ITMO UNIVERSITY

GPI RAS

INTERNATIONAL SYMPOSIUM FUNDAMENTALS OF LASER-ASSISTED MICRO-AND NANOTECHNOLOGIES

27-30 June

SAINT-PETERSBURG, RUSSIA

ABSTRACTS

INTERNATIONAL SYMPOSIUM FLAMN-22

Fundamentals of Laser Assisted Micro– & Nanotechnologies

Symposium Abstract Book

ITMO University

“Laser Center” Ltd

Avesta Project Ltd

Prokhorov General Physics Institute RAS

Journal PHOTONICS Russia

LaserEcoClean

Leningrad Laser Systems

Laser Association

Laser Technology School

Russian Science Foundation

Ministry of Science and Higher Education of the Russian Federation

Resolution no. 220 (The mega grants)

June 27 - 30, 2022,
St. Petersburg, Russia

NTERNATIONAL SYMPOSIUM

Fundamentals of Laser Assisted Micro– & Nanotechnologies (FLAMN-22)

June 27 - 30, 2022, St. Petersburg, Russia

FLAMN-22 program include two main directions:

Laser-Assisted Micro- and Nanotechnologies and Laser-Matter Interaction

which in turn include the following sections:

- **Physical foundations of laser technologies for nanophotonics and nanoscale systems (S04)**
  (Chairmen: Tigran Vartanyan, Sergei Makarov)
- **Ultrafast Laser-Matter Interaction & Technologies (S05)**
  (Chairmen: Dmitry Ivanov, Roman Zakoldaev)
- **Surface functionalization and related phenomena (S06)**
  (Chairmen: Galina Odintsova, Maksim Sergeev)
- **Industrial applications of lasers (S07)**
  (Chairman: Sergei Gorny)

and Special scientific events:

- **School for young scientists, engineers, and students “Laser / optical systems and technologies” (S01)**
  (Chairmen: Dmitry Sinev, Anna Voznesenskaya)
- **The 3rd international scientific school on “Biomedical laser technologies” (S02)**
  (Chairmen: Andrey Belikov, Valery Tuchin, Vadim Veiko)
- **The 2nd international scientific school on “Laser-based approaches in Art & Science” (S03)**
  (Chairman: Ol’ga Smolyanskaya)

ORGANIZERS

– National Research University of Information Technologies, Mechanics & Optics ITMO University, St. Petersburg, Russia
– Prokhorov General Physics Institute of the Russian Academy of Sciences (GPI RAS), Moscow, Russia

IN COOPERATION WITH:

– LLC "Laser Center";
– Laser Association;
– Laser Technology School;
– The Heritage Science Laboratory.

SPONSORS

– ITMO University;
– Russian Science Foundation;
– Ministry of Science and Higher Education of the Russian Federation
– LLC "Avesta";
– Journal "Photonics Russia";
– Leningrad Laser Systems;
– LLC "Laser Center";
– LaserEcoClean;
– RESOLUTION NO. 220 (THE MEGA GRANTS)

Honorary Chairs

Vladimir N. Vasiliev
ITMO University, St. Petersburg

Ivan A. Shcherbakov
GPI RAS, Moscow

Symposium Chairs

Vadim P. Veiko
ITMO University, St. Petersburg,

Vitaly I. Konov
GPI RAS, Moscow

Program Committee Co-Chairs

A. Belikov, ITMO University, Russia
B. Chichkov, Laser Zentrum Hannover, Germany
S. Garnov, GPI RAS, Russia
A. Rode, ANU, Australia
K. Sugioka, RIKEN, Japan

Scientific Secretary

G. Odintsova, ITMO University

International Advisory Committee

S. Gaponov, Russia
S. Garanin, Russia
A. Grigoryants, Russia
A. Ionin, Russia
P. Kashkarov, Russia
W. Kautek, Austria
I. Kazuyoshi, Japan
Yu. Kivshar, Australia
V. Klimov, Russia
V. Kopaeva, Russia
O. Krokhin, Russia
M. Menu, France
V. Ochkin, Russia
V. Orlovich, Belarus
V. Panchenko, Russia
A. Sergeev, Russia
V. Soifer, Russia
A. Zheltikov, Russia

