity of the system is comparable to that of isothermal amplification methods, allowing detection of up to 100 copies of the target sequence. The specificity enables the distinction of single nucleotide variations with statistical significance, which is critical for identifying antibiotic-resistant strains.

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PLASMON LOCALIZATION, GIANT EM FIELD, AND SERS EFFECT IN FLEXIBLE METASURFACES (INVITED)

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Key words: plasmonic, metasuface, giant field, SERS, AFM, SNOM

We explore the optical properties of plasmon localization and local EM field enhancement in metal-plastic metasurface. The flexible metal-dielectric metasurfaces are developed from modulated polycarbonate plastic coated by silver nano film [1]. Localization of an optical excitation is experimentally observed by near-field scanning optical microscopy within subwavelength areas in the regular open-resonator metasurface. The localized modes are seen as giant maxima of the local electric field spatially concentrated in dents of the metasurface. Local near-field spatial spectra consist of regularly distributed strong peaks. The hot spots of the electric field follow the topography obtained by atomic force microscopy. This experimental observation is consistent with the results of computer simulations of a double-periodic metal- dielectric metasurface and the predictions of our analytical theory. We find the silver nano-film has strong adhesion to polycarbonate substrate. The metasurface is used as an effective SERS substrate.

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SELECTIVE SENSING OF VOLATILE ORGANIC COMPOUNDS WITH LUMINESCENT QUANTUM NANOCRYSTALS (INVITED)

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Key words: cancer markers, volatile organic compounds, luminescent quantum nanocrystals, rGO, electron transfer, energy transfer

The early detection of cancer continues to be a major challenge in medicine. The development of effective strategies to reduce cancer mortality and shorten treatment times depends on the integration of modern theranostics and sensor technology. Recent advances in the detection of volatile organic compounds (VOCs), which can serve as cancer markers, are promising. Elevated levels of certain VOCs, such as acetone, acetonitrile, methanol and ethanol, in exhaled breath can indicate the presence of certain cancers.
Current research in sensor technology is focusing on nanomaterial-based sensing elements. The high surface-to-volume ratio of nanomaterials and their modifiable shape and chemical composition allow precise tuning of their physical and chemical properties, leading to improved sensor performance, sensitivity and selectivity. Luminescent colloidal quantum nanocrystals (NCs), such as quantum dots and nanoplatelets, and graphene family materials, such as graphene, reduced graphene oxide, graphene nanobelts and carbon nanotubes, are two of the most studied classes of nanomaterials for modern sensors. Despite significant progress in the development of luminescent and electrical sensors using these materials, achieving selectivity in the detection of VOCs with similar chemical compositions remains a key issue.

We present an approach for the selective detection of multiple VOCs with similar chemical compositions by simultaneously analysing the luminescence responses of multiple sensing elements. These elements use layers of quantum dots based on CdSe, CdTe, $AgInS_2$ and CdSe nanoplatelets, and multilayer structures combining reduced graphene oxide (rGO) nanosheets with NCs (NCs/rGO). We show that the nanostructures provide efficient photoexcitation energy transfer and photoinduced electron transfer from NCs to rGO sheets. We propose a physical model that describes the correlation between the response efficiencies on VOCs and the relaxation of electronic excitation in our structures. Our findings suggest the potential to design selective sensors by combining hybrid structures with different quantum nanocrystals and graphene-like materials.

DEVELOPMENT OF INNOVATIVE NANOMATERIALS FOR BINARY TECHNOLOGIES OF MEDIAL TREATMENT (INVITED)

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Key words: laser ablation in liquids, nanoparticles and nanoformulations, sensitization of binary radiation therapies

Development of new nanoparticles (NPs) and nanoformulations (NFs) is traditionally the research focus in innovative approaches to medical diagnostics and treatment. This research area appears to be extremely broad due to the variety of their properties determined not only by the size and chemical composition, but also by morphology and important nuances related to the fabrication techniques. In the view of versatility and broad range of allowed materials, laser ablation in liquids demonstrates the most promising results, at least at the research stage, due to fine control of physical and chemical characteristics of the resulting nanomaterials which is especially the case of ultrashort, femtosecond and short picosecond, laser pulses determining non-thermal decomposition of the target material. Colloidal solutions obtained this way are featured by exceptional purity and, in many cases, long time stability without using of ligands. That makes such NPs extremely promising for variety of biomedical applications including sensitization of radiation diagnostics and targeted local ray therapies.

The report comprises an extensive research data in ablative fabrication, characterization and biomedical applications of multimodal NPs and more complex NFs, which can be applied as effective contrast agents under external physical stimuli, including x-ray radiation, neutron and proton beams, and CW laser radiation [1-3]. The first group of such nanomaterials is based on heavy metals like gold and bismuth, the second includes boron-based and other materials featured by large interaction cross section with thermal neutrons, the third embraces a number of synthesized two element nanomaterials (nitrides and borides) demonstrating an excellent absorptivity of laser light in the biological tissue transparency window due to their plasmonic properties. In addition, we present our recent results on fabrication and study of more complex composite multimodal nanomaterials [4], produced via multi-step laser assisted technologies. Every component of such composites is activated by particular external physical factors or by combination of those. Significant number of the reported nanomaterials exhibits the potential for use in theranostic applications via combination of diagnostic and therapeutic modalities. The results presented are illustrated by biomedical experiments in cell biology, surgery, oncology and bioprinting.

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YF_3-CEF_3:TB^{3+} NANOPARTICLES CONJUGATED WITH AU NANOPARTICLES AND CHLORIN E6 AS A PLATFORM FOR COMBINED PHOTODYNAMIC THERAPY AND MOLECULAR SENSING

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Key words: nanoparticles, chlorine e6, photodynamic therapy, plasmonics, FRET, PLQY

Combined photodynamic therapy (PDT) is a promising approach that involves converting energy from ionizing radiation into the activation of PDT agents. This process is feasible when conjugating scintillator nanoparticles with PDT agents. Simultaneously, the light yield of quantum systems can be enhanced through interaction with plasmonic nanoparticles; in this study, gold (Au) nanospheres are investigated within the visible spectral range. In this work, we examined the spectral and kinetic characteristics of YF^{3-} CeF_3:Tb^{3+} (15%) nanoparticle conjugates with Au nanoparticles and chlorin e6. An amplification of Tb^{3+}-sensitized luminescence was observed, along with strong energy transfer from the nanoparticles to chlorin e6. To evaluate toxicity, MTT assays were conducted on A549 cells in the presence of nanoparticles conjugated with chlorin e6. The synthesis of $YF^{3-}$$CeF_3$:$Tb^{3+}$ (15%) nanoparticles was performed using a co-precipitation method at Kazan Federal University. Samples of Au nanospheres were prepared as colloids at IBPPM RAS. The luminescence and decay characteristics of YF_3-CeF_3:Tb^{3+} (15%) nanoparticle conjugates with chlorin e6 and Au nanospheres were studied under UV irradiation. Effective nonradiative energy transfer was demonstrated both from cerium to terbium ions and from terbium ions to chlorin e6. The maximum energy transfer efficiency was approximately 20% for solutions of chlorin e6 with uncoated nanoparticles, whereas the transfer rate increased to about 50% for nanoparticles coated with PVP, indicating the likely formation of conjugates. An enhancement in the photoluminescence quantum yield of YF_3-CeF_3:Tb^{3+} nanoparticles was observed in the visible spectral range in the presence of Au nanospheres, with an increase by a factor of 2 to 3 in colloidal solutions. The underlying mechanisms are discussed in terms of FRET, the Purcell effect, and cooperative energy transfer.

LONG-TERM EFFECTS OF AUNPS SURFACE COATING ON BIODISTRIBUTION IN MICE

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Key words: gold nanoparrticles, laser ablation, in vivo imaging, animal experiments

Gold nanoparticles (AuNPs) are currently being studied as potential agents for photothermal therapy, radiotherapy and contrast media for computed tomography. Surface modification options allow for improved stability and pharmacokinetics of AuNPs, which is essential for developing formulations for biomedical application. This presentation will focus on the pharmacokinetics and biodistribution of nanoparticles synthesized using the laser ablation method. Compared to chemical synthesis, laser ablation in liquid offers advantages such as high purity, controlled size dispersion, and cost-effectiveness for industrial-scale production. The study was performed wtih AuNPs ~5–8 nm in size with different coating options. Among the most commonly used coatings, polyethylene glycol (PEG) and bovine serum albumin (BSA) were selected for detailed investigation.

The dynamics of AuNPs uptake in organs and tissues of laboratory mice were assessed using computed tomography (CT). To evaluate contrast enhancement and pharmacokinetic properties, AuNPs were administered intravenously to healthy and tumor-bearing laboratory mice, and CT imaging was performed at multiple time points, ranging from 1 minute to 7 days post injection. Following intravenous administration, AuNPs remained in blood circulation for several hours before gradually redistributing to the liver and spleen. The circulation half-life, estimated from the radiodensity of the heart chambers, was ~18 h for PEG-coated AuNPs and ~3 h for BSA-coated. Tumor accumulation significantly depended on the cell line of the tumor model. The obtained data not only provided information on the AuNPs biodistribution over time, but also demonstrated the feasibility of developing AuNP-based contrast agents for CT. Thus, the study revealed the relationship between nanoparticle stabilizing coatings and pharmacokinetic properties. Based on these findings, the presentation will outline potential biomedical applications of gold nanoparticles.

CONCEPT OF CORE-SATELLITE Au@Fe NPS APPLICATION FOR NEUTRON FIELD MEASUREMENTS IN SITU

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Key words: laser ablation, nanoparticles, in vivo imaging, CT, MRI

A neutron field suitable for boron neutron capture therapy (BNCT) can be highly heterogeneous depending on the source parameters. Therefore, it is crucial to have a reliable tool for accurate field measurements. Fe_3O_4@Au nanoparticles can serve as such a tool, because the stable isotope gold-197 has a high neutron capture cross-section. The Fe_3O_4@Au-based agent will allow measuring the neutron flux in tumors and healthy tissues by in situ activation of iron-gold nanoparticles accumulated in tissues with thermal neutrons. Neutron beam irradiation of laboratory animals followed by SPECT of gold-198 will allow to evaluate the flux distribution. MRI allows to identify organs with nanoparticles, CT – to measure gold concentration, and SPECT – to measure neutron-induced radioactivity of 198Au. An integrated approach will allow to study in detail the distribution of nanoparticles and the interaction of neutrons with the tumor. Additionally, Fe_3O_4@Au nanoparticles can serve as contrast agents for preclinical CT and MRI diagnostics. Since effectiveness of conventional contrast media is limited in animal studies due to rapid elimination, nanoparticle-based contrast agents with long-term blood circulation will improve the information content of preclinical imaging. Fe_3O_4@Au nanoparticles can provide signal enhancement in both modalities after a single administration, thus considerably facilitating research in experimental oncology. The report will present a method for the synthesis and functionalization of Fe_3O_4@Au core-satellite nanoparticles for biomedicine. The results of tolerability, biodistribution and studies on tumor models will be presented. The activity of 198Au after neutron irradiation and the possibility of SPECT imaging will also be assessed.

STUDY OF BACTERIOSTATIC PROPERTIES OF COATINGS BASED ON QUARTZ NANOPARTICLES OF SHUNGITE ROCKS

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Key words: quartz nanoparticles, stable water dispersions, acrylic polymer, bacteriostatic properties

The object of the study is alpha quartz nanoparticles of shungite rocks, which form stable dispersions in water due to the stabilizing role of graphene-like carbon. When the dispersion is applied to a substrate, films are formed consisting of chains of quartz nanoparticles. The nanoparticle dispersions and films obtained from them were studied in detail using X-ray diffraction and X-ray phase analysis, Raman spectroscopy, scanning electron microscopy, and dynamic light scattering. Stable aqueous dispersions of nanoparticles obtained without the use of surfactants can be used in biomedicine, for example, for the delivery of medicines or special coatings. But before using quartz nanoparticle dispersions in medicine, it is necessary to study their interaction with various biological systems. The purpose of this work is to study the bacteriostatic properties of a coating based on quartz nanoparticles of shungite rocks. In the work, compositions based on acrylic polymers with quartz nanoparticles as a filler were obtained. Coatings obtained from compositions cured on glass substrates were studied the bacteriostatic properties of the coatings were tested on Staphylococcus aureus and Escherichia coli bacteria. Quartz nanoparticles in the dispersion showed sterility and bacteriostatic effect. After incubation, there is continuous bacterial growth in the uncoated area and under the pure polymer coating, and there is no bacterial growth under the coating of the quartz nanoparticle composition. These results indicate the presence of a bacteriostatic effect of the coating with quartz nanoparticles of shungite rocks on Staphylococcus aureus and E. coli bacteria. This coating, in the future, can be used in wound coatings to prevent the development of bacteria, or on fish farms to reduce biofouling of nets.

NANOSTRUCTURES WITH PLASMON-ENHANCED LUMINESCENCE FOR BIOIMAGING APPLICATION

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Key words: luminescence enhancement, localized surface plasmon resonance, porphyrin, hybrid nanostructures

Fluorescent labels are used in bioimaging, non-invasive diagnosis and therapy of cancer. At the same time, the biological tissues of the body absorb part of the emitted luminescence. One way to increase the efficiency of labels is to enhance their fluorescence through the metal-enhanced fluorescence effect. Hybrid molecular-plasmon nanostructures allow improving the optical properties of the luminescent molecules included in the composition. However, to create hybrid structures, several factors must be taken into an account.

Firstly, the peak position of the localized surface plasmon resonance of the metal nanoparticle should be in the absorption or emission region of the luminophore. Second, during synthesis, the surface of the nanoparticle should not have the same sign of the surface electric charge as the luminophore. Third, it is necessary to ensure a distance between the nanoparticle and luminescent molecules to prevent quenching of the emitted light.

The work demonstrates the development of hybrid molecular-plasmonic nanostructures with improved optical response, as well as optimization of parameters for synthesized fluorescent labels to get highest efficiency. In addition, it was shown that the obtained nanostructures are characterized by reduced generation of singlet oxygen, which is essential for luminescent markers.

Industrial laser technologies: automatization & application of ML

THE INFLUENCE OF GAS FLOW ON THE QUALITY OF METAL PARTS MANUFACTURED BY SELECTIVE LASER MELTING

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Key words: selective laser melting, porosity, flow rate, splatter, laminator

Selective Laser melting (SLM) is a technology for manufacturing metal parts by sintering particles of metal powder using laser radiation. SLM provides excellent mechanical properties for the manufactured parts and a high degree of freedom in the design process. During the manufacturing process of the part, a protective gas continually circulates through the work chamber, removing combustion by-products generated during melting and metallic particles ejected from the melt pool. In the specified processes, there is an emission of molten material from the melt pool, followed by solidification and possible deposition on nearby areas or removal using a gas flow. It has been established that Marangoni effects in the melt pool, combined with the recoil pressure generated during the expansion of metal vapors, are the main factors responsible for the ejection of molten material. This article, the authors investigate the impact of laser beam intensity on the process of molten powder material splattering. The study analyzes the causes, appearance, and composition of the splatter, as well as the methods for mitigating it. Since the SLM process is carried out in a protective atmosphere of inert gas, it has been shown that the gas flow is a crucial factor as it removes condensate and prevents material oxidation during melting. The hardened splatted particles have an average size of approximately 162 microns, which significantly exceeds the initial powder size of 32 microns. This study analyzed the powder expulsion during processing and the influence of gas flow on the quality of the samples, particularly in terms of porosity. The obtained results showed that the gas flow rate significantly affects the uniformity of the properties of the manufactured products.

ABOUT THE ADVANTAGES OF THE END-TO-END LASER TREATMENT TECHNOLOGY OF WIRE ROD SURFACE FOR CLINKER REMOVAL IN THE IN-LINE CALIBRATED ROLLED PRODUCTS MANUFACTURE WITH DEFINED PROPERTIES

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Key words: laser cleaning, wire rod, mill scale, scale removal

Currently, mechanical cleaning and chemical etching are the traditional methods of removing scale from the surface of wire rod in Russian metallurgical plants. Mechanical cleaning does not completely remove scale, so the next step is acid etching in acid in 3-4 baths, and after etching baths, the wire rod passes through alkaline baths and hot water. The traditional approach has three main disadvantages: accelerated wear of processing equipment, the use of highly hazardous substances, and the presence of an explosion and fire hazard due to hydrogen release.

Currently, the most promising, highly efficient and cost-effective technical solution that fully meets the high technical and environmental requirements for cleaning calibrated rolled products from scale is the end-to-end laser surface cleaning technology. The advantage of the technology is to obtain the surface of metal workpieces of high quality (according to GOST 2789-73). I.P. Bardin Central Research Institute of Ferrous Metallurgy, Russia, Moscow in laboratory conditions on samples of round rolled products of various diameters made of different types of steels. Laser surface treatment has no negative effect on the micro- and macrostructure of calibrated rolled products, which was confirmed during studies of the structure of these metal samples. The cost of the new technology of laser surface treatment of wire rod is 4-5 times lower than the acid etching method, and 20-35 times cheaper than the mechanical method (for example, acid-free abrasive blasting) due to low energy consumption, labor and time costs, disposal costs, preventive maintenance and repairs. There are no consumables, the installation requires only the supply of electricity and dust removal of scale. In addition, a by-product of the end-to-end technology of laser surface treatment of wire rod is a raw material (mill scale), which can be used to produce iron powder in additive 3D printing technology, as well as to produce porous metal-ceramic materials from a charge by self-propagating high-temperature synthesis.

APPLICATION OF LASER TREATMENT FOR STRAIGHTENING OF SHEET METAL BLANKS AND PARTS ON THE EXAMPLE OF FORMING OPERATIONS

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Key words: laser forming, residual stress, brass, copper, 3D-printing, scale factor

The application of lasers at modern blanking productions in mechanical engineering is mainly limited to laser fine cutting of metal sheets, so the search for new areas of application is an actual task. A significant advantage of nanosecond lasers is compressive stresses, created inside the material without ablation effect of the material surface. Forming operations of thin sheet materials often conducted with a mismatching of drawing dimension with the formed part due to the springback effect and incomplete forming in the area of radii of tools' rounding. Therefor the straightening of parts is strongly recommended to be carried out. The article deals with the evaluation of residual stresses in sheet blanks made of brass L63 and copper M1 with a thickness of 100 microns before and after processing by laser forming technology, as well as the influence of the induced level of residual stresses on the result of forming operations of forming operations. The forming tools were manufactured by 3D printing technology (LCD). The control of geometric accuracy of the deformed part and forming tool is performed using a non-contact 3D-scanning system. Prior the 3D-printing stage the geometric compensation was performed for four dimensions of the as-printed tools, three of which form the base coordinate system. After V-shaped (single-angle) and U-shaped (double-angle) bending of the blanks without laser pre-treatment the springback has been occurred after load removal. It was found out that for smaller values of scale factor (lambda) springback is reduced in case the workpiece pre-treated by laser, while for larger lambda - values the pre-treatment by laser may not affect the result. The small lambda -values increase the stiffness of the workpiece locally, resulting in non-filling the tools' radii. In this case, laser processing was performed to straighten the rounding radii, for parts with axisymmetric and planar geometry. The performed research extends the range of the diagram of laser-supported manufacturing technologies. The most important aspect is the estimation of residual stresses, especially due to lambda decreases and shifting towards micro-level. It is necessary to "dose" the surface with compressive stresses by means of precise adjustment of laser irradiation based on the geometry and material of the workpiece to make precision straightening operations real.

OPTICAL EMISSION SPECTROSCOPY FOR IN-SITU CONTROL OF THE 3D LASER ADDITIVE PROCESS WITH METAL WIRE OF TITANIUM-NICKELIDE ALLOYS

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Key words: additive manufacturing, laser metal deposition, energy deposition, optical emission spectroscopy, titanium-nickelide

Additive manufacturing, particularly laser additive manufacturing (LAM), has revolutionized the field of materials engineering by enabling the precise fabrication of complex geometries with bespoke properties. This technology uses laser energy to locally melt a source metal material, either in the form of powder or wire, layer by layer, to create three-dimensional objects. The versatility of LAM provides a unique opportunity to utilize a wide range of metallic alloys and composite materials, allowing for advancements in industries such as aerospace, automotive, and biomedical engineering. Despite the remarkable potential of LAM, a critical challenge facing its adoption is the possible variation in alloy compositions during the additive manufacturing process. This alteration can result from factors such as differential evaporation of alloying elements, oxidation, or variations in the thermodynamic conditions of melting-solidification cycle. Addressing these issues requires a nuanced understanding of the in-situ chemical and physical transformations that occur. Spectroscopic approaches provide real-time monitoring capabilities to detect and quantify compositional changes, thus offering a pathway to better control and stabilization of the LAM process.

We have developed an optical emission spectroscopy system for in-situ composition monitoring during the laser metal deposition process. The system is based on a high-resolution optical spectroscopy sensor and allows for the in-situ collection of unique spectral features intrinsic to the materials used. Using intelligent data analysis and machine learning methods, the system can tailor additive process parameters to achieve the desired material composition as well as optimal biochemical and biomechanical compatibility characteristics. The capabilities of the developed spectroscopic system have been demonstrated in the additive manufacturing of superelastic titanium-nickelide alloys with volume-stable mechanical properties and surface structure suitable for medical use.

MODELLING AND THE EXPERIMENTAL STUDY OF THE IMPACT OF PULSED LASER RADIATION IN SILICON WAFER SEPARATION TECHNOLOGY (INVITED)

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Key words: laser ablation, nanosecond laser, femtosecond laser, FEM

The growing demand for miniaturized and high-performance semiconductor devices necessitates advanced wafer dicing techniques that ensure high precision, minimal material loss, and reduced mechanical stress. Traditional mechanical cutting methods often induce microcracks, chipping, and surface damage, degrading device performance and yield. Laser-based separation has emerged as a promising alternative, offering non-contact processing, high spatial resolution, and compatibility with brittle materials like silicon. However, optimizing laser parameters is critical to avoid thermal damage, recast layers, and microstructural defects. This study investigates pulsed laser processing for silicon wafer dicing, comparing nanosecond (ns) and ultrafast (ps/fs) laser. While ns pulses induce significant thermal effects (e.g., melting and cracking), they offer cost advantages over ultrashort-pulse laser systems. In contrast, ultrashort pulses enable cold ablation with minimized heat-affected zones. Finite element modeling (FEM) is employed to simulate thermo-mechanical responses, including stress distribution, phase transitions, defect formation, and groove characterization. The model accounts for temperature-dependent optical/thermal properties and nonlinear absorption phenomena. The results demonstrate that FEM can accurately predict crack propagation thresholds and ablation crater dimensions. These findings provide practical guidelines for selecting laser parameters to achieve defect-free dicing, thereby advancing semiconductor manufacturing efficiency.

MULTI-OUTPUT MONITORING OF LASER WELDING BASED ON MACHINE LEARNING METHODS (INVITED)

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Key words: quality assurance, signal processing, laser beam welding

The growing industrial adoption of Laser Welding (LW) and the increasing complexity of fabricated assemblies have highlighted the urgent need for advanced quality control mechanisms. In response, this study explores the application of Artificial Intelligence (AI) and Machine Learning (ML) techniques for enhancing weld quality assessment through the fusion of multisensory data streams.

The experimental investigation focuses on laser welds produced on 09G2S structural steel using a 3 kW fiber laser. The proposed methodology decomposes the quality analysis into two primary streams. Firstly, weld cross-sections are segmented using the U-Net convolutional neural network to identify defect regions and assess joint integrity based on geometrical profiles. Secondly, temporal and spatio-temporal signals recorded during the welding process are examined. Spectrogram time series are classified using an automated ML pipeline (FEDOT), while thermal image sequences are analysed using state-of-the-art deep learning models, including Video Vision Transformers and convolutional neural networks.

It is envisaged that the integration of such AI-driven approaches will, soon, support the development of intelligent, in-process monitoring systems with adaptive feedback capabilities. These advancements are expected to contribute significantly to the digital transformation of LW processes, improving both reliability and efficiency in automated manufacturing environments.

AUTOMATION OF LASER TREATMENT PROCESSES IN SERIAL LASER MACHINES MANUFACTURING BY “LASERS & EQUIPMENT” (INVITED)

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Key words: automation, laser machines, laser technology, additive technologies

Since 2022, there has been an active growth of production volume, in a number of industries the growth compared to 2021 was about 30%. At the same time, there are shortage of qualified personnel associated with the outflow of specialists abroad and within the framework of the SVO. One of the main issues on the agenda is to increase production volumes while maintaining personnel. This can only be achieved through automation and optimization of processes in production lines. Versions of automation of serial laser machines manufactured by "Lasers & Equipment" for laser cutting, welding, microprocessing and additive technologies are presented in this work.