International Program Committee

S. Arakelyan, Russia
A. Caricato, Italy
Y. Cheng, China
V. Detalle, France
H. Demir, Turkey
O. Efimov, USA
M. Garcia, Germany
V. Gordienko, Russia
M. Hashida, Japan
P. Hermann, Canada
N. Inogamov, Russia
D. Ivanov, Germany
A. Kabashin, France
A. Kolobov, Russia
V. Komolov, Russia
S. Kozlov, Russia
S. Kudryashov, Russia
B. Luk'yanchuk, Russia
S. Makarov, Russia
V. Matiushkov, Belarus
I. Mihailescu, Romania
P. Serra, Spain
I. Shiganov, Russia
O. Smolyanskaya, Russia
I. Smurov, France
E. Sobol, Russia
M. Tribelsky, Russia
Y. Tsuboi, Japan
G. Turichin,Russia
V. Tuchin, Russia
T. Vartanyan, Russia
A. Voznesenskaya, Russia
Yongfeng Lu, USA
I. Zavestovskaya, Russia
I. Zergioti, Greece
Zhu Xiao, China

Organizing Committee

Yulia Fyodorova, ITMO University
Alina Korchilava, ITMO University
Ol'ga Kozlova, ITMO University
Julia Mironova, ITMO University
Anastasiia Olkhova, ITMO University
Valerii Romanov, ITMO University
Nadezhda Shchedrina, ITMO University
Victoria Shekel, ITMO University
Dmitry Sinev, ITMO University
Ol'ga Smolyanskaya, ITMO University
Alina Solovey, ITMO University

CONTENTS

Plenary talks

PL-2 Photoconductive terahertz antennas generation in nitrogen-doped diamond materials

V.I. Konov, P.A. Chizhov, M.S. Komlenok, V.V. Kononenko, V.V. Bukin, A.A. Ushakov, V.V. Bulgakova, A.A. Khomich, A.P. Bolshakov, S.V. Garnov
General Physics Institute RAS, Moscow, Russia
vik@nsc.gpi.ru

It is found that nitrogen doping of synthetic diamond results in high power THz generation by diamond-based photoconductive antennas irradiated by 400 nm fs laser pulses. Single-photon light absorption mechanism in doped diamond results in its strong ionization at relatively low beam intensity 500μW/cm^2 (unfocused). Second harmonic of Ti:Al_2O_3 laser with 150 fs pulse duration and 1kHz repetition rate was used as a light source. The assembled antennas consisted of diamond samples with aluminum foil electrodes glued to their side edges. Pulsed bias voltage (up to 3 kV) with pulse duration approximately 10 ns was synchronized with the optical pumping .Three types of diamond were used: high-pressure high temperate (HPHT) single-crystals, CVD mono and polycrystalline plates with characteristic sizes of about 1 mm. Nitrogen concentration was calcu lated from the 270 nm absorption band and varied in the range 10^{-1} -10^2 ppm.

Correlation between the doping level and performance of laser irradiated antennas was demonstrated. Terahertz wave forms and corresponding spectra were monitored. The measured energy of emitted THz pulses could reach about 100 pJ for pump pulse energy of 0.01 mJ, (as in our experiments) conversion efficiency was 10^{-5}. It can be essentially increased by growth of bias voltage above the used values of 14-18 kV/cm. Plus, sample size and correspondingly irradiation volume can be also increased.

The obtained results indicate that N-doped synthetic diamond is a highly prospective material for efficient THz large aperture conductive antennas.

PL-3 Tissue optical clearing opens new avenues for laser technologies in medicine

Valery V. Tuchin[1-4]
[1] Science Medical Center, Saratov State University, Saratov, Russia;
[2] Laboratory of Laser Molecular Imaging and Machine Learning, Tomsk State University, Tomsk, Russia;
[3] Laboratory of Laser Diagnostics of Technical and Living Systems, Institute of Precision Mechanics and Control, FRC “Saratov Scientific Center RAS,” Saratov, Russia;
[4] A.N. Bach Institute of Biochemistry, FRC “Biotechnology RAS,” Moscow, Russia.
tuchinvv@mail.ru

Lecture presents principles and advances in the field of tissue optical clearing (TOC) and a discussion of new fields of biomedical applications of laser technologies, in particular for optical and multimodal imaging, monitoring of drug delivery, effective antitumor and antimicrobial phototherapy, and optical communications with implants in the human body. TOC is based on control of the optical properties of tissues through the reduction of light scattering induced by introduction of immersion optical clearing agents (OCA). These biocompatible agents impregnate the living tissue of interest and make them transparent for a limited time in a wide spectral range from deep UV to terahertz, providing a higher imaging depth and a better contrast [1-3]. Various methods and kinetics of delivery of OCAs and their mixtures with photodynamic dyes and nanoparticles deep into tissues in the context of antitumor and antimicrobial phototherapy will be also discussed.

1. L. Oliveira and V.V. Tuchin, *The Optical Clearing Method: A New Tool for Clinical Practice and Biomedical Engineering*, Springer Nature Switzerland AG, Basel, 2019 – 177 p.
2. V.V. Tuchin, D. Zhu, and E. A. Genina (Eds.), *Handbook of Tissue Optical Clearing: New Prospects in Optical Imaging*, Taylor & Francis Group LLC, CRC Press, Boca Raton, FL, 2022 – 688 p.
3. V.V. Tuchin, E.A. Genina, E.S. Tuchina, A.V. Svetlakova, Y.I. Svenskaya, Optical clearing of tissues: issues of antimicrobial phototherapy and drug delivery, *Advanced Drug Delivery Reviews* **180** (1), 114037 (2022).

PL-4 Plasmon resonator hologram metasurface for generation giant optic fields

A. K. Sarychev [1], A. Ivanov [1], I. Bykov [1], I. Ryzhikov [1], K. Afanasev [1], N. Bakholdin [2], M. Mikhailov [2], A. Smyk [3], A. Shurygin [3], G. Barbillon [4]
[1] Institute for Theoretical and Appliance Electrodynamics RAS, Moscow, Russia
[2] National Research University "Moscow Power Engineering Institute", Moscow, Russia
[3] James River Branch llc, Moscow, Russia
[4] EPF-Ecole d'Ingénieurs, Cachan, France
sarychev_andrey@yahoo.com

We study optics of new metasurfaces made from a metal nanofilmы deposited on a periodically modulated dielectric substrate. The theory of plasmons excited in the open resonator formed by the metal nanograting is presented. The large local electromagnetic field is predicted for optical frequencies. In our experiments the metal gratings are formed on a silicon substrate using holographic lithography. The upper metal film consists of 30 nm thick silver layer, which is deposited by electron beam evaporation. Hologram silver metasurfaces have a period of 740 nm to 780 nm and a modulation depth of 10 nm to 80 nm. Minima in the reflectance spectra demonstrate the excitation of plasmon resonance and the light localization in the metasurface. The amplification of the Raman scattering is studied experimentally. In order to investigate the surface-enhanced Raman scattering (SERS) effect, metasurface was coated with 4-mercaptophenylboronic acid (4-MPBA) molecules, which form strong covalent bonds with the silver nanolayer. The distribution of giant Raman signal maxima generated by the modulated metasurface repeats the surface morphology. The metasurface makes it possible to achieve the SERS amplification factor by several orders of magnitude and obtain a stable signal with a uniform local distribution of the electric field over the entire surface. The detection limit of less than 230 nM for molecules of 4-MPBA is achieved. We propose that such a metasurface with metal micro gratings can be used as an effective SERS substrate for the detection of various proteins, bacteria, viruses and their derivatives that sizes are also about hundred nanometers.