ROBOTIC CELLS EQUIPPED WITH HIGH POWER FIBER LASERS FOR MANUFACTURING (INVITED)

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Key words: fiber laser, industrial robot, welding, cladding, cleaning

High Power fiber lasers have become a workhorse of a vast majority of industrial applications. The most widespread technology is laser cutting, though welding, cladding, hardening and cleaning with fiber lasers also gains much attention. Combination of a fiber laser, process head, technology and industrial robot presents very flexible solution for many industries that require automation of technological process. A review of projects developed by VPG LaserOne (Ex. IRE-Polus IPG) is presented.

TECHNOLOGY OF LASER SURFACE CLEANING OF HOT-ROLLED METAL PRODUCTS BY LASER RADIATION DUE TO THERMOMECHANICAL SCALE DESTRUCTION

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Key words: thermomechanical destruction of scale, laser cleaning, continuous ytterbium fiber laser, mill scale

Removal of oxide layers from the surface of hot-rolled carbon steels (mill scale) is an urgent task for modern production. The implementation of laser surface cleaning technologies for rolled metal will improve the quality of cleaning, increase process productivity, reduce metal losses and negative environmental impacts. Currently, two main approaches to laser cleaning are most common, based on the evaporation of oxide layers, characterized by the use of either pulsed nanosecond or continuous ytterbium fiber lasers. However, evaporation of oxide layers and, especially, scale is a very energy-intensive process. Evaporative laser cleaning of mill scale from the surface of hot-rolled steel has a low productivity (about 1.5 square meters per hour per 1 kW of average laser power). Heating of the steel surface during its cleaning in the evaporative mode of exposure to continuous laser radiation leads to oxidation, melting, quenching or tempering. In cases where such thermal effects on the steel surface are unacceptable, continuous laser radiation evaporation cleaning cannot be applied.

A new approach to the implementation of the process of laser cleaning of rolled metal from scale using the mechanisms of scale destruction due to the phase transformation of surface layers with the appearance of the wustite phase with its low adhesion to the base metal, accompanied by the occurrence of thermal stresses, is proposed. The process of scale destruction under the action of continuous fiber laser radiation has been studied. To increase the cleaning efficiency, a search and optimization of laser exposure modes was carried out. The features of scale formation and the phase transformations occurring under the action of laser heating are revealed. The range of modes of exposure to continuous laser radiation has been determined, which leads to thermomechanical destruction of scale without evaporation. A method and technology of two-stage roughing and finishing laser cleaning are proposed, which can significantly improve equipment productivity and cleaning quality.

KEY CHALLENGES AND PROCESS CHARACTERISTICS IN ULTRASHORT PULSE LASER MACHINING OF DIFFERENT MATERIALS (INVITED)

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Key words: laser machining, ultrashort laser pulses, picosecond pulses

This study investigates the fundamental characteristics and mechanisms of material processing via ultrashort pulse (USP) laser irradiation, with a focus on picosecond (ps) and femtosecond (fs) regimes. The interaction dynamics between USP laser radiation and diverse material classes—metals, semiconductors, and dielectrics—are analyzed, emphasizing distinct physicochemical responses. Comparative evaluation reveals the advantages of USP processing (e.g., reduced heat-affected zones, high precision) over conventional long-pulse (>1 ns) laser techniques, alongside inherent challenges (e.g., throughput limitations).

Experimental results demonstrate the feasibility of USP-based welding for dissimilar materials, exemplified by the silicon-steel system. Furthermore, process optimization strategies are proposed to enhance quality and scalability, supported by empirical data on parameter-dependent outcomes.

Work presents an investigation of interface region weld, formed by picosecond laser irradiation. With ultrashort interaction time, high peak power, and a wide selection of pulse repetition rates this technology enables a precise control over the amount of energy applied to the welded area and achieve strong joint alongside with effective prevention of semiconductor material from thermal destruction. Laser parameters (pulse energy, pulse repetition rate, exposition time) were studied to evaluate its impact on welding process. Well-tunable and precise control over ultrafast laser energy deposition made it possible to achieve surface silicon concentration up to 11% at an average power below 30 W. Structural features in the welded areas alongside with surface element distribution were studied to reveal the influence of processing parameters on the weld formation process.

Second part dedicated to the study on the process of the formation of bubble-like structures on a coated glass surface using 50 ps laser pulses. The high-intensity interaction of laser radiation on the film–glass interface allowed us to develop a process for efficient glass bump formation. The high peak energy of the picosecond pulses has allowed us to merge the processes of coating evaporation and bubble growth into one. The key aspects of the bump formation process were studied and are explained.

PHYSICAL PROCESSES DURING SELECTIVE LASER MELTING

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Key words: SLM, micromodel, mesomodel, multi-level simulation

Selective laser melting (SLM) technology is being incorporated into the product manufacturing cycle, enabling the production of complex, topologically optimized structural elements. It is imperative to comprehend the physical processes that transpire when laser radiation interacts with metal powder and their subsequent impact on the stress-strain state of the product during the printing process. The experimental methods employed to study molten metal within SLM installations are constrained by the available temperature ranges. Alternatively, these methods are executed as post-procedures to evaluate the quality of the resulting product, with parameters such as geometric dimensions, relative density, and mechanical properties being considered. The utilization of numerical modeling facilitates the analysis, prediction, and modification of the manufacturing process of a product employing SLM technology. To date, a common approach to modeling has yet to be established. Given the broad spatial and temporal scales involved, three levels of modeling can be distinguished: macro-scale (describing stress-strain states on the product scale), meso-scale (generally describing SLM processes on the scale of a characteristic element of the product), and micro-scale (describing in detail the hydrodynamic and thermophysical processes on the scale of the molten pool).

At the micro-level, the focus of modeling studies is on processes such as heat transfer (convective, conductive, and radiative), phase transitions, forced convection of liquid melt caused by surface tension forces, Marangoni effects, recoil pressure, and gravity. The mathematical model is described by a system of hydrodynamics of a continuous medium with variable properties. The VOF (Volume of Fluid) approach is traditionally employed to simulate flow dynamics, while the DPM (Discrete Phase Model) approach is used to simulate scattered particle. The micro-level model facilitates the analysis of undesirable effects, such as keyhole formation, balling up, and lack of fusion, and the identification of methods to enhance productivity. These methods include altering the spot shape through the use of a double beam laser or an elongated spot in a single direction, as well as exploring scanning strategies.

Mesoscale modeling is a method employed to study thermal deformations that occur during the manufacturing process of products with inclined surfaces. It has been demonstrated that preliminary local heating enables the fabrication of a broader range of product shapes that can be manufactured without the use of supports using the SLM method. The potential for printing products using contactless support structures can be investigated. Prospects for further development include the implementation of a model linking the macro and meso levels to assess the stress-strain state of the product. Therefore, a comprehensive understanding of the physical processes underlying SLM technologies can lead to novel opportunities for their integration and implementation in various production settings.

PERSPECTIVES OF SLM TECHNOLOGY DEVELOPMENT IN THE NATIONAL INDUSTRY (INVITED)

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Key words: SLM, additive synthesis on a substrate, promising areas

The report examines promising areas for the development of additive manufacturing using SLM technology in Russia. The text emphasizes the expertise of “Laser Systems” JSC in developing additive manufacturing methods for products composed of pure copper powders, employing conventional laser sources. The text provides data on the typical physical and mechanical properties of the synthesized materials, as well as promising areas of development. The report also includes data on the economic and market indicators of the technology, which collectively demonstrate the promising prospects for the development of this production area.

FROM MODIFICATION TO FABRICATION: APPLIED AND FUNDAMENTAL PROJECTS BASED ON INDUSTRIAL LASER TECHNOLOGIES

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Key words: laser nanofabrication, microfluidics, lab-on-chip, raman spectroscopy

The use of laser technologies is significantly accelerated the development of materials processing technologies, electronics, disease diagnostics, etc. Our research group has managed to use mass-produced domestic laser systems to unify simple laser-assisted fabrication with latest achievements of photonics and nanotechnology for creation of nanoparticles of various materials, smart systems for rapid diagnostics of organic compounds and their decomposition, advanced security labels. As a result, such technologies have the advantage of fabrication stability, high reproducibility as well as cost-efficiency. The proposed concepts are considered to possess high commercial application of fundamental research with access to the applied field.

LASER CLEANING OF SILICA CAPILLARIES

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Key words: laser cleaning, silica capillary, UV laser radiation, polyimide jacket, cold ablation

Laser cleaning of silica capillaries from a protective polymer jacket is a promising and high-tech method for processing silica capillary blanks and forming working samples used in capillary electrophoresis.

Capillary electrophoresis is an intensively developing, highly effective method of separating complex mixtures in a silica capillary under the influence of an applied electric field, which has found application in various fields of science: pharmaceutical industry, forensics, chemical industry, clinical biochemistry and others.

High efficiency and development of this method is ensured by the introduction of new, more advanced and promising technologies for preparing working test samples. For example, to conduct genetic analysis in the genetic analyzer of the “Nanofor” type, a line of silica capillaries with a transparent window (detection zone) is used as the main element. The transparent window of the silica capillary is a section of the silica capillary surface cleared of the polymer jacket. The efficiency and accuracy of genetic analysis depends, among other things, on the quality (transparency) of the formed detection zone. The article presents the results of a comparative analysis of the traditional thermal method of cleaning a silica capillary and the proposed cleaning method using UV laser radiation.
The parameters of laser radiation are presented, ensuring the implementation of the cold laser ablation mode of the protective polyimide jacket from the surface of the silica capillary without the occurrence of deformations and other defects of silica capillaries. A comparative analysis of the quality indicators of the considered methods of cleaning silica capillaries is presented.

To confirm the feasibility of implementing the proposed laser cleaning method, a trial sample of a capillary line for the Nanofor 05 genetic analyzer was manufactured and practical measurements were carried out, the results of which confirmed the high quality of cleaning, manufacturability and prospects of the proposed method.

ANALYSIS OF THE FACTORS AFFECTING THE QUALITY OF PRODUCTS OBTAINED BY SELECTIVE LASER MELTING TECHNOLOGY (INVITED)

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Key words: product quality, control system, selective laser melting, additive technologies

Additive technologies are currently undergoing rapid development, particularly selective laser melting (SLM), which allows products to be manufactured layer by layer from metal powder using powerful laser radiation. The development of SLM technology is focused on increasing the productivity of machines and the quality of manufactured products. The article discusses the main factors affecting quality: those related to laser processing modes and strategies, those related to the accuracy of the geometric dimensions of the computer model of the manufactured product, those related to the design solutions of a specific installation, and those related to the consumable powder material. In the first case, it is necessary to select the technological parameters of the process experimentally or numerically (power, scanning speed and hatch distance, layer thickness, etc.) and synchronize the control signals of the laser and the scanning system (LaserOn, LaserOff, JumpDelay, etc.). In the second case, it is necessary to strike a balance between triangulation accuracy and the size of the 3D model file, or to implement step-by-step reading. In the third case, solutions to the problems discussed (wall deformation, spattering) are proposed to achieve high print quality. In the fourth case, it is necessary to control the fractional composition and morphology of the consumable powder material, especially when it is reused. It is also necessary to improve the accuracy of beam positioning by calibrating the installation and providing additional control systems: quality control of the applied powder layer, control of the geometry of the grown product using photo/video cameras, monitoring of thermal fields of each layer using thermal imaging cameras, pyrometers, or other methods, control of the working atmosphere parameters in the build chamber, control of the hopper fill level. There are also software products for compensating for technological deformations in additive manufacturing, based on scanning manufactured products and re-manufacturing them taking into account the deviations obtained, which leads to an increase in the product manufacturing cycle. Thus, improving the quality of a product obtained using SLM technology is achieved through a comprehensive solution covering all stages of its creation: from the formation of a 3D model to post-processing.

LASER METAL WIRE DEPOSITION OF MAGNESIUM ALLOY SINGLE-TRACKS: MELTPOOL DYNAMICS AND DEPOSIT CHARACTERISTICS

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Key words: laser metal wire deposition, magnesium alloy, pyrometry, computer simulation, modeling, biodegradable material

The need for individualized medical implants, as well as stringent requirements for their biocompatibility and biofunctional properties, stimulates the study of possibilities of digital design and manufacturing as a promising avenue for development in the field of biomedical materials science. Magnesium and its alloys offer unique advantages in biomedicine due to their biocompatibility, biodegradability, and high tensile strength, making them ideal for use as bone implants. The mechanical properties of magnesium alloys are even closer to bone compared to titanium alloys. Low corrosion resistance allows one to consider this class of alloys as a biodegradable material for temporary implants that are dissolved by the body as bone tissue is restored, without requiring additional surgery to remove them. On the other hand, the problem arises of optimizing the rate of such degradation. In this study single tracks layers of magnesium-based alloy were successfully bult-up using the laser metal wire deposition (LMwD) technology. The deposition process was controlled using optical pyrometry. The obtained tracks have been studied in terms of their geometric characteristics, mechanical properties, and corrosion resistance. The hydrodynamic numerical model that accounts for magnesium wire addition is validated in the LMwD technology. The macroscopic parameters of tracks calculated using the developed model are compared with experimental data and show good agreement. Optimization of the processing parameters is carried out to achieve the solid magnesium deposition. Dependences of the main characteristics of tracks on processing parameters are obtained.

THE UNDERWATER LASER CUTTING (INVITED)

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Key words: underwater cutting, laser underwater cutting, continuous fiber laser, underwater work

At the moment, the problem of carrying out underwater, dismantling, repair, construction, rescue and other work is acute. The bulk of the work is carried out at depths up to 20 m. Almost all of these actions are performed exclusively using the manual labor of divers. Various thermal methods of underwater metal cutting are used for underwater work, such as flame cutting, arc cutting, oxygen arc cutting and plasma cutting. Each of them has its advantages and disadvantages. The underwater laser cutting technology consists in supplying a compact jet of working gas or oxygen to the cutting area, which promotes the combustion of metal heated by laser radiation and the removal of melt from a cut, which makes cutting continuous and uniform.

The use of additional drives allows you to evenly move the cutting head along the cutting line at a precisely set distance from the surface to be processed without lateral oscillatory deviations, which ensures automatic cutting without the participation of a diver. The advantages of underwater laser cutting technology are as follows. Safety of work for the diver, due to the absence of electric current and the exclusion of the danger of explosion of combustion products in confined spaces when using an air jet or inert gases.

Increased cutting performance due to the possibility of performing continuous work in automatic mode without the participation of a diver and the absence of the need to replace the cutting tool.

Low weight of the cutting laser head. Performing work at great depths inaccessible to divers. The report will present the results of laser underwater cutting of various materials, both in the experimental pool and during tests in real conditions.

INTELLIGENT WELD INSPECTION: MACHINE LEARNING-DRIVEN DEFECT DETECTION FOR AUTOMATED LASER WELDING QUALITY CONTROL

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Key words: laser welding (LW), instance segmentation, YOLOv8, weld detection, weld quality assessment, stable diffusion

Weld macrosection analysis is a standard procedure for evaluating weld quality, microstructure, and defects. Traditional analysis relies on manual inspection, which is time-consuming, subjective, and prone to human error. With advancements in machine learning (ML) and computer vision, there is growing potential to automate this process, improving accuracy, efficiency, and consistency.

This study explores the application of ML methods for the automatic analysis of weld macrosections. The work addresses two key areas: (1) analyzing weld images using instance segmentation for weld detection and (2) using generative image models to augment the dataset.

The primary objective of the first area is to develop a robust system capable of accurately detecting welds, identifying defects, and classifying and quantifying geometric features in macrosection images. To achieve this, YOLOv8 was chosen due to its state-of-the-art performance in instance segmentation. The model was trained and refined through multiple iterations to enhance accuracy and reliability.

A major challenge in training such models is the limited availability of weld images, as acquiring and processing these images is both costly and labor-intensive. To overcome this, data augmentation was applied using Stable Diffusion-based generative models, which expanded the dataset by producing variations of existing weld images, improving model generalization and robustness.

Through nine training iterations, the ML model achieved over 90% accuracy in defect detection and classification, with minimal deviation from expert annotations. Automating weld macrosection analysis significantly reduces processing time, from minutes per sample to microseconds, enhancing efficiency, minimizing human error, and optimizing expert labor, ultimately streamlining the entire evaluation process.

PROMISING AREAS OF APPLICATION OF LASER TECHNOLOGIES IN THE OIL AND GAS INDUSTRY

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Key words: laser casing opening, laser perforation of the annular space, laser cleaning of tubing, laser drilling

Laser processing technologies of materials are increasingly used in various fields of production, manufacturing and extractive industries. The use of laser technologies in the construction and operation of oil wells has a high potential for implementation. The paper considers promising areas of application of laser technologies in the field of oil and gas well construction, production, treatment and transportation of hydrocarbons. The most relevant technologies from the point of view of the possibility of implementation in the near future are laser cleaning from mill scale, anti-corrosion treatment and microstructuring of the surfaces of tubing and main pipes.

The paper presents the results of experimental studies of technologies: laser cleaning of tubing, including for subsequent laser microstructuring and anti-corrosion treatment of pipe surfaces, laser casing opening, laser and laser-mechanical rock drilling, laser drilling of coal seams.

The final properties of the surface after a complex of laser treatments aimed at improving operational properties depend on the quality of metal surface cleaning. The first important and most difficult stage of laser surface treatment of rolled pipes is laser scale removal. Studies of the processes of destruction and removal of mill scale under the thermal action of laser radiation are carried out. The main advantages of this approach are high cleaning efficiency and minimization of thermal effects on the steel surface. The possibility of industrial application of this method of cleaning rolled metal is shown. In addition, experiments were conducted on laser perforation of casing pipe, cement stone and rock. The experiments conducted with the materials used in the construction of wells have demonstrated the high prospects for the development of laser reservoir opening technology and cutting technological holes in the casing. The model samples consisted of a pipe with an outer diameter of 245 mm and a wall thickness of 10 mm, the casing was surrounded by a cement screed (cement grade PCT I-50 GOST 1581-2019).

As a result of the study, the principal possibility of opening the casing pipe with subsequent perforation of the cement screed and rocks of the productive reservoir by laser heating was confirmed. In laboratory conditions, channels with a length of 170 mm were formed using a continuous fiber laser at a radiation power density of 5 kW/cm^2. The perforation of the channels was carried out contactless and without digging the working tool into the channel. At the current stage of research, a laser cement perforation rate of 80 mm/min has been obtained.

Ultrafast laser-based microstructuring and modification of transparent materials

METHOD FOR THE FORMATION OF MICROSTRUCTURES INSIDE BULK TRANSPARENT DIELECTRICS USING LASER-INDUCED PLASMA

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Key words: laser back irradiation, glass modification, nano-second laser pulses, laser-induced plasma

Laser backside irradiation (LBI) focuses a laser beam on an absorber placed at the rear of a bulk optical glass sample, generating a localized heated zone that initiates a plasma spark propagating toward the source. This plasma alters the material along its path until beam defocusing drops the irradiance below the modification threshold. Initially explored with continuous-wave lasers, recent advances using nanosecond pulses provide improved control and distinct modification regimes. The resulting structures are promising for applications in optical components, integrated photonics, and microfluidic device fabrication.

This In this study, plasma generation via laser backside irradiation (LBI) was carried out using an IPG YLPM-1 pulsed fiber laser (1064 nm wavelength, 20 W max avg. Power, 4-200 ns pulse duration, and 2–100 kHz repetition rate). The laser beam was focused onto a metallic foil acting as the absorber, positioned between a glass sample and a cover glass, and held in place with a custom jig to ensure firm contact. The plasma initiation process was systematically studied by varying laser parameters such as pulse duration, repetition rate, average power, and pulse energy, allowing determination of the threshold values for both ignition and sustained plasma propagation within the glass. A high-speed AOS X-EMA camera (1280 × 75 px at 10,000 fps) was used to observe plasma dynamics. Spectral properties of the plasma were measured under different experimental conditions using an Avantes AvaSpec fiber-coupled spectrometer, which covers a broad detection range from 200 to 1100 nm. The obtained spectra were used to estimate the plasma temperature during propagation. The resulting modified region along the plasma path was examined in detail, and structural changes were analyzed and compared with plasma characteristics such as velocity, size, and stability during propagation.

COUPLED ORTHOGONAL GRATINGS IN KERR WAVEGUIDE INDUCED BY MID-IR ULTRASHORT LASER RADIATION

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Key words: MIR ultrashort laser radiation, semiconductors, Kerr effect, waveguide modes, discrete periods of interference gratings, Feigenbaum's universality

The perspective field of ultrafast laser-matter interaction investigation is the middle IR range laser radiation (LR) interaction with semiconductors [1]. The mechanism of coupled orthogonal grating formation under middle IR range laser irradiation of semiconductors is suggested which explains emergent experimental results [2, 3].

First, briefly outline the main experimental peculiarities of gratings formation in c-Si according to [2, 3]. The appearance of gratings $g_w \perp E$ have the threshold character on laser power density. Their periods have the following discrete values: λ/n, $\lambda/2n$, $\lambda/2^2n$, $\lambda/2^3n$, where E is the electric field vector of LR, λ is the wavelength of LR and n is the refractive index of c-Si. 2. For the normal incidence, the area of gratings formation has elliptical form, with semi-axis relation equals to 1.4 and the main semi-axis orientation along the vector E [3]. 3. The periods of g_w grating have very large spread in values not typical for structures formed in framework of the universal polariton model (UPM) [4]. 4. With the increasing of the numbers of laser pulses (N) the orthogonal G||E grating appears and coexist with g_w. Finely, the G grating dominate and its period is D=2.24 μm.

To explain the experimental data on the basis of nonlinear mathematical model in framework of UPM of laser induced gratings formation the new model is suggested in which LR induces the nonlinear waveguide formation, excitation TE type waveguide modes (WM) and interference the WM and their spatial harmonics with the discrete gratings creation periods of which follow the Feigenbaum's universality [5]. With the N and WM intensity increasing it is needed to account for their mutual interference (having nearby propagation directions). In this process the discrete grating G||E with suprawavelength period $D=2\lambda/n \approx 2.24$ μm is formed which dominates for higher N.

In conclusion, the model is suggested for creation of coupled orthogonal gratings g_w and G in semiconductors via the interaction with ultrashort laser radiation of middle IR range. It involves the production of nonlinear Kerr waveguide, excitation of WM, their participation in interference and coupled orthogonal spatially coexisting gratings formation. The model can be verified experimentally on germanium and chalcogenide glasses having large nonlinear electro-optical coefficients.

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LASER-INDUCED DICHROISM IN ZINC OXIDE FILMS WITH SILVER NANOPARTICLES

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Key words: nanoparticles, dichroism, zinc oxide, femtosecond pulses

Femtosecond laser radiation can induce the dichroism in materials containing plasmonic nanoparticles. In the case of laser irradiation of zinc oxide films with silver nanoparticles, dichroism will lead to different absorption at different polarizations of the incident radiation. Thus, when using ZnO:Ag as light-absorbing layers in various devices, such as photodetectors, the efficiency of the devices will depend on the polarization of the radiation. The aim of the work was to experimentally study the effect of polarization, wavelength and energy parameters of femtosecond laser radiation on the dichroic properties of ZnO:Ag films. Laser irradiation was performed in the scanning mode at a speed of 1 mm/s, a pulse duration of 224 fs, a pulse repetition rate of 200 kHz and an energy density of 30 to 131 mJ/cm^2. Two directions of linear polarization were used during the exposure, as well as wavelengths of 515 nm and 1030 nm. When using radiation with a wavelength near the plasmon resonance (515 nm), the value of linear dichroism increased to 0.25. With radiation with a wavelength far from the plasmon resonance (1030 nm), the dichroism did not exceed 0.1. The reason for the appearance of dichroism, as well as the shift of the plasmon resonance peak, was the reorientation of nanoparticles parallel to the linear polarization vector of laser radiation. Such a reorientation led to a change in the distance between particles and the formation of collective plasmon effects. Exposure to radiation with a wavelength of 1030 nm did not lead to a change in the orientation of nanoparticles due to differences in the absorption mechanism.

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FEMTOSECOND-LASER-WRITTEN PHOTONIC INTEGRATED CIRCUITS FOR LINEAR-OPTICAL QUANTUM COMPUTING (INVITED)

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Key words: femtosecond laser writing, photonic integrated circuit

Femtosecond laser writing (FLW) technology is the unrivalled tool for rapid prototyping of integrated photonic devices in various dielectric materials due to its low cost and simplicity. FLW has found a wide range of applications in astrophotonics, optical communications, topological photonics, optofluidics and quantum photonics. Here we report on our latest developments in writing photonic integrated circuits for linear optical quantum computing. Using waveguides at 800 nm based on type-II modification in silica glass, we have fabricated a universal two-qubit processor and a programmable 8-port interferometer with an overall insertion loss of 7-10 dB. Thermo-optic phase shifters were created on the top surface by patterning resistive micro-heaters on top of the waveguides in a deposited metal layer by laser ablation performed in the same fabrication setup. Using multiscan waveguides at 920 nm based on a type-I modification in silica glass, we have fabricated a low-loss programmable two-qubit entangled states generator and a 25-port interferometer for boson sampling experiments with an overall insertion loss of 2-3 dB. Some of these interferometers were packaged in 19-inch cases with built-in temperature stabilisers and power sources. In addition, by varying the size of the waveguide, we created different structures for different tasks in a wide range of wavelengths from 400 to 1550 nm. In addition, depressed cladding waveguides and directional couplers have been fabricated inside crystals doped with rare earth ions. These waveguides can be used as the basis for integrated optical quantum storage based on photon echo.