This work was supported by the Russian Foundation for Basic Research (Grant No. 20-21-00080). The reflection measurements were supported by the Russian Science Foundation (Grant No. 21-79-30048).

PL-5 Laser assisted nanotechnologies for nuclear medicine and radiology

I. Zavestovskaya[1,2]
[1] P.N. Lebedev Physical Institute, Moscow, Russia
[2] MEPhI, 31 Kashirskoe sh., 115409 Moscow, Russia
Zavestovskayain@lebedev.ru

Cancer is one of major problems of modern society counting about 15-16% of all death cases per year and the death toll from cancer continues to rise. Nuclear medicine has emerged as one of promising techniques for cancer treatment, which can offer both imaging and therapy modalities.

Our recent data show that the field of nuclear medicine can be significantly expanded by integrating with nanomedicine, which utilizes nanoparticles (NPs) as carriers of radionuclides or as radiosensitizers for radiation therapy and/or active agents for imaging (radiopharmaceutical medicines in situ). 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. The synergy of nanotechnology with nuclear medicine opens up a new direction of cancer imaging and therapy - nuclear nanomedicine.

Laser ablation has appeared as a new non-chemical pathway for the synthesis of nanomaterials, which is free of limitations of conventional chemical approaches and makes possible the synthesis of ultrapure nanostructures. In this approach, small nanoscale clusters are naturally formed during laser ablation from a solid target, and then released into a liquid ambient to form a colloidal nanoparticle solution. Laser ablation can provide nanomaterials exhibiting unique properties and functionalities. The properties of NPs as an increased ratio of surface area to volume, the ability of passive/active guidance and high load capacity, a large cross-section of interaction with biological tissues, unique properties of the surface of nanomaterials, easy giving of many functions to nanomaterials, etc. are used. All these properties of laser-synthesized nanomaterials promise their successful employment in nuclear nanomedicine tasks.

We will highlight our recent achievements in the development of laser assisted nanotechnologies for nuclear medicine and radiology and some important trends in the development of this technology.

PL-6 Resonant Light Scattering by Subwavelength Particles: New Aspects of Old Problem

M.I. Tribelsky
Faculty of Physics, Lomonosov Moscow State University, Moscow, Russia
tribelskym@gmail.com

Resonant light scattering by nanoparticles provides a unique opportunity to concentrate a high-amplitude electromagnetic field in a subwavelength area of space as well as to tailor and control its pattern. In addition to purely academic interest, this is extremely important for numerous applications ranging from medicine and biology to telecommunication and data processing. Despite more than a hundred years of extensive study, the problem is still far from completion. A review of new results in this field is presented in this contribution. It is shown that in many cases, in spite of the smallness of the scattering particles, their light scattering has very little in common with the conventional Rayleigh case. New, counterintuitive effects, especially those related to the violation of the quasi-static description of the scattering occurring at the action of (ultra)short laser pulses, are pointed out and inspected, discussed, and classified.

The author acknowledges the financial support of the Russian Foundation for Basic Research (Projects No. 20-02-00086) for the analytical study and that of the Russian Science Foundation (Project No. 21-12-00151) for the computer simulation.

PL-7 Emerging Semiconductor Nanocrystal Optoelectronics: Pushing the Limits, Breaking Records

Hilmi Volkan Demir[1,2]
[1] Bilkent University Department of Electrical and Electronics Engineering, Department of Physics, UNAM--Institute of Materials Science and Nanotechnology, Ankara, Turkey
[2] NTU Singapore – Nanyang Technological University School of Electrical and Electronic Engineering, School of Physical and Mathematical Sciences, School of Materials Science and Engineering, Singapore
volkan@bilkent.edu.tr, hvdemir@ntu.edu.sg, volkan@stanfordalumni.org

Semiconductor nanocrystals have attracted great interest for color conversion and enrichment in quality lighting and displays. Optical properties of these solution-processed nanostructures are conveniently controlled by tailoring their size, shape and composition in an effort to realize high-performance light generation and lasing. These colloids span different types and heterostructures of semiconductors in the forms of quantum dots and rods, most recently extending to the latest sub-family of nanocrystals, the colloidal quantum wells (CQWs). In this talk, we will introduce the emerging field of semiconductor nanocrystal optoelectronics, with most recent examples of their photonic structures and optoelectronic devices employing such atomically-flat, tightly-confined, quasi-2-dimensional CQWs, also popularly nick-named 'nanoplatelets'. Among various extraordinary features of theirs, we will show that these CQWs enable record high optical gain coefficients [1] and can achieve gain thresholds at the level of sub-single exciton population per CQW on the average [2], empowered by carefully engineering their heterostructures [3,4]. Next, we will present a powerful, large-area self-assembly technique for orienting these nanoplatelets (either all face-down or all edge-up) [5], which provides us with a tool to help engineering their interfaces. Using three-dimensional constructs of all-face-down self-assemblies of CQWs with monolayer precision, we will demonstrate ultrathin optical gain media and lasers of these oriented-CQW slabs [6]. Finally, we will show record high-efficiency colloidal LEDs using CQWs employed as the electrically-driven active emitter layer [7] and record low-threshold solution lasers using the same CQWs employed as the optically-pumped fluidic gain medium [8]. Given their current accelerating progress, these solution-processed quantum well materials hold great promise to challenge their epitaxial thin-film counterparts in semiconductor optoelectronics in the near future.

1. B. Guzelturk et al., HVD, Nano Letters 19, 277 (2019)
2. N. Taghipour et al., HVD, Nature Comm 11, 3305 (2020)
3. Y. Altıntas et al., HVD, ACS Nano 13, 10662 (2019)
4. F. Shabani et al., HVD, Small (2022) (in press)
5. O. Erdem et al., HVD, Nano Letters 19, 4297 (2019)
6. O. Erdem et al., HVD, Nano Letters 20, 6459 (2020)
7. B. Liu et al., HVD, Advanced Materials 32, 1905824 (2020)
8. J. Maskoun et al., HVD, Advanced Materials 33, 2007131 (2021)

PL-8 Laser technologies for perovskite photonics and optoelectronics

S.V. Makarov
ITMO University, St. Petersburg, Russia
s.makarov@metalab.ifmo.ru

Recently, halide perovskites have attracted enormous attention due to their exceptional optical and electrical properties being useful various optoelectronic devices. As a result, this family of materials can provide a prospective platform for modern nanophotonics and meta-optics, 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 [1,2] and nano/micro-lasers [3,4] to the large-scale designs working for surface coloration, anti-reflection, optical information encoding [4], and miro-optical elements fabrication [5,6].

1. Tiguntseva E.Y., Zograf G.P., Komissarenko F.E., Zuev D.A., Zakhidov A.A., Makarov S.V. and Kivshar Y.S. Nano Letters 18(2), pp.1185-1190 (2018)

2. Tiguntseva E.Y., Baranov D.G., Pushkarev A.P., Munkhbat B., Komissarenko F., Franckevicius M., Zakhidov A.A., Shegai T., Kivshar Y.S. and Makarov S.V. Nano Letters, 18(9), pp.5522-5529 (2018).

3. Zhizhchenko A., Syubaev S., Berestennikov A., Yulin A.V., Porfirev A., Pushkarev A., Shishkin I., Golokhvast K., Bogdanov A.A., Zakhidov A.A. and Kuchmizhak A.A. ACS Nano, 13(4), pp.4140-4147 (2019)

4. Zhizhchenko A.Y., Tonkaev P., Gets D., Larin A., Zuev D., Starikov S., Pustovalov E.V., Zakharenko A.M., Kulinich S.A., Juodkazis S. and Kuchmizhak A.A. Small, p.2000410 (2020)

5. AY Zhizhchenko, AB Cherepakhin, MA Masharin, AP Pushkarev, SA Kulinich, AP Porfirev, AA Kuchmizhak, SV Makarov Laser & Photonics Reviews, 2100094 (2021).