LASER ANNEALING OF COMPOSITE OPTICAL FILMS IN THE PHOTONICS APPLICATIONS

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Key words: femtosecond laser processing, laser annealing, sol-gel ZnO:Ag films, silver nanoparticles, metal-organic framework, lead selenide films

Laser annealing of semiconductor films is widely used in microelectronics, photovoltaics and photonics. Using laser micromachining, it is possible to locally change the optical and electrical properties of such materials.

Laser annealing of sol-gel zinc oxide (ZnO) films with silver nanoparticles (Ag NPs) by femtosecond laser pulses with a wavelength of 1030 and 515 nm allows to reduce the energy of the forbidden band of the zinc oxide matrix, as well as to change the size, shape and concentration of silver nanoparticles in it. When exposed to laser pulses with a wavelength near the peak of the plasmon resonance of Ag NPs, the formation of elongated particles oriented along the polarization line of the laser beam is initiated. Femtosecond laser action on films of metal-organic frameworks with copper (Cu) of the (HKUST-1) brand in the material modification mode leads to a change in the refractive index and extinction of the film, an increase of the matrix density at low fluence values. An increase in fluence leads to the destruction of the polymer matrix with its subsequent decomposition and deposition of metallic copper on the substrate. As a result of laser processing, it is possible to achieve both a change in the optical properties of the film and its decomposition with metallization of the substrate or evaporation.

Laser annealing of lead selenide films is of interest in photovoltaics, where such films are used as photosensitive detectors of gas analysis devices. Using laser action with continuous radiation or nanosecond laser pulses, it is possible to initiate partial or through oxidation of the film, thereby changing its electrical resistance and absorption in the middle and far IR spectrum.

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LIGHT-ONLY DOMAIN SWITCHING IN FERROELECTRICS BY PULSE INFRA-RED LASER IRRADIATION (INVITED)

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Key words: domain structure, pyroelectric field, femtosecond laser, domain engineering

The light-only domain switching in ferroelectrics by pulse laser irradiation is considered now as a very promising method of domain engineering. Two variants of this approach have been realized using absorbable and non-absorbable light. The first one was strongly absorbed in the surface layer UV and far IR irradiation. The absorbed energy stimulates nonuniform temperature change thus creating the pyroelectric field strong enough for domain switching. This field leads to domain nucleation on the surface only and domain growth in polar direction, thus, does not allow creation of 3D domain structures.

This drawback has been overcome recently using tightly focused irradiation of the near IR femtosecond laser. The main idea of this method is based on the high enough multiphoton absorption of the light from the transparent spectral range in the focusing region with extremely high light intensity. In 2015 such domain switching was demonstrated in ferroelectric lithium niobate $LiNbO_3$ crystals for the first time. Further research widely expended the number of ferroelectrics used for 2D and 3D domain patterning.
We study the creation of domain structures by local irradiation and linear scanning in the crystals of lithium niobate $LiNbO_3$ and lithium tantalate $LiTaO_3$ being the most popular nonlinear optical materials. The domain imaging in the bulk was done by Cherenkov-type confocal Second Harmonic Generation. We revealed that the domain nucleation near the focus point is caused by depolarization fields that arise around the microtracks, and domain growth is due to the pyroelectric field occurring due to nonuniform temperature change. The creation of the three-dimensional nonlinear photonic crystals and stable periodical domain structures in the bulk was demonstrated.

The work was made possible by Russian Science Foundation (Project № 24-12-00302). The equipment of the Ural Center for Shared Use «Modern Nanotechnology» Ural Federal University (Reg. 2968) was used.

FEMTOSECOND LASER FABRICATION OF D-SHARPED FIBER WITH REAL-TIME OPTICAL CONTROL CAPABILITY

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Key words: femtosecond laser processing, D-shaped optical fiber, real-time process control, laser ablation

This study investigates the application of femtosecond laser processing for the fabrication of D-shaped optical fibers, a critical component for surface plasmon resonance (SPR) sensors. Existing fabrication techniques for D-shaped fibers, including mechanical polishing and chemical etching, present limitations such as surface defects, imprecise corrosion control, and reduced fiber strength. Furthermore, CO_2 laser-based methods suffer from low surface quality and limitations in microstructure creation. In contrast, femtosecond laser ablation offers a promising alternative due to its capacity for precise material removal and high-quality surface generation.

This research focuses on optimizing the femtosecond laser processing parameters to achieve a balance between fabrication quality and speed. The study employed real-time process control methods to fine-tune the laser-matter interaction, enhancing the precision and reproducibility of the process. Specifically, the laser interaction with the silica fiber was controlled to efficiently ablate and reshape the fiber profile. The influence of laser power, scanning speed, and other key parameters on the resulting D-shape was examined to identify optimal processing modes.

Micrographs of the laser-treated fiber surfaces were obtained, providing detailed characterization of the fabricated D-shaped fibers. The results demonstrate the feasibility of generating high-quality D-shaped profiles through femtosecond laser ablation, as evidenced by the smooth surface finish observed in the micrographs. This approach addresses the limitations of conventional methods and offers a pathway for the development of high-performance SPR sensors with enhanced sensitivity and reliability. The study provides a foundation for further research into the integration of femtosecond laser processing for advanced fiber optic sensor fabrication.

FEMTOSECOND LASER-INSCRIBED FIBER BRAGG GRATING SENSOR ENCAPSULATED IN POLYDIMETHYLSILOXANE (PDMS) FOR VIBRATION MONITORING.

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Key words: fiber Bragg grating, femtosecond-laser pulses, optical fiber sensor, embedded vibration sensor

Fiber Bragg gratings (FBG) have recently been used as sensing devices owing to their high performance in different applications. These devices can be fabricated using UV lasers with phase masks or femtosecond laser pulses. FBG inscribed with femtosecond laser pulses have shown better performance than those inscribed with ultraviolet light since the FBG fabrication parameters can be better controlled, damage to the optical fiber is reduced because the microstructures are focused directly on the fiber core, and greater repeatability is obtained in the fabrication of FBG In addition, this method of fabrication by pulsed laser is not limited to these structures, expanding its range of applications for manufacturing devices in fiber optics.

In addition, FBG sensors encapsulated in polymers have been developed to enhance their sensing properties, increasing their response to mechanical deformations and/or temperature changes. Polydimethylsiloxane (PDMS) is one of these polymers because of its mechanical properties, such as flexibility and easy integration, in addition to being resistant to high temperatures, resistant to ultraviolet light, and hydrophobic in environmental conditions, making it a friendly polymer for the encapsulation of different types of sensors, including sensors based on fiber optics.

This work presents a prototype of a vibration sensor based on an FBG engraved with femtosecond laser pulses embedded in a PDMS membrane for vibration monitoring, mainly for structural monitoring applications.

STUDY OF THE DYNAMICS OF LASER-INDUCED PROCESSES ON ZnO:AG FILMS

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Key words: pump-probe, femtosecond laser, ZnO, ZnO:Ag

The present study shows the results of the laser influence on ZnO:Ag films measured by the pump-probe technique. The study of the dynamics of the process of laser-induced changes in the structure and optical properties of ZnO:Ag films is required to clarify the mechanisms of interaction of femtosecond laser pulses with semiconductor sol-gel films containing silver nanoparticles. This has been achieved by measuring changes in transparency for different pump and probe wavelengths. The femtosecond laser pulses have been demonstrated to induce alterations in the spectral transmittance and reflection of sol-gel films of ZnO with silver nanoparticles, manifesting as shifts in the plasma resonance peak within the spectral range of 400 to 800 nanometers. The observed changes in transmittance and reflectance of the film, ranging from 15% to 30% relative to the initial samples, can be attributed to the alterations in size, shape, and concentration of the silver nanoparticles. The pump-probe method is imperative for the estimation of electron emission times in metallic nanoparticles, electron-phonon relaxation in them, as well as heat transfer from nanoparticles to the material matrix. It is important to note that at each stage of transformation of the nanoparticle structure and the film matrix, a corresponding change in the optical properties is recorded through experimental means and can be used to optimize the manufacturing process.

DIRECT LASER WRITTEN WAVEGUIDES WITH HELICAL TUBULAR STRUCTURES (INVITED)

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Key words: direct laser writing, waveguides, Bragg grating, orbital angular momentum

Direct laser writing using a femtosecond laser is an efficient technique for fabricating waveguides in wideband dielectrics. The procedure involves tightly focusing the laser beam within the dielectric, where the generated electron-hole plasma modifies the material as the beam waist progresses. Nevertheless, this method presents a challenge due to the beam waist's elongated shape, which contrasts with the desired circular cross-section of waveguides. Various laser writing techniques and waveguide designs address this mismatch. Helical screw structures, created with lenticular beam waists, stand out for their perfect axial symmetry and ability to form Bragg gratings [1,2]. The helical depressed cladding waveguides and helical core waveguides can be manufactured in dependency of the sign of refractive index change (RIC) in a given material. The depressed cladding waveguide supports single mode with a perfect circular cross-section and low loss, enabling supercontinuum generation [3]. Additionally, the helical motion of the lenticular beam waist enables the creation of uniform Bragg gratings in single-mode and multimode fibers due to the consistent velocity and acceleration of this motion [4,5]. Most importantly, the helical Bragg structures both with positive and negative RIC serve as effective waveguiding mode converters, enabling the generation of modes with OAM [6,7].

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IN-BULK FORMATION AND FORWARD GROWTH OF FERROELECTRIC DOMAINS CREATED BY FOCUSED FS-LASER BEAM IN SINGLE CRYSTALS OF LITHIUM NIOBATE AND LITHIUM TANTALATE

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Key words: ultrafast laser, femtosecond laser, ferroelectric domains, nonlinear photonics crystals, ferroelectrics

Light-only switching of ferroelectric domains by a focused fs-laser has emerged as a promising technique for creation of functional 2D and 3D domain structures (domain engineering) for nonlinear optical applications [1,2].

In this work we present the results of ferroelectric domains inscription in the bulk of single crystals of MgO-doped congruent lithium niobate (MgOLN) and lithium tantalate (MgOCLT) and in congruent lithium niobate (CLN) by focused fs-laser during dot and linear-scanning irradiation.

We have used TETA-10 (Avesta, Russia) system delivering 250-fs-long pulses at 1030 nm with frequency 100 kHz and energy from 0.5 to 7 μJ and focused in the middle of the sample.

It was shown that linear-scanning irradiation of MgOLN along polar Z axis and nonpolar X axis and MgOCLT along polar Z-axis leads to formation of domains demonstrating a double-comb-like structure and localized at the microtracks. The height of the domains increased from 20 to 100 μm with increase of pulse energy. For energies >0.5 μJ for MgOCLT and >4 μJ for MgOLN for irradiation along Z axis additional domains were formed at the microtracks and grew towards Z- polar surface. No additional domains were formed for irradiation along X-axis.

We have shown that the domains inscribed in CLN single crystals during dot irradiation can serve as nucleation centers during further application of homogeneous field thus opening new possibilities for combined domain engineering methods.

The research was made possible by Russian Science Foundation (Project № 24-12-00302). The equipment of the Ural Center for Shared Use "Modern nanotechnology" Ural Federal University (Reg.№ 2968) was used.

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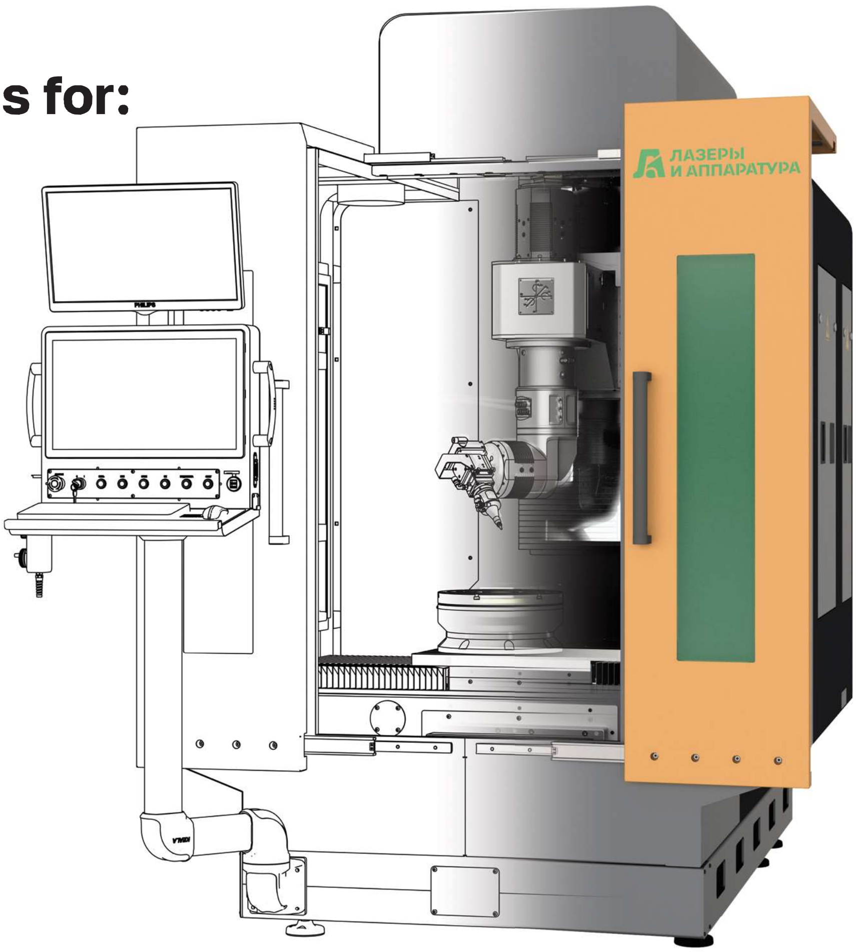

Poster session I
Laser-matter interaction & laser microtechnologies

Biomedical laser technologies

SPECTRALLY-SELECTIVE MECHANISMS OF PATHOGEN INACTIVATION USING MID-INFRARED FEMTOSECOND PULSES

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Key words: mid-IR irradiation, H-bonds, protein denaturation, induced absorption, bleaching

The emergence of new pathogenic microorganisms and their increasing resistance to antibiotics necessitate the development of alternative methods for their control. Mid-infrared (mid-IR) radiation is considered particularly promising, as it coincides with the absorption bands of key molecular structures in bacterial cells. Specifically, this includes the vibrational modes of amide group bonds (C=O, C–N) in proteins and nucleic acids in the 1500–1600 cm^{-1} range (~6 μm), as well as C–H bond vibrations in lipids within the 2800–3000 cm^{-1} range (~3 μm). Mid-IR radiation provides a contactless and environmentally safe method of bacterial inactivation.

In the present study, the mechanisms of inactivation of pathogenic P. aeruginosa bacteria were investigated using dynamic transmission spectroscopy with femtosecond laser pulses at wavelengths of 3.4 μm and 6 μm. The spectra of relative transmittance changes induced by 6 μm laser excitation (targeting C=O and C–N vibrations of proteins stabilized by hydrogen bonds responsible for protein tertiary structure) reveal three distinct interaction regimes: at pulse intensities of 1–10 GW/cm^2 – bleaching of the fundamental absorption band corresponding to harmonic C=O and C–N vibrations in the amide groups of proteins; at 10–100 GW/cm^2 – further bleaching of the same amide vibration band along with induced absorption of C=O vibrations in the blue spectral region, associated with the disruption of hydrogen bonds; at intensities above 100 GW/cm^2 – induced absorption of anharmonic C=O and C–N vibrations in the red region of the spectrum. For laser pulses at 3.4 μm (targeting C–H bonds), the relative transmittance spectra show bleaching of the fundamental C–H vibrational band and induced absorption of anharmonic C–H vibrations in the red spectral region.

LASER HYDROACOUSTIC PROCESSING OF AGAR-BASED GEL TISSUE PHANTOMS: A COMPARATIVE EXPERIMENTAL STUDY ON THE IMPACT OF OPTICAL FIBER OUTPUT END SHAPE

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Key words: Yb,Er:Glass-laser, microsecond pulses, laser-induced cavitation, fiber output end shape, ablation efficiency

Laser-induced hydroacoustic processes (LIHAP) are an important tool for effective, non-contact treatment of submerged biological tissues in applications such as laser cataract extraction. When laser energy is absorbed by a liquid medium, it can generate a steam-gas cavity, commonly referred to as a cavitation bubble. The characteristics of this bubble such as shape, size, and lifetime, are influenced by various changeable parameters, including the shape of the optical fiber's output end used for radiation delivery. Previous studies have indicated that the design of the output end significantly affects the efficiency of cavitation bubble generation by changing the distribution of the laser beam exiting the fiber, thereby impacting the overall effectiveness of tissue treatment. This study investigates the influence of fiber output end shape on laser-induced cavitation phenomena. Specifically, we examined cavitation bubbles formed in distilled water by delivering microsecond pulses of Yb,Er:Glass-laser radiation (1.54 μm) through quartz optical fibers (diameter of 500 μm) with special unconventional output end shapes by recording the process of bubble generation, expansion, and collapse with a high speed camera (105 fps), and measuring the values of the pressure drop induced in the liquid by bubble collapse with a hydrophone. Key parameters of the induced cavitation bubble, including maximum diameter, formation time, collapse time, and pressure drop during the "collapse-rebound" phase, were analyzed. Additionally, we conducted a comparative assessment of the laser-assisted ablation efficiency of agar-based gel phantoms, utilizing these special fibers to deliver the radiation. The results of this experimental study will be presented and discussed.

MOLECULAR MODELING OF THE POST-DIFFUSION STAGE OF OPTICAL CLEARING OF BIOLOGICAL TISSUES

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Key words: molecular modeling, optical clearing of human skin, hydrogen bonds, molecular dynamics, quantum chemistry, immersion agents

A comprehensive molecular modeling study was conducted using all-atom molecular dynamics (CROMACS), molecular docking, and quantum chemistry methods (HF/STO3G/DFT/B3LYP/6-311G(d)) to investigate the interactions of several optical clearing molecular agents—sorbitol, xylitol, D-xylose, and dimethyl sulfoxide —with collagen protein. The number of hydrogen bonds formed per unit time for each agent and their effect on the spatial volume of the collagen peptide were determined. The intermolecular interaction energy in immersion agent–collagen peptide fragment complexes was calculated. It was found that non-classical hydrogen bonds play a significant role in the association of dimethyl sulfoxide with collagen. Additionally, it was demonstrated that two molecules can independently occupy the same molecular pocket upon association with collagen.

Intermolecular complexes of the proline-glycine-hydroxyproline chain with dimethyl sulfoxide and a water molecule were constructed, along with analogous complexes involving hydroxyproline. Using the wB97XD/6-311+G(d,p) method, with consideration of the basis set superposition error, the association enthalpies at two different temperatures and the equilibrium constants for these complexes were calculated. The first hydration shell, consisting of five water molecules, was constructed, revealing that dimethyl sulfoxide effectively binds free water and strongly competes with water molecules that are tightly bound to collagen through two hydrogen bonds. To evaluate the effectiveness of optical clearing, the rate of change in the light scattering coefficient was determined using averaged A-scan optical coherence tomography signals in the dermis at depths ranging from 350 to 700 μm. Based on the results of in vivo immersion optical clearing of human skin using aqueous solutions of sorbitol, xylitol, D-xylose, and dimethyl sulfoxide, a correlation was established between optical clearing efficiency and association energy, allowing its use for predictive purposes.

The work was done with financial support from grant (no. 23-14-00287) of the Russian Science Foundation.

THEORETICAL STUDY AND OPTIMIZATION OF 810NM LASER RADIATION IMPACT DURING LASER TRANSPUPILLARY THERMOTHERAPY OF BENIGN VASCULAR TUMORS OF THE RETINA

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Key words: laser, model, coagulation, retina, tumors, capillary hemangioblastoma

The treatment of vascular tumors of the retina is an extremely important task of modern medicine. If patients with benign tumors do not receive timely medical care, then, as a consequence, they lose their vision and then the eye as an organ. 810nm laser transpupillary selective layered thermotherapy is a modern and promising method for treating benign vascular tumors of the retina. Despite the positive results of using this method, the problem of optimizing the parameters of laser impact still remains relevant. This work is aimed at the creation of a computer optical and thermophysical model of the effect of laser radiation with a wavelength of 810 nm on the eye with a capillary hemangioblastoma of the retina, as well as identifying the most effective and safe modes of exposure to laser radiation at different stages of that disease. The created model is based on the joint solution of the radiation transfer equation using the Monte Carlo method, the heat conduction equation and the Arrhenius equation. A computer optical model of the eye with capillary hemangioblastoma was created in the TracePro Expert 7.0.1 Release program (Lambda Research Corporation, USA), a computer thermal physical model of these tissues in the COMSOL Multiphysics program (COMSOL Inc., USA; version number 6.2). In the calculations, eye tissues are considered as a quasi-homogeneous medium with optical and thermal-physical characteristics, which are taken from literature. The dependences of the maximum temperature and the size of the coagulation zone of capillary hemangioblastoma and retina on the power, spot size and time of exposure to 810nm laser radiation are constructed. Optimized modes of thermotherapy for capillary hemangioblastoma at different stages of that disease are proposed.

Fundamentals of light-matter interaction

MODELLING OF THE HEATING OF Zn:Ag THIN FILMS ON GLASS SUBSTRATE BY SERIES OF FEMTOSECOND LASER PULSES

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Key words: thin films, plasmonic nanorarticles, femtosecond laser, thermal modelling

Thin films based on ZnO with plasmonic nanoparticles (ZnO:Ag) are widely used in the field of optoelectronics for the creation of photodetectors [1], solar cells [2] and photocatalytic devices [3]. By controlling the position of the plasmon resonance peak in the absorption spectra of these materials, it is possible to control the sensitivity range of the devices. A promising tool for such tasks is laser radiation, which allows for quick and local action.

The temperature to which the material is heated during laser action plays an important role in the process of modification of optical and electrical properties of ZnO:Ag thin films. In this work we present a theoretical model of the heating of ZnO:Ag thin films on glass substrate by series of femtosecond laser pulses. The model allows to investigate the temperature dynamics during the laser actions on different time scales and to trace the influence of laser parameters on achieved temperatures. The results of the simulations are compared with experimental data on femtosecond laser action on ZnO:Ag thin films.

This work was financially supported by the Ministry of Science and Higher Education of the Russian Federation (No. FSER-2025–0007).

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EXCITATION OF OPTICAL SKYRMIONS AND INITIAL STAGES OF CONDENSED MATTER SURFACE LASER DAMAGE

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Key words: condensed media, pulsed laser radiation, optical skyrmions excitation, subwavelength spatial size, surface damage

The problem of initial stages of condensed matter surface damage by pulsed laser radiation is well known. Recently the new quantum objects called optical skyrmions (OS) have been introduced into the optical science [1]. Those complicated quantum objects – stable topological defects of surface - involve the interference of evanescent electromagnetic waves. Their spatial scales have both suprawavelength and subwavelength discrete character. They were identified in laser induced surface morphology changes of metals [2], semiconductors [2] and dielectrics [3]. Below the recently published experimental data are considered where the subwavelength scales laser induced damage on ruthenium films was observed [4]. The interaction of ultrashort circular polarized laser radiation (λ=400 nm, τ=45 fs, N=1) with ruthenium films (t$\subset$8, 20 nm) on glass substrate produced chaotically distributed isolated circular sites damages with subwavelength spatial scales (S). Some values of S of circular type (OSC) for energy density Q=279 mJ/cm^2 and t=8 nm are: $S_1 = \lambda/14\eta \approx 27.8$ nm and $S_2 = \lambda/7\eta \approx 55.6$. Here is the real part of the refractive index for the metal-air boundary for surface plasmon polaritons, is the wavelength of laser radiation. For the increased Q value Q=409 mJ/cm^2 and t=15 nm the appearance of OS of hexagonal type (OSH) and increased S values were formed and identified as $S_3 = \lambda/2\eta \approx 190$ nm and $S_4 = 5\lambda/9\eta \approx 214$ nm. Note that in some cases the OSC were localized at the crystalline grain boundaries arising during laser action. The identified quantized S values are governed by a nonlinear sequence of Sharkovsky order.

The sufficiently subwavelength OSC were identified as earliest stage of (001) TiO_2 surface damage under ultashort laser irradiation (λ= 248 nm, J=450 fs, Q=150 mJ/cm^2) by N=1 pulse [5], for instance, $S=\lambda/4\eta \approx 60$ nm. OSC with minimal S value $S=3\lambda/128\eta \approx 24$ nm was identified on the quartz surface via irradiation by ultrashort laser radiation (λ= 1030 nm, E=0.7 μJ, τ=300 fs, N=50) [6]. In summary, account must be taken for subwavelength scales optical skyrmions excitation in earlier stages of condensed media surface damage.