6. Zhizhchenko A.Y., Cherepakhin A.B., Masharin M.A., Pushkarev A.P., Kulinich S.A., Kuchmizhak A.A. and Makarov S.V. Directional Lasing from Nanopatterned Halide Perovskite Nanowire. Nano letters, 21(23), 10019-10025 (2021).

PL-9 Functional chalcogenide semiconductors in optoelectronics and photonics

A.V. Kolobov
Department of Physical Electronics, Institute of Physics, Herzen State Pedagogical University of Russia, St. Petersburg, Russia
akolobov@herzen.spb.ru

Modern electronics and optoelectronics relies on silicon and AIIIBV semiconductors. At the same time it is interesting to note that all major semiconductor effects were discovered using chalcogenide materials. Now, again, chalcogenides are coming to the forefront of semiconductor research and technology. In this talk three major classes of functional chalcogenide semiconductors will be reviewed, viz., chalcogenide glasses, phase-change materials and two-dimensional (2D) chalcogenides.

Chalcogenide vitreous semiconductors, discovered by B.T. Kolomiets and N.A. Goryunova in the mid 1950s, changed the existing paradigm that the existence of the band gap is associated with the presence of long-range order and opened the era of amorphous semiconductors. Chalcogenide glasses are widely used as passive optical elements in various optoelectronic applications [1,2].

The switching and memory effects in Te-based chalcogenides, reported by S.R. Ovshinsky in 1968 [3], have eventually been commercialised as phase-change memory devices in the form of re-writable optical discs (CD, DVD and Blu-Ray) and non-volatile random-access memory such as 3D-XPoint Optane™ memory and also in reconfigurable electronics [4,5]

Several years ago, after the success of graphene, search of 2D materials with semiconductor properties boomed, the major studied materials being transition-metal dichalcogenides (e.g. MoS2) and AVBVI semiconductors (such as InSe). The layered structure of these materials with weak van der Waals forces between the layers makes it possible to obtain ultrathin semiconducting materials for uses in devices with ultimately low power consumption as well as in flexible and transparent devices [6].

In this talk the unique properties of different classes of chalcogenide semiconductors enabling their optoelectronic and photonic applications will be discussed along with the existing challenges for their wider practical usage, in particular, the possibilities of using direct femtosecond laser modification of functional chalcogenides.

This work has been partially supported by the Russian Science Foundation (grant 22-19-00035).

1. B. Eggleton, B. Luther-Davies, and K. Richardson, Nature Photonics, **5,** (2011) 141–148
2. A.V. Kolobov and K. Shimakawa (eds), The World Scientific Reference of Amorphous Materials, v. 1, World Scientific 2021
3. S.R. Ovshinsky, Phys. Rev. Lett., **21** (1968) 1450
4. A.V. Kolobov and J. Tominaga, Chalcogenides: Metastability and Phase-change Phenomena, Springer 2012
5. P.C. Taylor, A.V. Kolobov, A.H. Edwards, and J. Maimon, Chalcogenide Alloys for Reconfigurable Electronics, MRS, v. 918, 2006
6. A.V. Kolobov and J. Tominaga, Two-dimensional Transition-metal Dichalcogenides, Springer 2016

Biomedical laser technologies (S02)

S02-1 State of the art in laser printing of cells

B.N. Chichkov
Leibniz University Hannover, Institute of Quantum Optics, Hannover, Germany
chichkov@iqo.uni-hannover.de

In this lecture, we will discuss state of the art laser technologies which can be applied for tissue engineering and printing of living cells and microorganisms into 3D patterns.