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MULTISCALE MODEL OF MICROSTRUCTURE FORMATION IN THE PROCESS OF COMBINED LASER DEPOSITION OF NICKEL TITANIUM

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Key words: laser metal deposition, nickel titanium, microstructure, multiscale modeling, validation, viscosity

Laser additive manufacturing is a group of laser technologies for the building-up of individual parts, ideally suited for biomedical products. It has already been successfully used in biomedicine, but has not yet revealed its potential and still requires significant scientific efforts to create highly effective metal implants. The processes accompanying the additive build-up of metal parts occur on different time scales: the lifetime of the molten pool in a specific space is less than a second, but it may take several hours to obtain a finished part. This technology is associated with high temperatures, fluid flow, rapid phase change, and other processes that are quite difficult to control. Products are often not free of both geometric and microstructural defects, require mechanical and thermal post-processing. Nowadays direct numerical simulation is an effective tool for process planning, and modern numerical models of additive growth include almost all the phenomena that occur in the melt pool.

In this paper, a multiscale model of microstructure formation in the process of laser metal deposition using wire and powder (LMD-WP) is developed. The model takes into account heat transfer and convective flow in the melt pool and the free surface evolution due to combined metal addition. Within the framework of the kinetic approach to accounting for rapid crystallization, a new model for calculating phase change is developed, which takes into account the dependence of the crystal growth rate on the viscosity of the supercooled melt. The ab initio molecular dynamics simulations are used for the viscosity determination. The initial configuration is obtained using the Monte Carlo method based on experimental structure data. Modeling of diffraction data was carried out using the Born-Oppenheimer molecular dynamics implemented in the CP2K package. The calculated macro- and microparameters of single tracks of the model are compared with the experimental data and show good agreement. Optimization of the building strategy and processing parameters is carried out to achieve the target geometric and structural characteristics of 3D objects (implants). The possibility of creating solid objects with a given geometry by a method of laser metal deposition using wire and powder, as well as controlling the microstructural properties of such objects, is demonstrated.

DEVELOPMENT OF THE SOFTWARE FOR MODELLING THERMAL FIELDS DURING MULTIPULSE IRRADIATION OF METALS WITH BEAM SCANNING

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Key words: multipulse laser action, mathematical modelling, software, temperature distribution

Laser technologies such as marking (including color laser marking), surface functionalization, cutting, scribing and others are increasingly used in industrial processes. Multi-pulse irradiation by nanosecond laser pulses with beam scanning over the surface is often used. The modelling of thermal action of laser radiation at such conditions is important for choosing of the optimal processing mode. This determines the relevance of developing software for implementing such modeling. In this work we present a simple software tool, which allows to calculate the temperature distributions inside metals targets irradiated by the series of nanosecond laser pulses with beam scanning. To use the program, no specialized skills in calculating thermal fields are required. It shown that developed software allows performing calculations for actual processing modes faster than with available multi-physical modeling packages (such as Comsol Multiphysics).

INVESTIGATING LASER-INDUCED BACKWARD TRANSFER OF SILVER ON QUARTZ GLASS BY NANOSECOND LASER PULSES: A THEORETICAL PERSPECTIVE

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Key words: laser-induced backward transfer, laser ablation

For transparent materials, laser-induced backward transfer (LIBT) emerges as a promising solution for surface functionalization. However, a fundamental gap persists in the absence of a physical model that makes it possible to describe the deposition of materials using laser-induced backward transfer. The scientific novelty of the work consists of a combined approach: it involves the developing of a computational and theoretical predictive model of interaction, as well as the determination of laser exposure parameters for the deposition of material on the surface of the acceptor in direct combination with the obtained computational model.

The model addressed three critical aspects of the deposition process:

1) Solving the equation of thermal conductivity under boundary conditions that take into account the movement of the evaporation front. The estimation is performed to obtain the surface temperature at the time of the phase transition in order to further relate it to the gas parameters.
2) A description of the process in the Knudsen layer approximation and the relationship of the thermophysical parameters of the surface with the characteristics of steam and solving the system of gas-dynamic equations in order to describe vapor movement inside the gap.
3) Estimation of the diameter and thickness of the deposition layer at various non-zero values of the gap between the donor and the acceptor. In order to confirm the operability of the model, similar experiments were performed on silver deposition using the LIBT method in laboratory conditions. The diameter of the deposited spot was considered as the parameter to be compared. The calculated values of the dispersion diameter of the deposited material are in good accordance with the experimental data.

MODEL OF PERIODIC CHAIN OF ELECTRIC DIPOLES WITH TRANSVERSE SPIN EFFECT AT SUBWAVELENGTH VOLUME SCALE

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Key words: transverse spin, chiral coupling, nanophotonic waveguides

Nanophotonic waveguides are indispensable for regulating photon emission and scattering in contemporary photonic applications. Through the utilization of chiral coupling in specialized configurations, devices capable of polarization-dependent unidirectional light propagation can be fabricated. In this study, we propose an analytical model of a periodic chain of electric dipoles incorporating the transverse spin effect. Furthermore, we demonstrate a nanophotonic design based on the proposed analytical model with the transverse spin effect at the subwavelength volume scale. This design exhibits potential for magneto-induced devices in Voigt geometry, particularly for non-reciprocal phase shifting or for light-matter interaction devices with chiral coupling.

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LASER ABLATION OF THIN GOLD FILMS FOR THE NANOPARTICLES PRODUCTION

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Key words: gold nanoparticles, thin films, laser ablation

Nowadays gold nanoparticles are the most studied and widely used nanomaterials in biomedical technologies due to their unique properties: inertness, biocompatibility, and low toxicity. Modern synthesis technologies for gold nanoparticles enable the production of particles ranging in size from 10 to 100 nm in various shapes, such as nanospheres, nanorods, nanowires, and others. At the same time, there is a demand for the development of synthesis technologies that allow for the controlled formation of nanoparticles with sufficiently small sizes of 1-15 nm, increasing their proportion in the total volume of particles produced and reducing the number of additional procedures and production stages. One approach is the synthesis of nanoparticles from thin films, which are limited to nanometer-scale thicknesses.

This work presents the results of experiments on the ablation of thin gold film layers using a nanosecond laser system, SharpMarkFiber PRO 100F VAR (with a radiation wavelength of 1064 nm). It was found that the spot exposure mode provides a bimodal size distribution and the formation of a fine fraction of Au nanoparticles with sizes up to 10 nm. In contrast, the continuous laser beam movement mode leads to the formation of a single fraction of particles with sizes ranging from 10 to 50 nm. A theoretical study based on numerical modeling using the molecular dynamics (MD) method was conducted. The calculations allowed for the determination of threshold values of laser energy density required to obtain nanoparticles of the desired sizes and revealed the mechanisms of their formation. Experimental results confirmed the formation of colloidal solutions with nanoparticles whose sizes correspond to the modeling results.

INVESTIGATION OF THE ROLE OF LASER RADIATION COHERENCE AND OBJECT SURFACE MICROSTRUCTURE IN THE FORMATION OF SPECKLE STRUCTURES

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Key words: speckle, coherence, low-intensity laser radiation, interferometry, laser therapy

Lasers are widely used in science, technology, and medicine. Laser radiation differs from ordinary light, even monochromatic, in coherence and polarization. In laser medicine, there are two opposing points of view on the role of these properties in the mechanism of low-intensity laser therapy. In a number of cases, laser radiation is believed to affect the biosystem due to its coherence, which is embedded in the biosystem at any level of its organization as a basic property of living systems. However, this interpretation of the contribution of coherence to the therapy process is controversial and requires additional substantiation. Firstly, as it penetrates deeper into the biotissue, coherence and polarization disappear. Secondly, the secondary radiation of excited biomolecules (due to their diversity) is broadband, incoherent, and unpolarized. However, it is believed, in particular in ophthalmology, that the observation of diffusely scattered low-intensity coherent radiation allows the formation of a speckle structure on the retina, which has a stimulating and therapeutic effect.

The report experimentally studies the spatial and temporal coherence of radiation from various continuous visible lasers using interferometry methods. A software analysis of speckle structure contrast formed by laser irradiation of objects (paper, human skin) with different surface microstructures was carried out, and the fundamental spatial frequency of light intensity modulation in the speckle pattern was determined using the fast Fourier transform method. The dependencies of the speckle structure contrast and the fundamental modulation frequency on surface roughness and laser type obtained allowed us to assess the role of the spatial and temporal coherence of laser radiation and the microstructure of the object's surface in the formation of speckle structures. The regularities studied are important for a deeper understanding of the mechanism of low-intensity laser therapy and can contribute to increasing the effectiveness of its use in medical practice.

THE ROLE OF DEGENERATE OPTICAL MICROCAVITATION IN THE TRANSFORMATION PROCESSES OF CARBON BLACK NANOPARTICLE AGGLOMERATES UNDER MULTIPULSE NANOSECOND LASER IRRADIATION

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Key words: nanosecond laser pulse, carbon black nanoparticle agglomerates, laser fragmentation, defragmentation, microbubbles, accumulative heating

In recent years, carbon black nanoparticles (CBNP) have found wide application in biomedical laser technologies due to their biocompatibility. However, excessive agglomeration of CBNP in biotissues can pose potential health risks, requiring the development of effective methods for controlling the morphological parameters of agglomerates (CBNPA) in liquid media. A promising approach involves using high-repetition-rate nanosecond laser pulses, where various accumulative effects are most pronounced, which can enhance the efficiency of laser procedures. Laser exposure to suspensions forms vapor-gas microbubbles around CBNPA, and under certain conditions a transition to a degenerate optical microcavitation mode occurs, where microbubbles are preserved for a long time. Long-lived microbubbles can significantly influence the fragmentation and defragmentation processes of CBNPA by locally altering heat transfer, enhancing chemical reactions, and increasing radiation scattering. Currently, there is no consensus on the CBNPA fragmentation and defragmentation mechanisms, and the role of degenerate optical microcavitation in them under multipulse nanosecond laser irradiation remains unclear.

The report studies the role of degenerate optical microcavitation and accumulative effects in CBNPA fragmentation and defragmentation in a liquid medium under multipulse nanosecond laser irradiation. Based on the relationship obtained between the sizes of a microbubble and a carbon microparticle, the dynamics of CBNPA size distribution is explained, and a region of parameters (pulse number, repetition rate) for the transition from fragmentation to defragmentation of CBNPA occurs has been determined. A thermophysical calculation allowed analyzing the cooling dynamics of a carbon microparticle in the degenerate optical microcavitation modes and tracing the changes in the accumulated temperature depending on laser parameters. Differentiation of fragmentation and defragmentation processes helped define the role of degenerate optical microcavitation in combination with accumulative effects and their mechanisms. The results obtained can serve as a basis for developing laser technologies to modify carbon nanomaterials for medical applications.

Industrial laser technologies: automatization & application of ML

PROCESSING OF THE SIC CYLINDER SURFACE BY TANGENTIAL LASER ABLATION METHOD WITH NANOSECOND PULSES

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Key words: silicon carbide, tangential laser ablation method, nanosecond laser, surface roughness.

Laser grinding of silicon carbide (SiC) presents significant difficulties due to its extreme hardness and heat resistance. It requires high energy inputs and often results in extensive melting zones and damage. To address these issues, this study optimizes the nanosecond laser grinding of SiC using a tangential treatment method. We conducted a study on the micromachining of rotationally symmetric SiC parts using a nanosecond laser. The laser turning process with tangential exposure to laser radiation is implemented in such a way as to provide a high-quality approach to micro-machining on a laser lathe.

For the study, a nanosecond laser was used with a maximum output power of 20 watts, maximum energy of 1 mJ, pulse repetition rate up to 1 MHz, pulse duration ranging from 4 to 200 ns, and spot diameter in the treatment plane of 50 microns. To optimize the ablation rate and reduce surface roughness, various parameters were investigated, including pulse energy, scanning speed, overlap coefficient, pulse repetition duration, and beam angle.. To process silicon carbide rods, we use elements with a diameter of 10 microns. We have managed to achieve a surface roughness of 0.414 micrometers on an initially non-smooth surface, which is a satisfactory result.

LASER CLEANING OF LEATHER. A STUDY OF SURFACE TEMPERATURE IN THE CLEANING AREA

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Key words: heritage science, laser applications, laser cleaning, leather conservation

In recent years, laser technologies have been widely used in the preservation of Cultural Heritage (CH). One of the main fields of laser application in this area is the cleaning of CH objects from natural and anthropogenic contaminants. Laser cleaning technologies of stone and metal monuments are the most well developed. However, cleaning CH objects made out of organic materials such as leather and parchment is still an underdeveloped field of knowledge and requires intensive experimental studies. During laser cleaning in the process of photochemical ablation the material is heated due to the absorption of irradiation by the substance. Exposing leather to high temperatures could cause its damage, charring, or loss of elasticity, hardening. Therefore, control of the surface temperature in the cleaning area is essential to prevent the negative effect of the laser irradiation on the processed material.

This paper is devoted to investigation of surface temperature of leather under its laser cleaning. Experimental results of temperature measurements during laser cleaning of leather with the Ytterbium pulsed fiber laser (wavelength of 1064 nm) are presented for two approaches to laser cleaning, e.g. dry cleaning and wet cleaning. Results are obtained for model leather samples as well as for fragments of a real historical artefact such as XIX-th century bookbinding elements. Results obtained during experiments show that wet laser technique is safer and therefore more suitable for delicate organic materials such as leather and parchment due to the significantly lower heating of the surface (up to 15°C in comparison with the laser treatment without auxiliary liquid). The method of wet laser cleaning widens the applicability of laser cleaning technologies in the field of conservation of CH objects on leather and parchment base, thus making it a unique and effective instrument for conservators.

HIGH-STRENGTH LASER WELDING OF 3RD-GENERATION ALUMINUM-LITHIUM ALLOYS

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Key words: laser welding, synchrotron radiation, aluminum-lithium alloys

Third-generation aluminum-lithium alloys represent a new and unique class of materials with superior mechanical properties compared to conventional aluminum alloys. The primary joining technology for these alloys is riveting, where the edges of rivet holes act as initiation sites for fatigue cracks under cyclic loading. Laser welding technology eliminates this drawback and significantly reduces structural weight by avoiding rivets and overlapping joints. This study introduces, for the first time, a unified comprehensive approach combining laser micro-metallurgy—optimizing the interaction of high-energy continuous laser radiation in keyhole mode—with subsequent heat treatment optimization to establish the physical foundations for controlling the phase composition of the weld seam. The goal is to achieve high structural strength in the welded joint. Advanced independent diagnostic methods were employed, including synchrotron radiation diffraction (used for the first time in this context) alongside high-resolution transmission electron microscopy (TEM), scanning electron microscopy (SEM), and optical microscopy to analyze the evolution of the weld seam's structural and phase composition.

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OPTIMIZATION OF MODEL SAMPLES PREPARATION FOR STUDYING LASER CLEANING OF RADIOACTIVELY CONTAMINATED SURFACES

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Key words: radioactive contamination, radioactive contamination simulators, surface decontamination, X-ray fluorescence analysis, laser decontamination, laser cleaning

During the operation of nuclear industry facilities, as well as in the process of decommissioning such facilities, work is constantly carried out to decontaminate radioactively contaminated surfaces. The most promising method is laser decontamination, which involves exposing the contaminated surface to a series of laser pulses, leading to local evaporation of contamination. For a detailed and safe study of the processes occurring during laser decontamination, it is convenient to conduct research experimental work with nonradioactive coatings that simulate uranium-plutonium radioactive contamination. To simulate contamination with uranium dioxide (UO_2) and plutonium (PuO_2) dioxides, cerium dioxide (CeO_2) of natural isotopic composition is most preferable - due to the similarity of thermal and physical properties. Cerium dioxide has a similar crystalline structure under normal conditions and similar lattice parameters with uranium and plutonium dioxides, which confirms its optimality for experimental research. The traditional method of preparing model samples is that chromium-nickel steel plates are kept in a cerium nitrite solution and then annealed. When examining the obtained samples on the SEM, it is evident that the distribution pattern is nonuniform: there are both large particles up to 10 μm in size and small particles less than 1 μm in size. Such non-uniformity can lead to a significant scatter of experimental data in the study of laser cleaning and complicates the interpretation of the results. We proposed and implemented a method of ultrasonic spraying, which allows us to obtain a more uniform distribution of cerium atoms over the surface and avoid scattering from sample to sample. When studying the distribution of cerium dioxide particles on a sample obtained according to the proposed method using the SEM, it was found that the particles are distributed uniformly on the surface, there is no scatter in particle sizes, and all of them are less than 1 μm in size. Such a homogeneous coating allows for studies of laser cleaning mechanisms with high reproducibility and reliability, since the contamination layer more accurately imitates real radioactive contamination in its physical and chemical properties.

LASER PROCESSING A STAINLESS-STEEL PLATE TO CREATE A MICROFLUIDIC TOPOLOGY

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Key words: microfluidics, microfluidic topology, laser perforation, laser processing, laser polishing

Microfluidics as a separate scientific discipline studies the behavior of liquid and gas flows on a micron scale and controls these flows. Over the past few decades, microfluidic methods have become almost indispensable in solving a number of production and research problems, for example, in the field of pharmacology, biomedicine, cosmetology, microelectronics, etc. The creation of microfluidic devices is a complex task, primarily due to the high cost of the components included in their composition. Microfluidic chips can be made from a wide range of materials, and a microfluidic pattern can be created using various technologies. In this regard, numerous studies are being conducted to find new ones and modernize existing methods for the manufacture of such devices, aimed at simplifying and reducing the cost of their production technology.

The paper explores the possibility of creating microfluidic topology elements on stainless steel by laser ablation using an ytterbium pulsed fiber laser with a wavelength of 1,07 μm. In this work the results of a multi-stage impact on a metal surface are presented as experimental model channels. Polishing modes of laser processing have been developed to reduce the final roughness of structures. It was investigated with the use of the AFM method. 3D maps of the surface after laser treatment have been created in order to check the treated area for defects and microcracks. The effects of defocusing, metallic luster, and oxide film formation, as well as their effect on model structures, were investigated. Through holes in a 2 mm thick steel plate has been created by laser treatment. It forms a part of typical microfluidic topologies as well.

Laser-assisted surface functionalization & related phenomena

LASER METHOD OF METAL PROTECTION FROM BIOLOGICAL AND CHEMICAL EFFECTS IN AQUATIC ENVIRONMENT

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Key words: biofouling, mineral scale, laser treatment, hydrophobization, data processing automation

The formation of biofouling and sulfate or carbonate mineral sediments is common in a range of natural and industrial systems. These problems have damaging impacts on both water and energy industrial processes. For instance, the formation of biological or mineral fouling may cause further corrosion of underwater sensors, piping, heat exchangers and pumps.

In this work, it is proposed to consider a laser-based method to reduce biofouling and mineral sediments of stainless steel and duraluminum by forming microstructures with different wettability states. Laser processing was performed with an ytterbium fiber source with a central wavelength of 1064 nm and a scanning system based on pre-objective galvanometer scanners. Structures with different laser track density, and different raw surface area were tested. The influence of geometrical characteristics of the created periodic structures was also analyzed. The level of mineral fouling was analyzed by keeping the samples in a solution of distilled water with $CaCl_2$ added at a concentration of 940 mg/L. The quantitative level of biofouling was measured using chemical indicators based on resazurin and resorufin. In the purpose of the optimization process of creating microstructures with specified geometric parameters, the algorithm for segmentation of microphotographs and processing of profilometry results, realized in Python, was developed. The physico-chemical dependencies established in this work permit the development of a laser method of metal treatment for the reduction of fouling in aquatic environments. The creation of a new database to optimize the collection of the surface morphology variation results after laser treatment will further improve the process of microgeometry formation for various industrial applications.

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VISUAL EFFECTS OF LASER-DRAWN REVERSE GLASS PAINTINGS

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Key words: laser-induced backward transfer, laser art, laser-induced periodic surface structures, laser-material interaction

Laser-induced backward transfer (LIBT) is a well-developed technique allowing coating the acceptor glass locally with donor material by laser ablation in a confined area, forming a visible trace that might serve, for example, as QR code or other type of functional or decorative marking. Following the steps of masters of reverse glass painting, we show the possibility of creating full-scale images on glass substrates by applying laser action to the auxiliary metal substrate placed in close contact to the acceptor glass. Images can be created both with the motorized laser setups and with the handheld laser paintbrush, providing new opportunities for artists. Selected sections of the images might be additionally highlighted by second exposure, creating the rainbow-like colorful effects due to generation of laser-induced periodic surface structures (LIPSS) on the deposited metal layer. Furthermore, the structured glass slabs might be stacked together, allowing to demonstrate the 3D illusions, breaking in the new possibilities for the laser art.

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THE INFLUENCE OF LASER COMBINED PROCESSING ON THE MECHANICAL PROPERTIES OF SLM-MANUFACTURED PARTS

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Key words: laser hardening, metal hardness, laser microstructuring, surface modification, selective laser melting (SLM)

Laser technologies are one of the most promising methods of forming surface structures due to the possibility of changing specific mechanical and functional properties of materials, including hardness, wear resistance, adhesion and corrosion resistance. For this purpose, changes in laser radiation parameters can be used to provide increased machining accuracy. Of particular interest is the processing of materials under a layer of finely dispersed structure, giving in conjunction with the original surface more wear-resistant material. Such a processing method has shown its effectiveness when exposed to laser radiation through a layer of carbon powder on the surface of titanium, due to high spatial and temporal temperature gradients occurring during laser processing, uniform distribution of mechanical properties on the surface, change in roughness and change in the chemical composition of the surface layer due to recrystallization of the molten layer and increase in wear resistance due to residual stresses on the metal surface. To reveal the potential of laser treatment for improving the functional properties of molded surfaces, it is necessary to search for methods and parameters of optimal exposure and new approaches.

This study demonstrates the validation of the laser thermal hardening technique on parts made of heat-resistant steel, Hastelloy X and titanium alloy VT6 obtained by selective laser melting. The samples were studied using a PMT-3M microhardness tester, a LOMO MSP-1 optical microscope with a ToupCam UCMOS03100KPA digital camera. The initial samples were preliminarily subjected to mechanical polishing using sandpaper. Comparison of Vickers hardness values for initial and treated surfaces at different radiation parameters is shown. This research can be useful for industrial production, taking into account the possibility of optimization of processing parameters to improve the performance characteristics of materials.

THE USE OF PRE-LASER TREATMENT TO ENHANCE THE ADHESION CHARACTERISTICS OF THE STEEL SURFACE

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Key words: steel substrate, phosphating, laser treatment, coating adhesion

Objective: to develop a technology for preliminary surface preparation to enhance the adhesion of paint coatings.

Tasks:
- analysis of the possibility and advantages of using pre-laser treatment;
- investigation of the laser operating parameters, at which the treated surface receives a uniform ordered relief with a given level of roughness;
- investigation of the use of additional adhesive layers (cold phosphating) on the treated surface;
- assessment of the adhesion of the coating to the surface after treatment.

The idea is to use pre-laser treatment operations with preset operating parameters in conjunction with "cold" phosphating to increase the adhesion of paint and varnish materials to the steel surface.

Results:
- the analysis of the prospects of using pre-laser treatment in comparison with other methods of preparation is carried out;
- the operating parameters of the laser have been selected, which make it possible to obtain a given level of roughness with a uniform ordered surface;
- the composition of "cold" phosphating has been selected for application to the treated surface;
- a real increase in the adhesion of the coating to the surface after the treatment has been established.

Based on the results of the work carried out, a patent was obtained for a method of preparing the surface of carbon and low-alloy steels for applying polymer coatings, indicating the practical significance of the developed method. It is planned that this method of surface preparation will find wide application in the application of coatings with anti-adhesive characteristics. For example, such coatings can include coatings based on fluoroplastics. Further research shows that the use of this method of preparation makes it possible to increase their adhesion to the steel surface. These coatings can be used in various industries, such as the oil and gas industry.

LASER SURFACE TREATMENT OF SLM-PRODUCED TITANIUM AND NICKEL-CHROMIUM-MOLYBDENUM ALLOY COMPONENTS

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Key words: laser surface processing, selective laser melting (SLM), titanium alloys, nickel-chromium-molybdenum alloy, surface roughness

This research details the investigation into the influence of laser processing parameters on the microstructure and surface properties of components fabricated via selective laser melting (SLM) from Ti-6Al-4V titanium alloy and Hastelloy X nickel-chromium-molybdenum alloy powders. Selective laser melting (SLM) is a prominent additive manufacturing technique. However, a significant challenge remains: the inherent surface roughness of SLM-produced components, which roughness adversely affects their mechanical properties of the details. Traditional post-processing methods have limitations and often fail to achieve the desired surface quality. While laser processing offers a precise and adaptable solution for tailoring surface properties, it currently relies on expensive high-power lasers for SLM components. Laser processing offers a flexible and precision approach that allows to obtain surfaces with specified properties, however, at the moment, expensive high-power lasers are used in such processing of SLM products. Current study explores the feasibility of employing a low-power laser source to modify the surface of additively manufactured parts, aiming to reduce surface roughness. We present the results of an investigation into the effects of laser exposure parameters – radiation power density, pulse overlap, number of passes, and beam focusing – on the surface roughness of SLM–produced Ti-6Al-4V and Hastelloy X bars. The morphology and composition of the laser-treated surfaces are analyzed. A laser post-treatment method has been developed, achieving a surface roughness corresponding to grade 9 purity per GOST 2789-59, and enabling the creation of surfaces with both isotropic and anisotropic properties.

Laser surface treatment demonstrates significant potential for enhancing the surface quality of metallic SLM components, opening avenues for applications in industries such as aerospace and mechanical engineering. This method offers cost-effective, contactless processing of intricate channels and facilitates automated, waste-free manufacturing.

HYPERDOPING OF SILICON WITH TRANSITION METALS BY NS- AND FS- PULSED LASER IRRADIATION

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Key words: silicon hyperdoping, pulsed laser melting, sub-bandgap absorption, silicon IR photoresponse

In silicon-based optoelectronics, extending the silicon photoresponse to infrared light is essential to avoid costly hybrid integrations. Hyperdoping silicon – i.e., doping beyond its equilibrium concentration, often using transition metals – is a well-known approach for achieving sub-bandgap absorption by introducing shallow or deep-level impurities [1]. Pulsed laser melting, ranging from ultrashort to nanosecond durations, has proven to be a practical hyperdoping technique over the past few decades. However, some uncertainties regarding the achievement of successful outcomes remain. During laser-silicon interactions, the material is gradually heated above its melting point. Longer pulses tend to produce deeper molten layers, whereas ultrashort pulses facilitate rapid resolidification. Pulsewidth selection, combined with other parameters, is crucial in laser hyperdoping as it can result in different outcomes for various processed elements. Here we studied the hyperdoping of silicon with selected transition metals (Ti, Cr, Zn, Ag) using fs- and ns- laser pulses. We utilized Si (100) wafers (either nominally undoped or doped as p- or n-type) with pre-deposited metal film ranging from 5 to 100 nm in thickness. The sample surface was irradiated with either 100-ns laser pulses at 1064-nm wavelength (Yb pulsed fiber laser within MiniMarker2-M20 laser marking system, equipped with galvanoscanner) or with 240-fs laser pulsed at 1030-nm wavelength (TETA-10, Avesta Project, combined with motorized tables). The irradiated samples were analyzed for changes in the surface morphology (scanning electron microscopy), crystallinity (confocal Raman microspectroscopy), elemental concentration and chemical state (energy dispersive and X-ray photoelectron spectroscopies), vis-NIR optical absorption. Optimal parameters for laser processing and the thickness of metal films were determined to achieve fluence values for introducing impurities into silicon. The selection of the film thickness (for used material) impacted the doping process and needed to be considered when selecting the processing conditions. The results allow enhancement of doping efficiency and precision, providing a base for the development of silicon-based optoelectronics.

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LASER SURFACE MODIFICATION FOR BIOMEDICAL STUDIES OF CELL BEHAVIOR

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Key words: laser surface functionalities, titanium alloys, cell–interface interaction, polyhydroxyalkanoates

This study explores novel surface functionalization techniques designed to investigate cellular behavior on diverse microstructured surfaces. The morphology of these structures, encompassing shape, size, and periodicity, profoundly influences cell viability, growth, and differentiation. By fabricating templates with varying structural parameters, we enable biologists to systematically analyze these phenomena, focusing on key cellular responses such as proliferation, adhesion, and growth rates. Laser radiation is employed to precisely generate microstructures with defined geometries on material surfaces.

Surface modification experiments are conducted on titanium and polymer films. Nanosecond and femtosecond laser pulses are utilized to modify titanium, creating surfaces with geometries ranging from 27 to 100 μm, including square and triangular meshes, as well as open and closed grooves. During laser surface treatment, laser parameters, including pulse duration, power, pulse repetition rate, and scanning speed, were varied. Polymer films are structured using two distinct approaches. The first involves laser fabrication of templates on titanium, followed by replication onto polymer films via casting. The second method entails direct laser irradiation of the polymer films. These fabricated structures are then provided to biologists for comprehensive cellular studies. The preliminary results demonstrate a direct correlation between surface geometry and cellular behavior.

The resulting structures were analyzed using optical microscopy, scanning electron microscope (SEM), and contact profilometry. Cell behavior was studied through staining with the fluorescent dyes FITC and DAPI.

Laser-based surface functionalization offers unparalleled flexibility in creating structures with diverse shapes and dimensions. This accurate and relatively straightforward method facilitates the production of highly repeatable materials for biomedical research, opening avenues for advanced cellular studies and tissue engineering applications.

ENHANCED PHOTOCATALYTIC ACTIVITY OF TITANIUM OXIDES THROUGH LASER-INDUCED MICROSTRUCTURAL RELIEF

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Key words: biofilms, ultraviolet radiation, semiconductor coatings, TiO_2, oxides, microrelief

Bacterial contamination of surfaces poses significant challenges in modern medicine. Biofilms, formed by bacterial conglomerates adhering to surfaces, exhibit resistance to conventional antimicrobial treatments. This problem negatively impacts patient and healthcare worker health, contributing to the spread of infections via contaminated medical equipment, surgical instruments, and implantable devices. Current strategies to combat bacterial adhesion include the use of superantibacterial systems, addressing biofilm resistance, and preventing bacterial attachment. These strategies employ various methods, such as nanostructured surfaces, antibiotic treatments, and surface hydrophilization or hydrophobization. However, these methods often suffer from limitations, including low efficacy, potential harm to healthy cells, and the development of bacterial resistance.

A promising approach for combating pathogenic bacteria, warranting further investigation, involves the use of semiconductor coatings activated by ultraviolet radiation. This technique offers high efficacy and minimizes damage to healthy tissues. Previously, ZnO, SnO_2, and TiO_2 conductor coatings were investigated. While zinc oxide and tin dioxide exhibit antibacterial properties, their band gaps limit their activation efficiency compared to TiO_2, which effectively generates singlet oxygen and hydroxyl radicals across a broader range of wavelengths. Furthermore, the surface area of the samples influences the formation of oxides and, consequently, their activation. This study investigates the efficiency of reactive oxygen species generation on titanium dioxide semiconductors with varying microrelief.

To increase the surface area, preliminary surface microstructuring was performed by direct laser writing of microchannels in ablation mode. The second step of laser processing involved the formation of thin oxide films with microrelief on the surface by laser oxidation. A comparative study of the photocatalytic activity of the microstructured and oxidized surfaces formed by two-stage laser processing was carried out.

ANALYSIS OF THE METHOD OF PREPARING THE PIPELINE SURFACE FOR APPLYING POLYMER COATINGS BY LASER TREATMENT

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Key words: adhesion, morphology of the surface, laser treatment, profilometry

Objective: to analyze the possibility of using laser treatment as a preliminary operation before applying epoxy and polyurethane coatings.

Tasks:

1. Comparison of the morphology of the surface of a steel part for painting after laser, sandblasting and shot blasting.
2. Evaluation of the physico-mechanical properties of polymer coatings applied after preliminary laser treatment.

The idea: the use of laser treatment of steel to create a high-quality morphology of the surface of the part for painting with polymer coatings instead of the applied methods of inkjet processing.

Results:

1. The morphology of the surface of the samples after shot blasting, sandblasting and laser treatment was assessed using visual assessment, profilometry, and analysis of the surface layer of the sample.
2. Physico-mechanical tests of two polymer coatings applied to a steel sample after laser treatment were performed. Properties such as adhesion, impact and bending strength, and continuity were evaluated.

STUDY OF AMPLITUDE-PHASE POLARIZATION ANISOTROPY OF ZnO:Ag FILMS WITH THE SINGLE-SHOT POLARIZATION HOLOGRAPHIC MICROSCOPE

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Key words: digital holography microcopy, polarization, quantitative phase imaging, laser processing, sol-gel films

The polarization holographic microscope based on the Rozhdestvensky interferometer with input laser emission consisting of two linearly polarized mutually orthogonal beams from two different sources was developed. A Wollaston prism was installed in the reference beam, which provides spatial separation of the field from the two laser sources used. The FLIR BFS-U3-51S5P-C polarization matrix photodetector, which is a CMOS array with an array of micropolarizers, is used as the receiver. Above each quadrant of the camera's pixels is a linear micropolarizer with a corresponding rotation direction of 0, 45, 90 and 135°. Due to the polarization camera, we can simultaneously capture four off-axis digital holograms, from which we reconstruct the amplitude and phase distributions of the vector field by means of the Jones formalism.

The optical properties of sol-gel films containing silver nanoparticles (ZnO:Ag) were analyzed in the assembled polarization holographic microscope. The films were pretreated with a series of femtosecond laser pulses with a wavelength of 515 nm. Jones matrices for films with different processing regimes were obtained. The findings clarify the relationships between processing modes and polarization anisotropy properties. The developed polarization microscope can be implemented into a laser processing system with the possibility of real-time monitoring.

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THE EFFECT OF LASER EXPOSURE PARAMETERS ON THE SURFACE ROUGHNESS OF HARD ALLOYS

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Key words: pulsed laser ablation, nanosecond laser, tungsten carbide, micro-tool manufacturing, beam-matter interaction

Short pulse laser ablation method has a particular advantage when it comes to processing workpieces made of hard materials since it provides material removal without wear of the forming tool and load on the workpiece. This paper describes a method for processing tungsten carbide using nanosecond pulse laser ablation. The results of tungsten carbide surface quality analysis after exposure to short laser pulses are presented. The roughness of the treated surface was investigated by contact profilometry. The influence of laser exposure parameters (pulse repetition frequency, pulse duration) on the geometric parameters (ablation depth and roughness) of the surface of tungsten carbide workpieces has been studied. It was found that the roughness of the treated surface increases with an increase in energy density and the percentage of laser pulses overlap. With an increase in the pulse duration, an increase in the values of surface roughness is observed. It was also found that the tangential laser processing strategy ensures the best surface quality.

LASER STRUCTURING OF METAL SURFACES TO ENHANCE PAINT ADHESION

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Key words: enhance adhesion, laser treatment, paint adhesion, metal surfaces

Increasing bonding between the metal surfaces and paint layer could be useful in a variety of industries, for example machine engineering, automobile, aircraft, and shipbuilding. Laser treatment of metal surfaces enhances paint adhesion by modifying surface structures. This method tends to be beneficial due to non-contact treatment and the absence of consumables such as primer.

Preliminary research indicated that enhancing paint adhesion on metal surfaces could be achieved by increasing roughness of the surfaces (for example, for the automobile industry it is necessary to increase both the number of peaks per cm^2 and increase R_a). In addition, the surface after treatment should be hydrophilic, but not superhydrophilic, so that corrosion-causing oxides will not form. Furthermore, these structures should be selected according to the size of the paint particles. A decrease in strength is often found when the bonded surface is too rough. Excessive roughness increases cavity or gap formation where air is trapped. It negatively affects the adhesion strength of coating to the treated surface. Achieving a balance in surface roughness is crucial for strong adhesion. In this paper it is proposed to consider the laser method as a technological operation that allows enhanced paint adhesion on metal surfaces. Laser microstructuring is realized at surfaces of constructional steel and aluminum alloy. Acrylic auto enamel and thermosetting powder paints are chosen as tested paint coatings.

INVESTIGATION OF THE POSSIBILITY OF PASSIVATION OF METAL SURFACE DURING LASER CLEANING

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Key words: laser, cleaning, corrosion, metal, passivation, treatment

This study considers the possibility of passivation (increase of corrosion resistance) of steel along with the process of laser cleaning. For effective protection a metal against corrosion after a cleaning, a continuous and dense oxide layer has to be formed on its surface to ensure passivation. The power density of laser radiation should be selected in such a way as to remove the contaminating film due to thermomechanical stresses, explosive mechanisms or vaporisation, as well as to provide oxidation of the surface to increase corrosion resistance. At the same time, it is necessary to avoid micro-damage and excessive roughness during laser treatment.

Steel cleaning and passivation are performed by the pulse fiber laser to achieve oxidation, melting and vaporisation thresholds of the steel. The degree of steel cleaning from impurities such as rust and pitting, steel corrosion properties and surface composition were investigated. Laser treatment with large pulse overlapping was used to form a continuous oxide layer and to remove contaminants uniformly. It was shown that the treatment with power density exceeding the melting threshold of the steel surface acquires greater roughness and micro-damage, so treatment with lower power density was preferred for effective combined cleaning and corrosion treatment. The development of the laser passivation method includes: experiments on contaminant removal in different modes, formation of a dense oxide layer, analysis of the chemical composition of the surface before and after treatment, and determination of the optimal laser treatment modes to achieve maximum corrosion resistance, degree of cleaning and microhardness.

FORMATION OF THE DOMAIN STRUCTURE IN THE BULK OF STRONTIUM-BARIUM NIOBATE SINGLE CRYSTALS BY FEMTOSECOND LASER PULSES

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Key words: femtosecond laser, relaxor ferroelectrics, strontium-barium niobate, domain structure

The light-only methods are currently used for creation of the tailored ferroelectric domain structures by pulse laser irradiation without application of electric field. The most spectacular achievement is the ability to switch domains in crystal bulk by means of focused NIR femtosecond laser irradiation.

In this work the domain structures were created by femtosecond pulse laser irradiation in single crystals of relaxor ferroelectric strontium-barium niobate ($Sr_{0.61}Ba_{0.39}Nb_2O_6$) pure and doped by Ni (0.05 wt.% Ni_2O_3). The samples cut perpendicular to the polar axis were in polydomain state or monodomain state. Yb-solid state femtosecond laser TETA-10 (Avesta Project, Russia) with 1030 nm wavelength and 250 fs pulse duration was used for irradiation using 50x objective with NA = 0.65. The focusing was at the depth of 200 µm. The energy from 0.07 to 2,1 µJ and number of pulses from 1 to 1000 were used. Irradiation was carried out in matrices with a distance between domains from 1 to 30 µm. Cherenkov-type second harmonic generation microscopy (SHGM) was used for 3D domain imaging after femtosecond laser irradiation.

It was found that at the point of femtosecond laser irradiation the spindle-shaped domains are formed. The microtracks previously observed in lithium niobate and lithium tantalate crystals were not detected. The length of domains increases with pulse energy and is almost independent on the number of pulses. The length of created domains was up to 100 µm, diameter was about 1.5 µm.

The obtained results can be used for the creating of 3D nonlinear photonic crystals based on SBN single crystals and in-bulk waveguides with periodical domain structures.

The work was supported by Russian Science Foundation (project 25-22-00231). The equipment of the Ural Center for Share Used «Modern Nanotechnologies» Ural Federal University (Reg. 2968) was used.

INVESTIGATION OF SURFACE STRUCTURE OF TITANIUM SUBSTRATE AFTER COMBINED LASER TREATMENT USING A TWO-COMPONENT SYSTEM OF $SrCo_3$ AND TiO_2 POWDERS

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Key words: laser microstructuring, surface modification, piezoelectric properties, hardness

Laser processing of titanium under a layer of auxiliary substances enables the formation of surface layers with enhanced mechanical and functional properties. One promising direction is the creation of piezoelectric coatings that accelerate implant biofouling under ultrasound exposure. However, there is currently no combined technology that integrates laser deposition of piezoelectrics, surface structuring for osteointegration, and increased wear resistance, opening new possibilities for improving implant biocompatibility.

The developed technique of additive laser treatment of titanium using graphite powder allows to modify the surface layer of titanium substrate to achieve a significant increase in hardness and wear resistance of the surface layer with preservation of all elastic and plastic characteristics of the part. Based on the above technique, a new experiment on sintering of a two-component system of $SrCO_3$ and TiO_2 powders by pulsed laser impact in the near infrared range to create a surface structure on titanium with enhanced piezoelectric properties was developed. This technique allows to use the mechanism of titanium shock hardening to increase the hardness of the surface layer, a coating with increased piezoelectric properties is clad on the surface of titanium, which should provide an increased rate of surface fouling by bone tissues to reduce the risk of implant rejection. This study investigates the piezoelectric properties of a modified titanium surface after sintering a two-component $SrCO_3$-TiO_2 powder system under pulsed laser irradiation. The hardness and wear resistance of the modified surface were evaluated and compared with the characteristics of the original titanium substrate. The developed methodology is of interest as a unique processing technology for titanium implants, utilizing $SrCO_3$ and TiO_2 powders and pulsed laser treatment in the near-infrared range to create functional surface structures.

The research was supported by ITMO University Research Projects in AI Initiative (RPAII) (project #640114).

Laser-induced periodic surface structures

INVESTIGATION OF WAVE MECHANISMS IN THE FORMATION OF PERIODIC STRUCTURES USING PICOSECOND LASER ABLATION OF METALS IN AIR

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Key words: nanostructure, LSPL, HSFL

In this presentation, we introduce the latest research on the reaction of laser-induced periodic surface structures (LSPL) and high-spatial-frequency laser-induced periodic surface structures (HSFL) on solid surfaces by their sub-nanosecond laser ablation in air. The laser formation of periodic nanostructures (NS) model is based on the theory of wave processes in materials. We found that thermocapillary instability in the melted layer on the surface leads to HSFL synthesis. Accompanying formation of self-organized NS on HSFL and LSFL is studied in relation to laser parameters and target material. This report showcases the transformation of surface morphology from HSFL to LSFL formed through laser ablation in air varying laser parameters. In our experiments we used two types of lasers. The first was the Nd:YAG laser with wavelength of 1064 nm, pulse duration of 30 ps and repetition rate of 1kHz. The second laser beam was Yb:fiber fs-laser with wavelength of 1030 nm, pulse duration of 6 ps and repetition rate of 1kHz. As targets were used Ti and stainless steel. Images from field emission scanning microscopy (Mira TESCAN) show that number pulses and fluens of incident laser irradiation affect to target's morphology as transfer from HSFl to LSFl. In special laser conditions such NS can co-exist as in melt bath of co-rectangle periodic structures with period from 10 to 1000 nm scale. Presented experimental data was used as base for theoretical calculations of HSFL formation as wave mechanism. Laser nanotechnologies discussed in this context have diverse applications, such as significantly boosting external applied field strength, altering antifriction properties, and creating structured surfaces with unique optical properties like ultra-black absorbance.

Additionally, the presentation will cover recent progress in understanding the mechanisms behind these structure formations, address current limitations, and explore emerging possibilities and future prospects.

INFLUENCE OF LASER-INDUCED THERMOCHEMICAL PROCESSES ON TITANIUM SAMPLES CHEMICAL COMPOSITION

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Key words: LIPPS, TiO_2, polymorphism, Grade 2

The polymorphism exhibited by titanium-oxygen compounds is of considerable scientific interest owing to their extensive potential applications in materials science. Fewer than 10 polymorphic modifications of titanium dioxide (TiO_2) have been experimentally synthesized, including phases such as columbite, brookite, cotunnite, baddeleyite, anatase, rutile, which correspond to the following space groups: Pbcn, Pbca, Pnma, $P2_1/c$, Cmma, $I4_1/amd$, and $P4_2/mnm$. The present study focused on investigating the chemical composition of the surface layer of BT1-0 titanium alloy following laser irradiation to induce the formation of laser-induced periodic surface structures (LIPSS). In this study, LIPSS were generated on the Grade 2 titanium alloy sample surfaces using a system equipped with a Yb-doped nanosecond fiber laser source (YLPM-1-4x200-20-20, NTO “IRE-Polus”) operating at a wavelength of λ = 1.064 μm. The laser parameters employed were as follows: power density ξ = 7.5 J/cm², pulse repetition rate f = 24 kHz, and pulse duration τ = 100 ns.

The first image identified TiO_2 phases corresponding to the space groups Pbcn, $P2_1/c$, $P4_2/mnm$, and Pnma, as well as TiO (c^2/m) and $Ti(NO_3)_4$ ($P2_1/c$). The second image revealed TiO_2 phases with space groups $P2_1/c$, Pbcn, Pbca, and $P4_2/mnm$, alongside TiO (C2/m) and $Ti(NO_3)_4$ ($P2_1/c$). Chemical composition of the surface layer is hypothesized to result from a combination of physical processes (e.g., laser ablation) and chemical reactions (e.g., oxidation). The findings of this study hold potential significance for applications in photocatalysis and surface-enhanced Raman scattering (SERS) spectroscopy.

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CORRECTING OF PATTERN DISTORTION AT THERMOCHEMICAL LASER WRITING OF CROSSED DIFFRACTION GRATINGS ON THIN CHROMIUM FILMS

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Key words: thermochemical laser writing, diffractive optical elements, crossed diffraction gratings, thin chromium films, pattern distortion error

Diffraction optical elements (DOEs) play a crucial role in various fields such as interferometry, laser systems, and optical information processing. The application of DOEs significantly enhances the physical characteristics of numerous optical devices and systems, including scanners, laser radiation converters, and interferometers. One promising method for creating DOEs is direct thermochemical laser recording on metal films [1]. It is widely used for fabrication of computer-generated holograms intended for optical testing of aspherical surfaces [2]. However, this method is limited by the thermal expansion of the recorded beam's trace. These limitations are particularly significant in the fabrication of crossed diffraction gratings which structure consists of rectangular microelements. The objective of this study is to develop and validate a recording algorithm aimed at minimizing thermal pattern distortions that occur during binary modulation of the laser beam intensity by correcting the boundaries of the exposed rectangular regions of the grating microstructure.

As a result of the research conducted, a model for laser recording on thin chromium films was developed based on the finite element method. Calculations of the matching coefficient for various recording scan speeds were performed. The experiments yielded a correlation function that describes the relationship between the distortions of the boundaries of the formed rectangular microelements and the power of the recording beam. This dependency aids in improving the characteristics of crossed diffraction gratings by allowing for the individual adjustment of each boundary of the formed rectangular microelements.

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LIPSS GENERATION ON THIN METAL FILMS: THE PHENOMENOLOGICAL THEORY

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Key words: laser-induced periodic surface structures, surface electromagnetic waves, laser-material interaction, thin titanium films

Period and orientation of the laser-induced surface periodic structures (LIPSS) was found to be dependent on the film thickness, when obtained by oxidation the thin titanium films of different thicknesses on various substrates. Submicron structures were recorded in the multi-pulse mode (about tens of thousands pulses) under the radiation of a fiber Yb laser (λ = 1.064 μm) with a maximum output power of 20 W, a pulse repetition rate of 2 kHz to 100 kHz, and a pulse duration τ from 4 to 200 ns. At a film thickness less than 60-70 nm, in contrast to thicker films and bulk materials, the resulting structures were parallel to the polarization vector of the incident radiation, and the period of the structure was λ/n, where n is the refractive index of the substrate.

These results were used as a basis for the proposed phenomenological model of surface periodic structures formation under the assumption that they are formed due to the generation of a surface electromagnetic wave (SEW) at the film-substrate interface. In this case, the non-uniformity of film transmission at the film-substrate interface is considered as the main reason for the influence of the SEW on the formation of structures. Based on the analysis of the wave equation, analytical and numerical calculations of the SEW propagation in the substrate were performed. The SEW characteristics that affect the efficiency of structure growth were determined, particularly, the attenuation coefficient of the SEW in depth depending on time and coordinate. It was shown that positive feedback is formed between the thickness of the formed oxide layer in the film and the attenuation coefficient of the SEW. The effect of the film thickness on the growth efficiency of the LIPSS was analyzed, and the parameters providing high resolution of the recorded structures were determined.

Research was financially supported by Russian science foundation, project #24-79-10230, https://rscf.ru/en/project/24-79-10230/.

THEORETICAL ANALYSIS OF LASER-INDUCED PERIODIC SURFACE STRUCTURES (LIPSS). INFLUENCE OF MATERIAL PROPERTIES ON LIPSS FEATURES

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Key words: laser-induced periodic surface structures (LIPSS), surface electromagnetic waves, efficiency factor, laser-material interaction

The formation and propagation of surface electromagnetic waves play a crucial role in the laser-induced periodic surface structures (LIPSS) formation process, leading to energy distribution and creation of regular patterns along the surface. In this work we report a theoretical analysis of the laser induced surface structures features. We are addressing the issue of material properties influence on LIPSS formation, which is rarely considered in the literature. Numerical calculations were performed using Python 3.11.11 in Microsoft Visual Studio based on the theory proposed by Sipe et al., which explains the inhomogeneous absorption of energy on the target surface due to the interference between the incident laser beam and the scattered electromagnetic waves caused by surface roughness.

The LIPSS period was determined by identifying the efficacy factor and using the relation $k = \lambda/\Lambda$, where λ is the laser wavelength. This research shows how to effectively identify materials suitable for LIPSS recording by predicting their characteristics. Our results illustrate the morphological features of surface structures, which are explained by taking into account the variation of the parameters of the laser and target surface such as wavelength, polarization, angle of incidence, material optical properties (refractive index, extinction coefficient), and surface roughness (shape and form factors). The study presents numerical results for several materials, including Ag, Cu, Ti, AISI304, CuZn, and Cr, showing the calculated LIPSS periods and efficacy factors. The results are visualized through plots, highlighting the relationship between material properties and the formation of LIPSS by analysing the peaks on the plot.

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FORMATION OF LASER-INDUCED PERIODIC SURFACE STRUCTURES (LIPSS) ON GLASS ASSISTED WITH LASER-INDUCED BACKWARD TRANSFER OF METAL (LIBT)

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Key words: laser-induced periodic surface structures (LIPSS), transparent solid materials, laser marking of glass, laser-induced backward transfer (LIBT), rainbow holograms

The patterning of the optically transparent solid surfaces is a highly relevant technology with applications ranging from anti-counterfeiting measures to fabrication the photonic and electronic devices. Transparent surfaces featuring submicron structures capable of producing structural colors offer new opportunities for the nano-modification of glass. In this work, we introduce a novel method for generating laser-induced periodic surface structures (LIPSS) on glass by patterning a metallic coating formed via laser-induced backward transfer (LIBT). This process utilizes a single nanosecond fiber laser system, which includes a Glan-Taylor prism and a polarization plate, making it a promising approach for industrial-scale production. The thickness of the transferred film is on average 240 nm. The re-irradiation of the film for the purpose of structuring is performed using the following laser parameters: P = 1 W, f = 40 kHz, V = 1 mm/s, t = 4 ns, and a writing resolution of 50 lines/mm. In addition to images with diffracted light, dynamic effects can be achieved, which include motion, switching, and volumetric effects. These dynamic effects are realized by rotating the polarization plate during the recording of periodic structures. The resulting periodic structures exhibit a period of approximately 730 nm and demonstrate structural color, which holds significant potential for applications in product authentication and anti-counterfeiting technologies.

Research was financially supported by Russian science foundation, project #24-79-10230, https://rscf.ru/en/project/24-79-10230/.

Light sources & optical solutions for laser technologies

COMBINED IMPEDANCE AND RI SENSORS FOR DETECTION OF VOLATILE LIQUIDS

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Key words: sagnac interferometer, acoustic sensor, optical fiber, signal processing

The detection of volatile liquids has been carried out using techniques based on both optical and electrical principles. To characterize the evaporation process of volatile substances by recording signals obtained from the same sample within the same detection area, a measurement system was integrated using an optical fiber sensor (MSM) and a coplanar capacitive sensor with parallel electrodes (CCS). The electrodes of the CCS sensor measure 20 mm in length, 5 mm in width, and have a separation of 500 μm, while the sensitive region of the MSM sensor is 20 mm long. The integration was achieved by positioning the MSM sensor over the gap between the CCS electrodes and securing it with a magnetic clamping mechanism. The CCS sensor recorded changes in its impedance components (ZR and ZC), while the MSM sensor measured the transmitted optical power after depositing a 5 μL droplet onto the system. The system was characterized by using acetone to evaluate whether the response of each sensor was affected by the presence of the other, as well as to determine response time and signal-to-noise ratio. The results show that ZC registers a peak upon droplet deposition and progressively decreases as the liquid evaporates. The ZR signal initially decreases, followed by an increase proportional to the evaporation rate. In the MSM sensor, optical power decreases due to light absorption by the sample, and when the sensitive region detaches from the CCS sensor substrate, signal peaks appear, varying according to the evaporation process. This behavior was reproducible as long as environmental conditions remained constant, and the same liquid volume was deposited. To detect other volatile substances, droplets of ethanol, methanol, and isopropanol were tested. The signals obtained allowed for the determination of characteristic evaporation curves for each alcohol, from which their respective evaporation rates were calculated.

INVESTIGATION OF THE UNIFORMITY OF HOLOGRAPHIC OPTICAL IMAGES FORMED BY PHASE-ONLY SHAPING ALGORITHMS

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Key words: beam shaping, phase retrieval algorithms, computer-generated holograms

Modern laser technologies require precise control over optical fields for applications such as material microprocessing, biomedical imaging, quantum communications, and many others [1]. High-efficiency, arbitrary beam shaping can be achieved using spatial light modulators (SLMs) by dynamically modulating the phase of an input laser beam. However, the problem of determining the phase required to obtain a desired target distribution is usually ill-posed, and, in general, requires a numerical solution. In practice, there are numerous phase-retrieval algorithms that offer specific trade-offs between accuracy, diffraction efficiency, and the uniformity of the resulting optical pattern. In this study we numerically and experimentally investigate computational algorithms for generating optical patterns, focusing on their diffraction efficiency and the uniformity of the generated intensity profiles. Specifically, we implement the iterative Fourier transform algorithm (IFTA) [2] and a gradient minimization algorithm [3] for the calculation of high-fidelity intensity patterns. We analyze the dependence of the performance metrics on the initial phase guess, and examine the effects of spatial filtering of the target intensity distributions. As an alternative approach, we implement a single-pass algorithm [4], that employs a phase grating encoded on an SLM to deflect a tunable portion of the light through spatial-frequency filtering. We find the optimal shape and contrast of the gratings, and additionally enhance the flatness of generated intensity profiles via a closed-loop approach.

Our results contribute to the understanding of features of spatial beam modulation approaches, providing a foundation for their utilization in laser material processing applications.

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BINARY AND THREE VALUED OPTICAL LOGIC GATES MODELS IMPLEMENTING LOGIC VECTOR STATES AND LOGIC OPERATION MATRICES

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Key words: integrated photonics, optical coprocessor, optical logic, optical MAC operations

Conventional logical gates are based on operations with binary logical states “0” and “1”. However, a number of applications in the analysis of sensory data, require usage of three states: less, equal, more. In this regard, an approach has been developed for processing logical states as vectors with two or three dimensional vectors.

In this work it is demonstrated that, by representing logical states as basic vectors in the logical state space, logical operations can be expressed as binary matrices of linear mapping between linear spaces of input and output logic state spaces. It is shown that those linear mapping matrices can be derived from truth tables for logical elements of arbitrary complexity. Furthermore, it is suggested that this approach allows for the construction of logic with more than two states, enabling three valued logic gates design. The ability to represent logical operations using matrices presents the opportunity for the use of photonic integrated circuits (PICs) for matrix multiplication as an optical logic circuit. Such designs can be implemented for logical elements with arbitrary complexity, for both binary and tree valued logic. These logic gates require only linear elements with no electrical or linear control as there is an only requirement for the element to multiply on 0 and 1. Micro-ring resonator (MRR) based logical elements are proposed as potential candidates for implementing the elements within the proposed framework. Construction algorithm for logic gate which generates schematics of the element from logic gate truth element is proposed.

Compact models of logic gates have been implemented using a vector-matrix framework based on MRR. OR gates have been implemented for two valued and three valued logic, and it has been demonstrated that these gates perform the logical OR operation. Additionally, a model of a NOT binary logic gate within vector-matrix framework has been implemented using finite difference in the time domain (FTDT) method.

FIBER-OPTIC MAGNETIC FIELD SENSOR

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Key words: fiber optics, Fabry-Perot interferometer, magnetostriction, sensor

The magnetostrictive characteristics of the sample were measured using a high-precision fiber-optic displacement measurement method. The method is based on processing the spectrum of broadband radiation reflected from a Fabry-Perot fiber-optic interferometer used as a mechanical displacement sensor. The mirrors of the interferometer are the ends of the fiber, which supplies and removes radiation, and the ends of the sample, which changes its length under the influence of an applied magnetic field. A super luminescent LED pigtailed with a single-mode fiber is used as a broadband radiation source. The spectrum of radiation reflected from the sensor acquires periodic modulation, for measuring the period of which specially developed software is used, the algorithm of which allows measuring the base of the interferometer (the distance between its mirrors) with subnanometer accuracy. To demonstrate the capabilities of the technique, a 99.99% nickel (Ni) rod was used as a sample. The dependence of its mechanical deformation on the strength of the applied magnetic field is measured. The high accuracy of the deformation measurement of this method makes it possible, in particular, to carry out measurements in weak (up to ~0.2 uT) magnetic fields.

SENSING SYSTEM BASED ON THE SAGNAC INTERFEROMETER FOR ACOUSTIC WAVES IN DIFFERENT PROPAGATION MEDIA

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Key words: Sagnac interferometer, acoustic sensor, optical fibre, signal processing

In the present study, a sensing system based on a basic Sagnac interferometer in an optical fiber was designed to measure acoustic activity in different propagation media, water, and air. The designed system consists of sensors that share a common light source, have the capacity to measure the acoustic activity of their environment, and are capable of measuring acoustic waves in different propagation media. The measurements obtained with the designed system were compared with those obtained using conventional sensors to estimate the sensitivity and measurement bandwidth in both propagation media. For acoustic waves propagating in air, the comparison was made with measurements obtained using a MEMS microphone. The response of the system to acoustic waves propagating in water was compared with that of a needle hydrophone. The comparison was made by measuring the signal emitted by a source under the same conditions of amplitude and position for each sensor in different propagation media. Using the signals measured by the sound source system at different positions, digital signal processing algorithms were implemented to estimate their direction of arrival. One of the main characteristics of the designed sensing system is that it does not require reconfiguration of its components to measure the acoustic activity in different media.

ANALYSIS OF PLASMA PLUME SPECTROGRAM FOR ASSESSING WELD QUALITY IN LASER WELDING

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Key words: Plasma plume, spectroscopy, laser welding

Fiber laser welding is one of the key technologies in modern industry, but the quality control of welds remains an urgent task. In this paper we propose a method of weld quality assessment during laser welding of 09G2S low-alloy steel based on the analysis of plasma plume emission spectrograms and application of machine learning methods. Plasma emission spectra in the range of 400-700 nm were recorded using a spectrometer, after which the statistical parameters of spectrograms and their correlation with welding defects were analyzed. Machine learning techniques such as classification and regression were used to predict the weld quality and classify the defects. The results of the study showed that the proposed approach allows to identify the most significant parameters of the plasma spectra, which can be used for automated real-time weld quality control. This method opens new opportunities for improving the accuracy and efficiency of quality control in laser welding, which is especially important for the automotive, aerospace and construction industries.

The research was supported by ITMO University, project 640115.

Poster session II

Laser nanotechnologies & nanophotonic applications

Laser chemistry and materials science

DIRECT LASER DEPOSITION OF NICKEL COATINGS FROM DEEP EUTECTIC SOLVENTS

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Key words: *laser deposition, deep eutectic solvents, nickel coatings, direct laser writing*

In the field of creating sources of ionizing radiation, there is a technological challenge in depositing a metallic coating of a specified configuration onto a metallic substrate for the subsequent production of the desired radionuclide. The main requirements for metallic coatings include tolerances for thickness and continuity, as well as target component consumption. This work demonstrates the possibility of forming nickel coatings on a copper substrate using the laser deposition method from deep eutectic solvents. To optimize the deposition process and increase the effective rates of obtaining a coating of the desired thickness, the composition of the deep eutectic solvent was determined, and the possibility of controlling the thickness of the nickel deposit was shown through repeated exposure with additional solvent salt. This approach allowed for the creation of coatings with a thickness of at least 10 micrometers and good adhesion (at least 2 points according to GOST 31149-2014). The elemental composition of the deposit was investigated using EDX, XRD, and Raman spectra analysis, revealing the presence of metallic nickel with a content of at least 80%. Methods of optical and electron microscopy were employed to investigate the surface morphology, allowing to investigate the coating uniformity. The method studied in this work allows the variation and scaling of the geometry of the deposited coatings, indicating its promise in the field of creating radionuclide sources.

The work was carried out with financial support from the research grant for Master's and PhD students of ITMO University.

CONSTRUCTION OF LAYER-BLOCKED COVALENT ORGANIC FRAMEWORK HETEROGENOUS FILMS VIA SURFACE-INITIATED POLYCONDENSATIONS WITH STRONGLY ENHANCED PHOTOCATALYTIC PROPERTIES

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Key words: condensation, covalent organic frameworks, extraction, layers, uranium

Imine-linked covalent organic frameworks (COFs) usually show high crystallinity and porosity, while vinyl-linked COFs have excellent semiconducting properties and stability. Therefore, achieving the advantages of imine- and vinyl-linkages in a single COF material is highly interesting but remains challenging. Herein, we demonstrate the fabrication of a layer-blocked COF (LB-COF) heterogeneous film that is composed of imine- and vinyl-linkages through two successive surface-initiated polycondensations. In brief, the bottom layer of imine-linked COF film was constructed on an amino-functionalized substrate via Schiff-base polycondensation, in which the unreacted aldehyde edges could be utilized for initiating aldol polycondensation to prepare the second layer of vinyl-linked COF film. The resultant LB-COF film displays excellent ordering due to the crystalline templating effect from the bottom imine-linked COF layer; meanwhile, the upper vinyl-linked COF layer could strongly enhance its stability and photocatalytic properties. The LB COF also presents superior performance in photocatalytic uranium extraction (320 $mg{\times}g^{-1}$), which is higher than the imine-linked (35 $mg{\times}g^{-1}$) and the vinyl-linked (295 $mg{\times}g^{-1}$) counterpart. This study provides a novel surface-initiated strategy to synthesize layer-blocked COF heterogeneous films that combine the advantages of each building block.

OPTICAL WAVEGUIDE AWG SPECTROMETER FOR HIGH RESOLUTION CASCADE SPECTROMETER ON CHIP

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Key words: planar waveguide spectrometer, spectrometer on chip, DPH, AWG

Spectrometers with a sufficiently high resolution, preferably at a level of 10 pm, are required for the tasks of measuring laser spectra, interrogating signals from optical sensors, and a wide range of sensory tasks. Currently, spectrometers with such a resolution have relatively large dimensions and cannot be mobile devices. Achievements in integrated photonics already make it possible to create small-sized waveguide spectrometers on a chip with a resolution of 0.0375 nm/channel [1]. However, such spectrometers have an extremely narrow dispersion region of the order of a nanometer. To overcome limitation of small dispersion region, a cascade spectrometer structure can be used, where a coarse resolution spectrometer precedes a higher resolution spectrometer. Provided that high-resolution DPH spectrometers with a dispersion region of 0.8 nm [1] are used, a spectrometer with a corresponding interchannel resolution of 0.8 nm with a dispersion region of 20…40 nm should be installed in front of it, which can be preceded by a spectrometer with an interchannel resolution of 20 nm and a dispersion region of 150…300 nm. In this way, it is possible to create a spectrometer with a resolution of about 40 pm/channel and a dispersion region of 150…300 nm. Such a spectrometer will allow measuring the spectrum from Bragg and interference sensors with high accuracy in the parallel data processing mode. Moreover, in the case of implementing a high-resolution spectrometer based on a digital planar hologram (DPH), and all other spectrometers based on AWG structures, due to the isoplanatism property inherent in both DPH and AWG structures, each of the cascades can consist of identical structures. This paper presents the results of the research carried out in developing a DPH- and AWG-compatible spectrometer with 20 nm interchannel resolution, which will allow all stages of a composite spectrometer to be placed on a single chip.

A design based on phased waveguides (AWG) was selected to develop the spectrometer on a chip. The target working spectral range was 1300…1550 nm, the interchannel interval was 20 nm, the spectral shape of the channels was chosen to be Gaussian with interchannel crosstalk of no worse than -30 dB for a channel width of no less than 5 nm. SiON was chosen as the waveguide material. The technology of manufacturing planar waveguide structures with a contrast of up to 3% were studied, numerical modeling of AWG structures of types 5x5 and 8x8 was carried out and the spectral characteristics of the manufactured devices were studied.

The dependence of the refractive index of the waveguide layer on the N_2O and NH_3 gas flows involved in the formation of waveguides was investigated in the process of developing the technology for manufacturing waveguide layers. The deformation occurred by waveguides manufacturing is one of the problems of planar waveguides formation. In this regard, the influence of the waveguide formation technology on the plates geometry was investigated, in particular, the dependences of the deformation on the flows rate of SiH_4, NH_3 and N_2 were investigated. The distribution of chemical elements in the cross section of the waveguide structure was also investigated, and, in particular, the distribution of nitrogen at different levels of the waveguide layer was investigated.

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FABRICATION OF PHYSICAL UNCLONABLE FUNCTIONS (PUF) LABELS USING LASER-INDUCED SINTERING OF COPPER FROM DEEP EUTECTIC SOLVENTS (DES)

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Key words: laser metallization, laser sintering of copper, deep eutectic solvents (DES), physical unclonable functions (PUF) labels

This study presents a new method for producing optically unclonable security labels (PUF labels) using direct laser metallization from Deep Eutectic Solvents (DES). The method takes advantage of special properties of DES-based solutions—particularly their high viscosity and adhesion—to deposit different metal patterns onto bendable surfaces. In this study, we used polyimide films coated with a dilute solution of water and xanthan gum using the Doctor Blade method. Throughout the research, key parameters of laser irradiation were carefully optimized to create the necessary patterns: scanning speed, number of passes, laser fluence, and thickness of the deposited DES composition. PUF labels were created using laser irradiation with microscopic structural features. These characteristics arise inherently from the laser metallization process itself, making precise replication difficult. As a demonstration of the technology, copper patterns of a single template were produced and analyzed. The authentication process utilizes our database of multiple photographic images per label, where for each image pair the system detects distinctive features and quantifies their matches. Our analysis revealed consistently high match counts for same-label images versus markedly fewer matches for different labels, enabling establishment of a reliable decision threshold - matches exceeding this threshold verify identical labels while those below indicate different ones. The proposed fabrication technology offers a scalable, cost-effective, and environmentally safe approach to producing security PUF labels for applications in anti-counterfeiting, authentication, and tracking systems. The adaptability of the technology to work with curved surfaces, the ability to use different metals, and high deposition rates make it a promising solution for creating next-generation security markers.

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CONSTRUCTION OF FUNCTIONALIZED METAL ORGANIC FRAMEWORKS AND PHOTOCATALYTIC ENHANCEMENT FOR URANIUM EXTRACTION FROM SEAWATER

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Key words: photocatalysis, metal organic frameworks, crystalline porous polymer uranium extraction from seawater

The ocean has vast uranium resources. In recent years, photocatalytic technology has emerged as a promising approach for advancing seawater uranium extraction due to its solar-driven uranium reduction capability. Metal-organic frameworks (MOFs) are crystalline porous semiconducting materials formed by the self-assembly of metal nodes and organic ligands. Owing to their programmable topological structures, high specific surface areas, and tailorable photosensitive active sites, MOF semiconductors exhibit significant application potential in the field of photocatalysis. This talk will elucidate the research of MOFs in the direction of photocatalytic uranium extraction from seawater. Firstly, the structural design and synthesis methods of MOFs are presented. Subsequently, the functional modification MOFs of photocatalysis is introduced. In addition, the application of functionalized MOFs in the field of photocatalytic uranium extraction from seawater will be discussed.

HYBRID NANOPHOTONIC-MICROFLUIDIC SENSOR INTEGRATED WITH MACHINE LEARNING FOR OPERANDO STATE-OF-CHARGE MONITORING IN VANADIUM FLOW BATTERIES

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Key words: hybrid photonic-microfluidic sensors, vanadium redox flow batteries, machine learning, refractive index, state of charge, battery management system

This study presents the application of a hybrid photonic-microfluidic sensor for analyzing the State of Charge (SoC) in Vanadium Redox Flow Battery (VRFB) electrolytes. The sensor's performance was evaluated by measuring spectral characteristics, including Resonant Wavelength (RW), Free Spectrum Range (FSR), Extinction Ratio (ER), and Full Width at Half Maximum (FWHM) of the resonance peak. The methodology was tested under both ex-situ and in-operando conditions. Ex-situ measurements utilized manually prepared electrolyte samples to simulate specific SoC levels, revealing a linear relationship between RW and SoC. However, during in-operando experiments, the linear calibration derived from ex-situ conditions and exhibited reduced accuracy over cycling due to imbalance processes taking place during VRFB operation. These deviations even lead to non-physical SoC values exceeding 100%.

To address this limitation, a Machine Learning (ML) approach was employed to enhance prediction accuracy. The in-operando measurements involved ten charge-discharge cycles for ML model training, with the final three cycles reserved for validation. Various ML algorithms, including Random Forest, Support Vector Machine, and LightGBM, were evaluated. LightGBM demonstrated superior performance, achieving a Mean Absolute Error (MAE) of 9.46 and Root Mean Square Error (RMSE) of 11.36 on the test dataset. Further improvements in accuracy are achievable through reduction of measurement noise. A key contribution of this research is the demonstration of refractive index (RI)-based techniques for SoC measurement in VRFB electrolytes under long-term cycling and in-operando conditions. This approach offers significant advantages, particularly its insensitivity against non-linear imbalance processes during VRFB operation. The findings highlight the potential of PIC with ML for reliable and accurate SoC monitoring in flow batteries.

SIMULATION OF THE THERMAL LOAD OF A RADIATION-BALANCED LASER

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Key words: radiation-balanced laser, photoinduced cooling, crystal doped with rare-earth ions, balance equations and density matrix formalism

This work investigates the dependence of the thermal load of the active element of a solid-state laser with an active element in the form of a crystal doped with two rare-earth ions on several key parameters. These parameters include the concentration of rare-earth ions, the lifetimes of excited ion levels, and the characteristics of optical pumping. Understanding these dependencies is essential for achieving a radiation-balanced laser, where the heating and cooling processes within the active medium are balanced, minimizing thermal effects that could degrade laser performance.

A theoretical model describing the generation of radiation in such systems has been developed, taking into account both photoinduced heating and cooling processes. This model is based on balance equations and the density matrix formalism, allowing for a comprehensive description of energy transfer mechanisms occurring within the doped crystal. The approach enables precise predictions of the thermal behavior of the active element under different excitation conditions. To validate the theoretical model, numerical simulations were carried out for two different crystalline systems: YAB: Yb, Er and YAG: Yb, Er.

The simulation results were analyzed and compared with experimental data obtained from passive Q-switched lasers utilizing these materials as active elements. The agreement between the theoretical predictions and experimental observations confirms the validity of the proposed approach and provides insights into optimizing laser parameters for efficient operation with reduced thermal effects.

LASER-INDUCED STRUCTURAL AND OPTICAL MODIFICATION OF HKUST-1 METAL-ORGANIC FRAMEWORKS BY 1030 nm FEMTOSECOND LASER PULSES

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Key words: HKUST-1 MOF, femtosecond laser pulses, structural modification, optical properties, dielectric function, laser-material interaction.

This research delves into the dynamic alterations in the optical and structural properties of the HKUST-1 Metal-Organic Framework (MOF) facilitated by femtosecond laser pulses. Utilizing a high-precision 1030 nm laser with ultra-short pulse durations of 224 femtoseconds, this study aims to precisely control the recrystallization processes within HKUST-1 MOF to tailor its material properties for advanced applications. Our focus centers on the interaction between these femtosecond pulses and the MOF substrate, examining how variations in laser energy density and pulse repetition rates influence the material's crystallinity, morphology, and optical characteristics.

Through detailed experimental setups, we have systematically varied the laser parameters to explore their effects on the optical properties of HKUST-1. Microscope spectrophotometry was utilized to assess reflection (R) and transmission (T) values, facilitating the calculation of the refractive index (n) and extinction coefficient (k). Scanning electron microscopy (SEM) offered in-depth observations of the surface morphology. Additionally, the real and imaginary components of the dielectric function were determined to enhance understanding of the MOF's optical behavior under various laser conditions. The analysis provides a deep understanding of the physicochemical transformations induced by laser energy, particularly the mechanisms driving the recrystallization and modification of the MOF structure.

Furthermore, this investigation sheds light on the potential of precise laser engineering to create materials with customized properties, extending the functionality of MOFs. The comprehensive study of femtosecond laser interactions with HKUST-1 not only broadens the scientific understanding of material-laser interactions but also demonstrates the versatility of laser processing in materials science and engineering. The implications of these findings for the design and development of functional materials will be thoroughly discussed, emphasizing the innovative approaches in material processing and application.

Nano- and molecular systems for optical and biomedical applications

PHYSICAL PROPERTIES OF AQUEOUS COLLOIDAL SOLUTIONS CONTAINING OPTICALLY RESONANT SILICON NANOPARTICLES

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Key words: nanoparticles, laser ablation, silicon, colloid, properties

Colloidal systems are widely used in the modern world. The areas of application are far from limited to medicine and biosensing. Nanoparticles can be useful in the agricultural industry, electronics, and many other areas. Special interests represent colloids of optically resonant nanoparticles, as such systems are prospective for creation of various nanophotonic devices. Before starting to develop an innovative device, it is very important to understand what properties the object being used has. This research represents the investigation of aqueous colloidal solutions of resonant silicon nanoparticles produced by pulsed laser ablation in a fluid flow. The flow rate of the water ranged, while other ablation parameters remained constant. The following parameters of the colloidal solutions were examined: average particle size, size distribution, viscosity, zeta potential, and mass fraction of silicon in the colloid. The concentrations of colloids were determined by comparing the viscosity, measuring the absorption in the wavelength range from 250 to 800 nanometers, and evaporating the liquid to determine the amount of silicon present in the colloid. Analyzing the results, we can conclude that as the flow rate decreases to 300 ml/min, the average particle size tends to increase. With a further decrease in flow rate, the average size decreases as well. At the same time, a flow rate between 500 and 400 ml/min ensures the maximum concentration of the colloid. The viscosity of the colloids at 23°C was also studied.

The results obtained are critically important for describing the physicochemical properties of colloidal solutions of resonant silicon nanoparticles, which have a huge potential for expanding the functionality of existing and developing promising optics and photonics devices.

This study was supported by the Russian Ministry of Higher Education and Science (State Assignment No. FSER-2025–0011).

ANALYSIS OF PHOTODITAZINE STATE IN PAH/PSS POLYMER MICROCAPSULES BY FRAP METHOD

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Key words: photoditazine, polymeric microcapsules, FRAP, laser scanning microscopy, spectroscopy

Polymeric microcapsules of PAH/PSS with embedded drug Photoditazine (PD) were synthesized and investigated. The microcapsules were synthesized by freezing-induced loading and layer-by-layer polymer deposition methods. Photoditazine is a photosensitizer designed for fluorescence diagnostics and photodynamic therapy of malignant tumors. These microcapsules have potential for use in targeted drug delivery. It is important to know what state the drug is in under certain conditions as it directly affects their therapeutic efficacy. Thus, in this work the state of Photoditazine inside model polymeric microcapsules was investigated by FRAP method (fluorescence recovery after photobleaching) using confocal laser scanning microscopy. Laser scanning luminescence methods revealed that Photoditazine is localized inside the capsules, and the polymer shell is impermeable for it. Spectroscopic methods used for investigation solution with microcapsules. It was found that PD retains intense luminescence inside the microcapsules, but a bathochromic shift of the absorption and luminescence bands by 10 nm was observed. The luminescence kinetics PD inside microcapsules show biexponential decay, one of the components of which corresponds to the monomeric form of PD. In addition, the FRAP method was applied inside a single microcapsule and in Photoditazine solution. The experimental results demonstrate that the diffusion coefficient of PD inside the microcapsule is an order of magnitude smaller than in the free solution. Analyzing all the data obtained, we can conclude that part of Photoditazine in microcapsules is bound to the polymer shell. It can be assumed that charge transfer can occur between PD and shell components. Thus, a comprehensive study of the state of Photoditazine inside polymer microcapsules was carried out by spectroscopy, FRAP and laser microscopy. PD inside the microcapsules appears to be in a bound state, in which case its properties, including optical properties, change compared to the free solution. These changes may lead to a decrease in the therapeutic properties of the drug.

WHISPERING-GALLERY MODE POLYMER MICRORESONATORS DOPED WITH LUMINOPHORES AND PLASMONIC NANOPARTICLES

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Key words: whispering-gallery modes, microresonator, quantum dot, carbon dot, plasmon nanoparticle, emission

Early diagnosis of infectious diseases and cancer remains a critical task of modern medicine. Optical sensors based on microresonators with whispering gallery modes (WGMs) offer a fundamentally new approach to solving this problem. Since such microresonators have high quality factor, compact size and high spectral sensitivity to small changes in the refractive index of the surrounding medium as it leads to a measurable shift of the resonant wavelength. However, the widespread application of these microresonators is constrained by limitations such as low biocompatibility and low energy conversion efficiency. The incorporation of plasmonic nanoparticles (NPs) into the configuration of microresonators can improve lasing properties and extend the capabilities of existing sensor devices based on them.

Here, we investigate the effect of plasmonic nanoparticles on the optical characteristics of spherical microresonators, doped with luminophore. WGM microresonators were fabricated by impregnating monodisperse polystyrene microspheres of 5.3-micron diameter with an aqueous solution of carbon dots (or $AgInS_2$ quantum dots) and plasmonic NPs for 24 hours. After impregnation, the microspheres were centrifuged three times and washed with deionized water. Then 3.5 μl aqueous solution of the microresonators were deposited on a glass substrate and dried at room temperature. The emission spectra of the obtained samples were measured using a Raman spectrometer. Narrow periodic resonance peaks on the emission spectra of the microresonators correspond to whispering gallery modes. To investigate the dependence of WGM on the excitation radiation power, the input-output characteristic was measured at different excitation levels for samples with and without plasmonic NPs. The intensities of WGM peaks were sublinear, with characteristic saturation, which can be explained by amplified spontaneous emission of the luminophore.

CHEMILUMINESCENCE ENHANCEMENT IN THE VICINITY OF SILVER NANOPARTICLES

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Key words: metal-enhanced chemiluminescence, luminol, silver nanoparticles

The study of chemiluminescence (CL) enhancement mechanisms is relevant for biomedical diagnostics and analytical chemistry, requiring high sensitivity and minimization of reagent consumption. In this work, the effect of silver nanoparticles on the quantum yield of the CL reaction of luminol was investigated. The proposed technique, based on direct mixing of luminol and oxidizing agent droplets on the glass slide surface, provides minimal reagent consumption in contrast to the microfluidic technique used previously.

The measuring setup consisted of a photomultiplier (PM) and a syringe pump that provides a metered supply of chemiluminophore and analyte, in the present case the oxidizer, in droplets. A mixture of aqueous solutions of sodium hypochlorite (NaOCl) and sodium hydroxide (NaOH) was used as an oxidizing agent. The acidity level (pH) of the solution was varied from 7 to 12 by the NaOH addition. The CL kinetics of luminol was recorded using a PM set to photon counting mode, which provided high sensitivity and low noise level. After a drop of luminol with a concentration of 308 mM/L fell into a drop of oxidizer applied to the glass slide in advance, a flash of CL was observed for several seconds. Under identical experimental conditions the CL intensity variation did not exceed 20%. The dependence of CL intensity on oxidant concentration was close to linear. To study the influence of silver nanoparticles on the luminol CL a colloidal solution of silver nanoparticles obtained by laser ablation in water was added to the luminol solution immediately before the experiment. Upon introduction of the nanoparticles, a fivefold increase in the luminol CL intensity was observed. The observed CL intensity enhancement may be interpreted in the framework of the plasmon-enhanced CL theory that connects the CL quantum yield enhancement with the increased radiative transition rate of the excited chemiluminophore molecule in the vicinity of a metal nanoparticles possessing a localized surface plasmon resonance.

The developed method of dropwise reagents mixing allows for the analysis of small samples of analyte without prior concentration, which is critical for biomedical research with limited samples and minimization of reagent consumption, while increasing CL intensity by adding silver nanoparticles reduces photodetector requirements, expanding the applicability of the method with limited resources or low-cost equipment.

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DETECTION OF SERUM PROTEINS USING COPPER NANOCLUTERS

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Key words: nanomaterials, copper nanoclusters, tyrosine, serum proteins, luminescence

Metal clusters stabilized by biopolymer matrix are specific class of nanoobjects. Noble metals (such as copper, silver and gold) are commonly used for synthesis of these objects. In particular, the potential ability of copper clusters to interact with various analytes makes them attractive candidates for the role of nanosensors for effective and inexpensive diagnostics of various diseases.

In this work, copper nanoclusters stabilized by the amino acid tyrosine were successfully synthesized. It was found that when adding serum proteins (albumin and immunoglobulins), the effect of enhancing cluster luminescence is observed. To evaluate the workability of the sensor, the cluster solution was titrated with each protein separately. As a result, the linear plots of the concentration dependence of the luminescence intensity allowed us to determine serum protein concentrations. We expect that this study offers an experimental basis for the future development of this sensory system for clinical practice.

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FORMATION OF AN OPTICAL NOTCH FILTER AT THE END OF AN OPTICAL FIBER DURING DEPOSITION OF QUASI-ORDERED C-Ag FILMS

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Key words: linear carbon chains, nanophotonics, colloidal systems

The paper considers a technique for forming optical filters at the end of an optical fiber by depositing multilayer coatings of linear carbon stabilized with silver nanoparticles. A design for semi-automatic film deposition using the drip deposition method of water-based colloidal systems is proposed, and the results of measuring transmission spectra for a filter with 10, 20, and 30 layers are presented. It is shown that the transmission spectrum of the resulting filter narrows with an increase in the number of layers, and the central region of the spectrum shifts to a wavelength of 1100 nm. As a result of the work, a fast and cheap method of forming optical notch filters at the end of an optical fiber is demonstrated.

A NOVEL CHEMILUMINESCENT PEROXIDASE-LIKE DNA NANOMACHINE FOR THE DETECTION OF BACTERIAL NUCLEIC ACIDS

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Key words: nucleic acid detection, chemiluminescence, G-quadruplex, DNA-nanomachine

Accurate and rapid nucleic acid detection is crucial for public health security. We introduce a novel and versatile chemiluminescent peroxidase-like DNA nanomachine (PxDm) system within a compact, closed device for simplified pathogen detection. This system enables a complete workflow from sample to result, targeting bacterial nucleic acids from E. coli (16S rRNA) and S. aureus. Remarkably, the PxDm efficiently detects targets across varying sample purities, including crude cell lysates, purified nucleic acids, and amplicons. The E. coli PxDm achieved a 12 nm limit of detection with 86% selectivity, while the S. aureus PxDm reached 5 nm for single-stranded DNA and 81% mismatch discrimination. The device facilitates rapid detection (155 nm LOD for double-stranded DNA), showcasing the PxDm system's potential for diverse applications in rapid diagnostics and streamlined safety monitoring due to its minimal sample preparation requirements.

NANOSENSORS FOR AMINO ACID DETECTION

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Key words: amino acids, tryptophan, gold nanoparticles, fluorescence, SERS, aptamer

Various pathological processes occurring in living organisms can lead to changes in the concentrations of certain compounds in biological tissues and fluids. For example, amino acids are key mediators in human metabolism and health. That is why new sensor systems that allow for their simple detection are in high demand. In our study, we propose two approaches based on the use of gold nanoparticles (NPs).

First, we design an aptamer-based sensor for glutamine. We have developed a DNA aptamer (5'-AGCACGTTGGTTAGGTCAGGTTTGGGTTTCGTGC) containing a specific binding site with glutamine, modified with thiol (5'-end) and the dye Cuanine 5.5 (3'-end). When mixing the aptamer solution with a solution of gold NPs and successively adding glutamine, the effect of fluorescence quenching is observed. This can be explained by a change in the aptamer structure when binding to glutamine and, as a consequence, a change in the distance between the surface of the particles and the dye. The Stern-Volmer plot allows us to determine the concentration of glutamine in the mixture with the LOD as low as can 4 nm.

Second approach is the use of the surface-enhanced Raman scattering (SERS) method using aggregated Au nanoparticles in solution. The electromagnetic field is enhanced due to collective oscillations of free surface electrons in the metal. One of the possible ways to enhance the signal is to change the geometry of the nanoparticles or to combine (agglomerate) particles to obtain localized regions, called "hot spots", where a significant increase in scattering occurs. In this study, we achieve significant enhancement of the SERS signal for various amino acids due to agglomeration of gold nanoparticles.

PHOTOCATALYTIC FENTON-LIKE DEGRADATION OF ORGANIC POLLUTANTS USING TRANSITION METAL MOFS: ACTIVITY, STABILITY, AND BIOSAFETY

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Key words: metal-organic materials, water decontamination, advanced oxidation processes, visible-light photocatalysis, adsorptive properties, cytotoxicity evaluation

The development of highly efficient materials for water purification plays a key role in combating global environmental challenges. In this work, transition metal-based metal-organic frameworks (MeBDC MOFs, where Me = Fe, Co, Ni; BDC - benzene dicarboxylic acid) were prepared by solvothermal synthesis and investigated as dual-functional photocatalysts for adsorption and decomposition of organic pollutants.

A comprehensive analysis of the synthesised samples included scanning electron microscopy (SEM), powder X-ray diffraction (PXRD), energy dispersive X-ray spectroscopy (EDX), FTIR spectroscopy (FTIR), Raman spectroscopy, nitrogen adsorption-desorption isotherm analysis (BET) and diffuse reflectance spectroscopy (DRS). The obtained materials showed a high visible light absorption capacity with forbidden band widths of 1.76 eV (FeBDC), 3.08 eV (CoBDC) and 3.73 eV (NiBDC), and BET specific surface areas of 28.2 m^2/g (FeBDC), 74.3 m^2/g (CoBDC) and 31.4 m^2/g (NiBDC). The photocatalytic activity was evaluated by degradation of methylene blue (MB) under visible light under conventional and Fenton-like conditions. FeBDC showed the highest efficiency with a reaction rate constant of 0.2719 min^{-1} upon addition of 50 mmol/L H_2O_2, which was attributed to its excellent light absorption and catalytic properties. This prompted its selection for an in-depth study of the catalysis mechanism. T

he proposed mechanism involves ligand-metal charge transfer (LMCT) and the formation of reactive oxygen species (ROS) such as hydroxyl radicals due to the involvement of iron. In vitro tests on human monocytes (THP-1), mouse embryonic fibroblasts (MEF-NF), and breast cancer (4T1), melanoma (B16-F10) and colorectal cancer (CT26) cells confirmed the high biocompatibility of the obtained MOFs. MeBDC MOFs are efficient, biocompatible and stable photocatalysts promising for industrial and domestic applications in water purification, reducing the dependence on toxic chemical methods.

Nanophotonic phenomena & materials

MICROFLUIDIC SEPARATION OF RESONANT SILICON NANOPARTICLES USING CENTRIFUGAL FORCE

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Key words: microfluidics, resonant silicon nanoparticles, microfluidic separation, automation, nanotechnology

Resonant silicon nanoparticles have emerged as a pivotal material in modern nanotechnology, offering unique optical properties that hold promise for applications in photonics, biosensing, and nanomedicine. Traditional separation methods, such as centrifugation using density gradients, are often labor-intensive, costly, and lack the cleanliness required. This study presents a novel microfluidic separation technique that overcomes these limitations, providing a more efficient, automated, and cost-effective solution. Our microfluidic chip utilizes advanced fluid dynamics to achieve separation of resonant silicon nanoparticles. The chip's design allows for precise control over the separation process, ensuring the separation of nanoparticles with exceptional purity and yield.

The key advantages of this method include automation, which reduces manual labor and potential human error, lower operational costs due to reduced reagent consumption, and simplicity in setup and operation. We began by optimizing the separation parameters for polystyrene microparticles, which served as a model system to validate the chip's functionality and reliability. The successful separation of polystyrene microparticles confirmed the chip's ability to handle diverse particle types and sizes. Building on this success, we applied the microfluidic separation technique to silicon nanoparticles, demonstrating its effectiveness in isolating resonant particles. The results showed a significant improvement in separation efficiency compared to traditional methods, highlighting the potential of microfluidic technology in advancing nanoparticle research. This work not only confirms the feasibility of microfluidic separation for resonant silicon nanoparticles but also opens new avenues for future developments in nanotechnology. The ability to separate high-purity resonant nanoparticles efficiently and cost-effectively could accelerate advancements in various fields, including optoelectronics, biomedical imaging, and drug delivery systems.

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TRANSITION METAL DICHALCOGENIDES: A PROMISING PLATFORM FOR PLASMON-FREE SERS

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Key words: plasmon-free SERS, transition metal dichalcogenides, nanoparticle, biological mobility

Despite advances in early cancer diagnostics and treatment, material limitations persist, including toxicity risks from nanoparticles (NPs), size/shape constraints for biological mobility, and the need for optical absorption in the tissue transparency window (650–1000 nm). Transition metal dichalcogenides (TMDCs) offer a promising alternative due to their biocompatibility, near-infrared absorption for photothermal therapy, and surface modifiability. Unlike chemically synthesized NPs, femtosecond laser ablation produces uncontaminated TMDC NPs ideal for biomedical applications. We characterized WSe_2 and $PdSe_2$ flakes (ultrasonically exfoliated) and NPs (laser-ablated) using confocal Raman spectroscopy (Horiba LabRAM HR Evolution, 532 nm excitation, 2.2 mW power). SERS substrates fabricated from these materials were tested with rhodamine 6G and crystal violet (10^{-4}–10^{-10} m). WSe_2 NPs showed superior performance to flakes, with a detection limit (LOD) of 10^{-7} m and enhancement factor (EF) of 7.7×10^3 versus 10^{-6} m and 1.3×10^3 for flakes. Remarkably, $PdSe_2$ NPs achieved unprecedented sensitivity (LOD ~10^{-9} m, EF ~10^6 for crystal violet), significantly outperforming literature values for similar TMDC materials, while $PdSe_2$ flakes showed moderate performance (LOD 10^{-7}–10^{-8} m, EF 10^4–10^5). These results highlight the critical role of nanoparticle morphology in SERS performance and demonstrate the potential of single-component TMDC NPs as next-generation biosensors.

The work was supported by the Russian Science Foundation Grant No. 24-45-00021.

RESEARCH OF AMPLIFIED SPONTANEOUS EMISSION IN CD-DOPED CsPbBr3 PEROVSKITE NANOCRYSTALS

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Key words: perovskites, quantum dots, nanocrystals, amplified spontaneous emission, charge carrier

Optoelectronic devices based on lead halide perovskite have recently attracted great attention. This is due to the presence of many useful properties, such as high photoluminescence quantum yield, strong absorption and direct bandgap, which allows the use of such perovskite as the main component in solar power products, optical detectors, light-emitting and laser devices.

Nanocrystal films are one of the most interesting perovskite structures for study and subsequent application. These nanoscale particles are unpretentious in synthesis and capable of generating amplified spontaneous emission, which can be used to create active laser media based on them. However, such material is prone to modification and subsequent destruction due to the dominance of Auger recombination - the main mechanism of charge carrier relaxation during optical pumping. This leads to an increase in the thresholds of amplified spontaneous emission, which also makes the material unsuitable for use as a laser medium. Doping may solve this problem by modifying the electronic properties of the material. Passivation of the surface with additives affects the recombination rate of charge carriers and their mobility, which can improve the available properties.
In this work, the properties of $CsPbBr_3$ nanocrystals doped with cadmium(II) are studied. Different fraction of Cd ions (5%, 10%, 15%, 20%, 25%) was introduced into the lecithin ligand-coated nanocrystals during synthesis by hot injection. This modification of the synthesis led to a higher mobility of charge carriers and a change in their recombination rate in perovskite. The study of optical properties revealed that the additives passivate the surface and lead to an increase in the photoluminescence quantum yield, lifetime and thresholds of amplified spontaneous emission in samples of quantum dots and nanocrystals of perovskite $CsPbBr_3$.

This work was supported by the Ministry of Science and Higher Education of the Russian Federation (Project No. 075-15-2024-625).

ENHANCEMENT OF LUMINOL CHEMILUMINESCENCE BY JOINT ACTION OF SILVER NANOPARTICLES AND METAL IONS

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Key words: chemiluminescence, luminol, Purcell effect, plasmonic nanoparticles, catalyst

Chemiluminescent sensors are actively used to study a variety of biological processes. One of their main potential applications is detection of oxidative stress. However, due to low intrinsic intensity of chemiluminescence, it is crucial to enhance chemiluminescent response. Joint action of plasmonic nanoparticles and metal ions promises an increase in signal due to the Purcell effect and catalysis. Plasmon-enhanced chemiluminescence of luminol being oxidized by sodium hypochlorite in the presence of various metal ions is the content of the present work. Silver nanoparticles about 13 nm in diameter were produced by reduction of silver nitrate with sodium citrate acting as a stabilizer of nanoparticles' surface. The choice of silver nanoparticles is due to the effective overlap of their absorption spectrum with the chemiluminescence spectrum of luminol. Their interaction changes the dipole moment of the radiation transition and accelerates radiative recombination. Iron (Fe^{+}), cobalt (Co^{+}), manganese (Mn^{+}) and copper (Cu^{+}) ions obtained by dissolving sulfates of the corresponding metals in deionized water were used as chemical catalysts. A droplet of sodium hypochlorite and sodium hydroxide mixed aqueous solution with pH=7 was injected into the solution of luminol (100 µl), metal ions (25 µl) and plasmonic nanoparticles (25 µl). The luminescence was detected using a Hamamatsu H11890 photon counter. Chemiluminescence enhancement by a factor of 2-3 due to catalysis with metal ions was observed, while silver nanoparticles were found to ensure additional increase in the intensity by a factor of 2 to 3.

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LEAD-FREE PEROVSKITE BASED MICRORESONATORS FOR NONLINEAR PHOTONICS

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Key words: perovskite, second harmonic generation, nonlinear optics, Mie-resonances

Conversion of infrared (IR) radiation to visible (400–700 nm) and near-IR (700–1000 nm) ranges is a critical issue for applications in information technology, communications and biomedicine. This conversion can be achieved using nonlinear optical effects such as harmonic generation or multiphoton photoluminescence. However, advanced applications such as photonic chips or deep tissue imaging require micro- and nanoscale solutions such as subwavelength nanostructures that provide strong field localization and resonance effects (plasmonic, Mie, Fano resonances) tunable by geometry and size. However, conventional materials for these applications face limitations: plasmonic materials suffer from high losses and low damage thresholds, limiting conversion efficiencies to 10^{-10}–10^{-6}%, while semiconductor-based resonators, although promising for efficient upconversion, require expensive and complex nanostructuring.

Lead-free germanium halide perovskites such as $CsGeI_3$ and $MAGeI_3$ offer a compelling alternative combining high quadratic nonlinear susceptibility ($\chi^{(2)}$ = 125 pm/V for $CsGeI_3$), greenness, and simple synthesis. This work focuses on the development of resonant nanostructures based on these perovskites. High-quality $CsGeI_3$ and $MAGeI_3$ thin films exhibiting strong second-harmonic generation (SHG) were synthesized. Nanoimprint lithography was optimized to create metasurfaces with enhanced SHG efficiency. Furthermore, our previous study [1] showed that SHG in submicron Mie-resonant $CsGeI_3$ particles can be significantly enhanced by pumping at wavelengths corresponding to magnetic dipole resonances in the near-IR region (e.g., 1400 nm for 480 nm particles). Based on these results, spherical SiO_2 templates were used to stabilize perovskite structures with controlled size, morphology, and optical properties.
In this study, we synthesized and characterized novel perovskite-based materials for nonlinear nanophotonics by creating resonant nanostructures that efficiently convert IR radiation to visible light. The results advance practical solutions for bioimaging, optical communication, and laser technologies, highlighting the potential of lead-free perovskites in next-generation photonic devices.

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[1] Ilin, Stepan, et al., Advanced Optical Materials 2024, 12(22), 2400170.

STRONG COUPLING OF CHIRAL LIGHT WITH CHIRAL MATTER: A MACROSCOPIC STUDY

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Key words: photonic crystals, effective Hamiltonian, light localization, flat dispersion, resonance approximation, dispersion engineering

Localization of radiation in a small volume is one of the key challenges in photonics. Various approaches have been developed to address this problem. Localized plasmons in metallic nanoparticles and surface plasmon-polaritons at the metal-dielectric interface are widely used. Additionally, various dielectric nano-resonators and systems supporting quasi-bound states in the continuum are well known, exhibiting modes with extremely high-quality factors. An alternative solution may be systems with a flat dispersion, which support light with zero group velocity over a wide range in the Brillouin zone. In this work, we developed a method for calculating photonic crystal lattices with a superperiod and proposed a gradient dielectric lattice that supports a mode with flat dispersion. Calculating the optical response of a system with a large superperiod requires significant computational resources. To determine the modes of a system with a superperiod, we use the effective Hamiltonian method, in which the bandgap position and effective mass vary with the coordinates. The quasi-waveguide modes of a conventional photonic crystal lattice exhibit parabolic dispersion, with a bandgap and shape that can be tuned by modifying the lattice geometry.

The system parameters for constructing the Hamiltonian can be directly obtained using the resonance approximation developed in our group. In this study, we demonstrate good agreement between the results obtained using the effective Hamiltonian method and direct calculations for harmonic lattices. The developed method enabled us to identify the conditions for achieving flat dispersion modes in photonic crystal lattices with a rectangular profile. Flat dispersion of the mode in real space leads to field localization near the center of the lattice superperiod.

These modes can be used to achieve strong coupling with quantum emitters, particularly excitons in a monolayer of the two-dimensional semiconductors, enabling the formation of polaritonic states.

DIFFUSIVITY OF COLLOIDAL PEROVSKITES STUDIED BY LASER BLEACHING TECHNIQUES FOR BUILDING PHOTONIC STRUCTURES

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Key words: perovskite nanocrystals, photoluminescence, diffusion dynamics, holographic relaxation, phototransformation

Lead halide perovskite nanocrystals have drawn significant interest due to their exceptional optical and electronic properties, including efficient linear and nonlinear light absorption, bright green photoluminescence with quantum yield close to unity, and remarkable defect tolerance. These features make perovskites promising for various advanced optoelectronic applications such as high-performance light-emitting diodes, bioimaging, and chemical sensing. Understanding their mobility, diffusion, and luminescence behavior under light exposure is crucial for optimizing their stability and performance in real-world optical and biomedical technologies, for constructing photoinduced-diffusion-conceived holographic structures of sensoric, distributed feedback-lasing, and other applications.

In this work, we explore the diffusion and phototransformation of specially synthesized CsPbBr3 perovskite nanocrystals exhibiting a symmetric photoluminescence spectrum peaked at 510 nm that is consistent with previously reported data. In order to investigate diffusion dynamics, we employ stripe fluorescence recovery after photobleaching technique based on laser microscopy and holographic grating relaxation technique, both introducing optical heterogeneity into a specimen followed by monitoring its evolution. These approaches enable the assessment of nanoparticle mobility by analyzing how the transversal distribution of luminescence intensity or light diffraction efficiency evolve due to diffusion, thus addressing either imaginary or real components of complex refractive index modulation, hence the modulation of nanoparticles' concentration. The two optical bleaching techniques involved proved sensitive to photoinduced changes not only in nanoparticles' optical properties, but also in their diffusivity.

The research was financially supported by Russian Science Foundation (grant № 25-23-00708 "Photoinduced diffusion of perovskite quantum dots as determined by laser microscopy and holographic relaxometry for diffractive photonic devices").

$FAPbBr_3$ IN METAL-ORGANIC FRAMEWORK COMPOSITES FILMS FOR AMPLIFIED SPONTANEOUS EMISSION

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Key words: perovskite nanocrystals, metal-organic frameworks, amplified spontaneous emission, one-pot strategy

Metal-halide perovskite nanocrystals are known for their exceptional optoelectronic properties but suffer from instability under environmental conditions such as moisture, temperature, and ultraviolet radiation. In this study, we present a one-step method for fabricating composite thin films of formamidinium lead bromide and a lead-based metal-organic framework, aimed at improving stability. The metal-organic framework was synthesized using a sonochemical method and integrated with formamidinium lead bromide to form a stable composite material. X-ray diffraction analysis confirmed the formation of the cubic perovskite phase along with the metal-organic framework peaks, indicating successful composite formation. Transmission electron microscopy revealed encapsulation of formamidinium lead bromide nanocrystals within the metal-organic framework matrix, with an average size of 11.6 nm. The optical properties of the films were characterized by photoluminescence, revealing a peak at 530.1 nm with a full width at half maximum of 24.3 nm. Time-resolved photoluminescence measurements showed an increase in radiative recombination and a decrease in carrier lifetime with increasing pump fluence. The composite films exhibited a low amplified spontaneous emission threshold of 10.5 μJ·cm², indicating their potential for efficient optoelectronic applications, including light-emitting devices and lasers.

MICROSCALE METAL-HALIDE PEROVSKITE PHOTODETECTORS FOR GAS SENSING APPLICATION

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Key words: perovskites, photodetector, gas sensor, photocurrent, nano- and microcrystals

The creation of highly sensitive, wide-range and selective gas sensors is an extremely urgent task, the solution of which will facilitate the transition of high-tech industries to a new, higher level of chemical safety. Various detectors are used to determine the concentration of gases in the air and the most common are electrochemical ones which measure the change in the electrical conductivity of the active element when they absorb gases. Despite their ease of manufacture, they have serious drawbacks. Thus, to increase the sensitivity of sensors to a certain type of gas, selective filters are used, which not only reduce the sensitivity range of the device, but also increase the response time. To solve this problem, effective optoelectronic microstructures based on single lead-halide perovskite crystals were created. In the past 10 years metal-halide perovskites have been intensively studied as promising semiconductor material with high photoluminescence quantum yield, high carrier mobility and tunable bandgap suited for advanced photonics and optoelectronics. The main competitive advantages of such sensors compared to commercially available gas sensors are their fast response and recovery times and the ability to tune the sensitivity to the analyte by changing the chemical composition of the crystal, rather than using selective and inertial filters. In order to detect analytes, reversible adsorption-desorption of analyte molecules by structural defects on the surface of a perovskite crystal was used. The device was pumped with electrical pulses under continuous LED irradiation forming photocurrent in the crystal. Due to the change of conductivity after adsorption/desorption of the gas at the different concentration the photocurrent value decreased/increased respectively.

RUBIDIUM-DOPPED PEROVSKITE QUANTUM DOTS AND NANOCRYSTALS FOR NANOPHOTONIC APPLICATIONS

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Key words: lead halide perovskites, nanocrystals, crystal doping, nanophotonic materials

Lead halide perovskites are promising materials for nanophotonics and optoelectronics. Today, the most modern light-emitting and laser devices are under development on their basis. These materials provide high efficiency with cheap fabrication, but their practical usage is limited by the low stability under atmospheric conditions. This work investigates the doping of perovskite nanoparticles with rubidium cations to enhance their properties for nanophotonic applications.

Perovskites are a class of compounds with the densest cubic packing and an ABX3 stoichiometry. Their structural stability is determined by the Goldschmidt tolerance factor and the octahedral factor. $CsPbBr_3$ is one of the most stable lead halide perovskites, while $RbPbBr_3$ does not form a stable perovskite structure. But rubidium can be incorporated into the crystal lattice to passivate the defects due to the smaller ionic radius. Partial substitution of cesium during synthesis improves the morphology of the crystals and enhances their optical properties.

Rubidium doping of lead halide perovskites has already been used in the development of LEDs and laser devices, generally targeting blue emission. Most studies focus on 2D and 3D perovskite materials. However, perovskite quantum dots and nanocrystals are more promising materials for highly efficient optoelectronic devices and new laser systems nowadays. In this case, rubidium doping provides more efficient and stable materials, expanding potential application prospects.

Obtained materials with mixed cation composition are promising for LED and laser technologies. Rubidium cations fill vacancies within the crystals and on their surfaces, which suppresses nonradiative recombination processes and improves the photoluminescence quantum yield. Also, smaller-radius cations in nanocrystals form energy sublevels by lattice distortion. This reduces the number of recombination ways and facilitates population inversion, so we have lower thresholds of amplified spontaneous emission.

These studies were supported by the "Priority 2030" Program, project 925043.

HIGH-EFFICIENCY LEAD-FREE HTL-FREE BA_3NCL_3 PEROVSKITE SOLAR CELLS FOR INDOOR AND OUTDOOR PHOTOVOLTAICS: A NUMERICAL STUDY

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Key words: perovskite solar cells, SCAPS-1D, lead-free perovskites, Ba_3NCl_3, indoor photovoltaics, HTL-free design

Lead-free inorganic halide perovskites are gaining traction as sustainable alternatives in photovoltaics due to their benign environmental profile and promising optoelectronic characteristics. In this work, we investigate a hole transport layer (HTL)-free perovskite solar cell (PSC) employing Ba_3NCl_3 as the absorber, simulated using SCAPS-1D. The structure Al/FTO/WS_2/Ba_3NCl_3/Au was analyzed and optimized by varying absorber thickness, doping concentration, and back contact work function. Under standard test conditions, the optimized device achieved a power conversion efficiency (PCE) of 37.79%, with an open-circuit voltage (V_{oc}) of 1.1020 V, short-circuit current density (J_{sc}) of 38.61 mA/cm², and fill factor (FF) of 88.81%. Under white LED illumination, the cell showed a PCE of 36.36%, with V_{oc} of 0.9171 V, J_{sc} of 26.78 mA/cm², and FF of 85.74%, indicating strong indoor performance. These results surpass earlier studies on similar architectures, highlighting the potential of Ba_3NCl_3 as a lead-free candidate for next-generation photovoltaics. The findings also emphasize the significance of contact engineering and absorber optimization in achieving high efficiencies without the need for toxic elements or complex HTL layers.

THIRD HARMONIC GENERATION IN PLASMONIC METASURFACE SUPPORTING PROTECTED BOUND STATES IN THE CONTINUUM

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Key words: plasmonics, nonlinear optics, nanophotonics, metasurface

To achieve a robust nonlinear response within a structure, it is essential to generate intense electric fields in combination with non-zero nonlinear susceptibility coefficients. Localized plasmonic resonances in metallic particles and nanostructures are particularly effective in fulfilling this requirement. However, despite the advantage of highly confined fields compared to dielectric structures, plasmonic resonances suffer from a notably low-quality factor, which represents a significant drawback. This limitation can be addressed by harnessing the collective interactions of modes within periodic arrays of plasmonic structures.

In recent years, bound states in the continuum (BICs) have attracted significant attention for their remarkable property of zero radiation losses. These states can be effectively manipulated by introducing asymmetry into the geometry of the structure or by creating a non-zero projection of the incident field's wave vector in the plane of the metasurface. In this study, we propose a semi-theoretical model that provides a detailed description of the mechanisms responsible for the formation of BICs in plasmonic metasurfaces and outlines the criteria for achieving optimal coupling for efficient harmonic generation. Furthermore, we provide an analysis of the mechanisms that lead to the enhancement of non-radiative losses during the nonlinear conversion process.

Our findings emphasize the critical role of the interplay between localized plasmonic resonances and bound states in the continuum, introducing fresh perspectives and innovative strategies for designing highly efficient nano-optical devices. These devices hold great promise for diverse applications across a wide range of scientific disciplines and technological domains. This work was supported by the Ministry of Science and Higher Education of the Russian Federation (Project FSER-2025–0012).

Ultrafast laser-based microstructuring and modification of transparent materials

LASER WRITING OF WAVEGUIDES AND PERIODIC STRUCTURES IN TRANSPARENT MATERIALS

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Key words: ultrafast laser writing, waveguides, periodic structures, refractive index modification, photonic devices, quantum photonics

Laser writing of waveguides and periodic structures in transparent materials has emerged as a powerful and versatile technique for fabricating integrated optical components. This method relies on the precise modification of the refractive index within a bulk material using tightly focused ultrafast laser pulses. The ability to induce localized structural changes enables the direct inscription of optical waveguides, Bragg gratings, and photonic lattices in various transparent substrates, including fused silica, borosilicate glass, and nonlinear crystals.

One of the key advantages of laser writing is its flexibility in three-dimensional structuring, allowing the fabrication of complex photonic circuits without the need for masks or lithographic processing. The quality of the inscribed structures is highly dependent on laser parameters such as pulse duration, energy, repetition rate, and focusing conditions, as well as material properties and processing strategies. Nonlinear absorption mechanisms, including multiphoton ionization and avalanche ionization, play a crucial role in determining the modification regime, which can range from smooth refractive index changes to highly periodic nanostructures.

Periodic structures such as fiber Bragg gratings (FBGs) and photonic crystal waveguides are of particular interest for applications in optical filtering, sensing, and quantum photonics. By carefully controlling the writing conditions, it is possible to achieve high-quality periodic modulations with sub-micron precision, leading to enhanced optical functionalities. Advances in laser processing, including adaptive beam shaping and interferometric methods, further expand the capabilities of this technique. This paper reviews recent developments in laser inscription of optical waveguides and periodic structures, discussing key mechanisms, fabrication techniques, and emerging applications in photonics and quantum technologies.

CONTROLLING THE WETTABILITY OF QUARTZ SURFACES BY FEMTOSECOND LASER: DESIGN, FABRICATION, TESTING

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Key words: LIPSS, femtosecond laser, quartz, wettability control

Processing of material surfaces by lasers has been a popular trend in recent years to create a desired functionality, LIPSS – laser induced periodic surface structures is caused by the interference of incident laser radiation with electromagnetic waves scattered on the surface of an object, resulting in a spatially modulated intensity pattern [1]. In 2019, Papadopoulos et al. succeeded in fabricating periodic structures on quartz by using a circularly polarized laser radiation, which provides reliable evidence for changing the roughness directly on the surface of glass [2]. Such structures can be used as templates to govern the process of nanoparticle assembly [3]. Thus, in our study, a femtosecond laser with a wavelength of 1030 nm was used to induce LIPSS on the quartz surface. The laser was focused by an objective lens to a diameter of 8 μm at the focal point. We successfully developed LIPSS both on the small ("dot") and large (scanning of the sample by coordinate stages with a different period of lines) areas. The large area is considered to be used for nanoparticle assembly.

We present the possibility of preparing LIPSS-based periodic structures on quartz surfaces using the fabricated samples were characterized by AFM to get their corresponding roughness data. The experimental results show that the surface roughness coefficient is positively correlated with the increase in the number of pulses in a period of 4 - 20 pulses at a fixed laser fluence (6.5 J/cm^2). At a fixed number of pulses (NP = 8), the surface roughness coefficient of the material becomes higher with the increase of laser fluence up to 8.5 J/cm^2. We demonstrate that with a suitable number of pulses and fluence it is possible to adjust glass wetting properties (the contact angle of the material) by changing the period of scanned lines. The lowest value of contact angle (7° as compared to 32° for initial glass) is found for the period of 9 μm. The possible reason for this is the appearance of surface damage at scanning with smaller periods of 5 μm and 7 μm. Samples with different wettability will be considered for particle assembly and applied in the fields of biodetection, sensing, green manufacturing, etc.
The study is funded by Priority 2030 Federal Academic Leadership Program.

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LASER-INDUCED MODIFICATION OF AMORPHOUS ARSENIC SULFIDE THIN FILMS: STRUCTURAL PROPERTIES AND PHOTOLUMINESCENCE

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Key words: arsenic sulfide, chalcogenide vitreous semiconductors, spin-coating, structural modification, laser irradiation, photoluminescence

Chalcogenide vitreous semiconductors (ChVS), such as arsenic sulfide (As_2S_3), possess significant interest for infrared (IR) optics and optical data storage applications due to their transparency and high refractive index in the near-IR range. A relevant task is to improve functionality of ChVS thin films by developing methods of their structural modification without changing the chemical composition. These methods include variation of film deposition techniques as well as post-deposition treatment such as laser irradiation. In our study the effect of laser irradiation on the photoluminescence (PL) of thin (1-10 μm) As_2S_3 films prepared by thermal evaporation and spin-coating methods was investigated. Pulsed (τ = 300 fs) and continuous laser irradiation at a wavelength of 515 and 532 nm respectively and a fluence of up to 56 mJ/cm^2 was used for this purpose. The results of the study reveal that the PL intensity in the 1.6–2 eV range increases after laser treatment for both film deposition techniques, owing to creation of defect states changes in the Urbach edge. These defects in the form of “wrong” homopolar bonds act as radiative recombination centers for carriers, while paramagnetic defects in a form of S dangling bonds observed by electron paramagnetic resonance spectroscopy do not contribute to PL. Additionally in the spin-coated As2S3, laser-induced formation of sulfur polymer chains in the irradiated film is observed, while the local chemical composition of thermally evaporated films remains intact. The obtained results can be helpful for further development of infrared optics and electronics based on ChVS thin films.

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COMPOSITE PERIODIC STRUCTURES INSCRIBED WITH NEAR-IR FEMTOSECOND LASER PULSES IN SINGLE-MODE FIBER

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Key words: femtosecond laser modification, composite periodic structure, fiber Bragg grating, spectral filters

Direct point-by-point femtosecond (fs) inscription inside transparent materials has garnered significant attention for creating both active and passive photonic devices. In particular, involved method opens up possibilities for the inscription of 3D complex structures with various spectral characteristics in optical fibers due to localized refractive index change resulted from the nonlinear absorption of fs laser pulses focused in the fiber core. Moreover, the use of fs laser pulses allows us to inscribe inside non-photosensitive fibers in contrast to traditional approach based on UV-radiation and phase mask that requires only photosensitive fibers with a high concentration of GeO_2. UV-inscription also has limitations on desired period, length and geometry of structures caused by the use of a phase mask. So, point-by-point fs inscription is the most promising and flexible approach for creating composite periodic structures that represent an array of gratings with different periods. The goal of such structures is to combine numerous resonant reflection peaks (>100) in one short structure with low optical losses. Inscribed composite periodic structures can be used as spectral filters for astronomical observations. We present the results of writing composite periodic structures using fs laser pulses and a high-precision linear positioning platform to tailor the refractive index profile of these structures. This approach allows for the precise control of modification area along the fiber by synchronizing the laser shutter and the current positioner's coordinates. Moreover, the influence of variations in the period on the reflection spectra was investigated. Additionally, the reflection spectra calculations of a composite periodic structure are demonstrated.

The work was supported by the Russian Science Foundation (№21–72–30024-п).

LASER-INDUCED REFRACTIVE INDEX ENGINEERING IN PHOTO-THERMO-REFRACTIVE GLASS FOR VORTEX BEAM GENERATION USING POLYMER FILMS

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Key words: vortex beams, photo-thermo-refractive glass, refractive index modulation, laser-material interaction, polymer film patterning

Vortex beams, known for spiral phase structure and orbital angular momentum, are essential in photonics applications. This study focuses on the development of photo-thermo-refractive (PTR) glass that can be used for formation of vortex beams. PTR glass serve as a medium for recording extra-deep volume holographic optical elements, amplitude-phase masks, and images. Under exposure to UV irradiation (325 nm) and subsequent thermal processing, i.e., through photo-thermo-induced crystallization, metallic silver nanoparticles with a shell composed of silver halides and sodium fluoride are formed at a temperature of 50 ℃. The refractive index contrast ($\Delta n=5\text{x}10^{-4}$) between the unirradiated glass matrix and the nanoglass-ceramic with NaF phase enables recording of highly efficient Bragg gratings within the bulk of PTR glass as well as phase masks. To record a phase mask for vortex beams, an amplitude mask with variable transmission over the cross-section of the recording beam of a He-Cd laser (λ=325 nm, power 0.8 mW) was used. The amplitude mask was created on a polymer film with a thickness of 40 μm by printing a special coating using a printer. The laser light gradually damaged the mask, increasing its optical density. Tests showed that higher initial density areas degraded more (e.g., D=1.3 increased by 0.5 after 6 W exposure). This degradation must be considered when choosing the UV dose for accurate results. Different areas of the mask with different transmissions allowed controlling the irradiation doses of the PTR glass at wavelength of 325 nm. Different exposure doses were realized across the cross-section of the recording laser beam, which led to different changes in the refractive index in the PTR glass. The paper discusses prospects for using PTR glass to create phase masks that allow the obtaining of vortex beams and a method for obtaining such masks using amplitude masks created on polymer film.

FEMTOSECOND LASER WRITING OF PHOTONICS ELEMENTS INSIDE THE VOLUME OF POROUS GLASS

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Key words: femtosecond laser, porous glass, waveguides, refractive index change, nonlinear absorption

Porous Glass (PG) is a type of porous silica material possessing opened nanopores connected with surrounded environment. The composition of PG in major part corresponds to fused quartz, and its inherent porosity allows it to be densificated or rareficated, allowing a significant variation of the refractive index Δn. A very important feature of PG is the size of pores: it is possible to create pores much smaller than the wavelength of light in the visible spectral range. This provides high transmittance of the material in the visible spectral range and allows its use as a matrix for photonic applications. Femtosecond laser writing allows creating various photonics elements inside the volume of porous glass. Femtosecond direct writing is a universal tool for three-dimensional integration of functional structures inside glass materials. So, one can create such structures as waveguides, nanogratings, local densifications, submicrometer birefringent dots, Bragg gratings. Also, a possibility of creation of Fresnel lenses inside the volume of PG is being studied.

The impact of femtosecond laser pulses focused in PG induces non-linear ionization, generation of electron plasma, whose relaxation leads to a thermal source formation. Internal heat accumulation affects a nanoporous framework and activates non-reversible pore collapse resulting in material density change. Depending on the temperature gradient in the irradiated zone, several types of structural modification occur. To achieve the best possible profile of refraction index changes, the optimal laser working parameters such as wavelength, pulse energy, pulse frequency, translating speed along different axes are being studied. The new methods of waveguides coupling are being developed.

MULTISCAN CAPABILITIES FOR LASER WRITING OF WAVEGUIDES WITH CIRCULAR EIGENMODE AND NEAR-ISOTROPIC COUPLINGS

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Key words: femtosecond laser writing, optical waveguide, multiscan, waveguide array, fused silica

Fabrication of integrated optical waveguide circuits using direct femtosecond laser writing is based on changing the refractive index of transparent dielectric materials by focused ultrashort laser pulses. At sufficiently high laser pulse energies nonlinear absorption of optical radiation takes place, leading to a local change of the refractive index at the beam waist and making it possible to create three-dimensional waveguide circuits. The modified region is elongated in one direction due to the inherent asymmetry of the beam waist, making the eigenmode non-circular and leading to dependence of the coupling constant not only on the distance between waveguides, but also on their mutual orientation. In the case of two-dimensional waveguide arrays possessing certain symmetry, such behavior of the coupling constant can reduce symmetry of the entire system and suppress certain discrete diffraction effects. In our work, we investigated the application of multiscan approach to the problem of eigenmode ellipticity reduction. This is a method of forming a waveguide as a sequence of mutually displaced modifications, enabling writing of rectangular cross-section waveguides with almost circular eigenmodes. We analyzed the impact of multiscan parameters on the degree of localization and ellipticity of an eigenmode. It was found that a small offset between multiple writing passes enables more efficient eigenmode localization than without it and also enables acceleration of the writing process compared to single-pass writing. For the obtained waveguides with a symmetrical eigenmode, we demonstrated a reduced sensitivity of the coupling constant to the mutual orientation of the waveguides. Square 2D arrays with symmetric discrete diffraction in two directions were also presented. In conclusion, we investigated the application of multiscan approach to the task of writing waveguides with circular eigenmode. A significant acceleration of the writing process has been demonstrated, as well as the possibility of manufacturing waveguide arrays with near-isotropic couplings.

OPTIMIZATION OF FEMTOSECOND LASER EXPOSURE MODES FOR WAVEGUIDE FORMATION IN FOTURAN GLASS

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Key words: femtosecond laser, photosensitive glass, waveguides

This research investigates the use of femtosecond lasers for modifying the structure of photosensitive glass to create high-quality optical waveguides. Femtosecond lasers, characterized by ultra-short pulses and high emission intensity, enable precise local modifications in transparent materials, such as glass, by inducing structural phase transformations. The study focuses on identifying optimal laser parameters—pulse energy, duration, repetition rate, and beam focusing—to achieve controlled changes in material properties, ensuring minimal optical losses and high stability.

Experiments were conducted using a 1030 nm femtosecond laser to scan photosensitive glass, creating tracks up to 5 mm long at a depth of 300 μm. Variations in radiation power and scanning speed were tested, and the resulting structural changes were analyzed using optical microscopy and spectroscopy. The findings reveal a compaction of the glass structure in the central treatment area and the formation of a crystalline phase at the edges, accompanied by reduced optical losses in the visible range.

The study concludes that optimal waveguide formation is achieved with laser pulses of energy less than 1 μJ, duration of 224 fs, and a repetition rate of 400 kHz. These results provide a foundation for developing advanced technologies in integrated optics and photonics, enabling the creation of high-performance optical waveguides in transparent materials.

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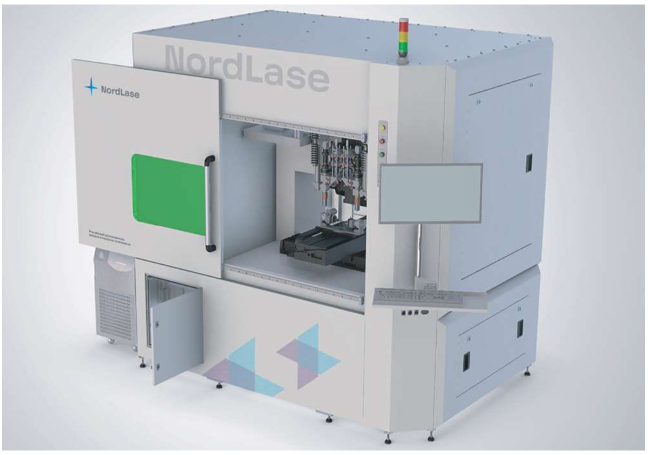

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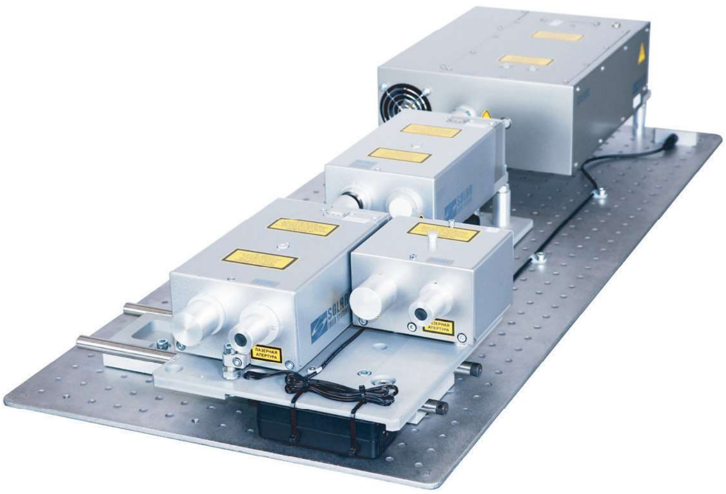

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