For arranging cells in 3D patterns, laser bioprinting based on the laser induced forward transfer process is used. Different cell types, including primary cells, stem cells, and induced pluripotent stem cells embedded in hydrogels as extra-cellular matrix, have been printed. Our current progress in laser printing of microorganisms will be also discussed.

These techniques are capable of advancing 3D cell culture towards CAD defined and precisely arranged 3D cell models and “organ-on-chip” systems. Printed tissue, for example skin, can be used for analyzing the effect of agents like pharmaceuticals or cosmetics ex vivo and, by applying human primary cells, it might be applied instead of animal tests.

S02-2 Laser technologies and tissue regeneration: working together

P.S. Timashev [1,2,3,4], A.I. Shpichka [1,2,4], P.Y. Bikmulina [1], A.A. Antoshin [2]
[1]World-Class Research Center “Digital Biodesign and Personalized Healthcare,” Sechenov University, Moscow, Russia
[2]Institute for Regenerative Medicine, Sechenov University, Moscow, Russia
[3]Department of Polymers and Composites, N.N.Semenov Federal Research Center for Chemical Physics, Russian Academy of Sciences, Moscow, Russia
[4]Chemistry Department, Lomonosov Moscow State University, Moscow, Russia
timashev_p_s@staff.sechenov.ru

To date, it becomes impossible not to mark the crossing filelds of laser technologies and tissue engineering fields. Lasers are successfully applied for the all stages of the tissue engineered construct creation: 3D scaffolds formation (two-photon polymerization, 2PP), cell precise positioning and printing (laser-induced forward transfer, LIFT), and post-printing construct viability and maturation (photobiomodulation, PBM).

To solve the goals of the tissue engineering, the scaffolds should ensure the specific microenvironment for the cell spreading, proliferation and differentiation. Depending on the tissue, the scaffold microarchitecture should match the mechanical cues required by cells. Laser-based techniques of scaffold production, such 2PP, provides a wide spectrum of materials and CAD models available to produce tailor-made scaffolds. 2PP-produced matrices resembling native tissue structure can direct cell fate on such scaffolds.

For the precise cell distribution inside the scaffold, the bioprinting methods are of high interest. In particular, LIFT allows to manipulate cells with high resolution. The building blocks of future tissue, spheroids, can be orchestrated to create defined patterns as well. Laser parameters can be optimized to each individual cell type and bioink. The use of a non-Gaussian beam makes it possible to achieve the highest cell survival by reducing the kinetic energy of their transfer.

However, the stress conditions during bioprinting often result in extensive cell death inside the scaffold. Therefore, the techniques for the stimulation of cell survival are required. One of the candidates for this goal is photobiomodulation (PBM). PBM is a non-invasive, non-thermal method using red and near-infrared light to stimulate cell mitochondrial activity. When applied to the 3D-bioprinted hydrogel structures, PBM stimulates cell viability, metabolic activity and proliferation. Thus, it helps to produce more viable tissue equivalents obtained via 3D bioprinting.

The study was supported by the Russian Science Foundation (№18-15-00401).

S02-3 Anti-aging laser technologies in gynecology: problems, realities, prospects

K.V Shatilova.[1], A.D. Khlopkov[1], T.M. Motovilova[2], L.Z. Sirotina[3], I.A. Kruglova[4], O.A. Pauzina[5], L.B. Spokoiniy[6]

[1] «Melsytech» LLC, Novgorod region, Russia

[2] Federal State Budgetary Educational Institution of Higher Education «Privolzhsky Research Medical University», Nizhny Novgorod, Russia

[3] State Healthcare Institution of the Nizhny Novgorod region «Nizhny Novgorod Regional Clinical Hospital named after N.A. Semashko», Nizhny Novgorod, Russia

[4] State Budgetary Healthcare Institution of the Nizhny Novgorod Region «City Hospital № 35», Nizhny Novgorod, Russia

[5] Federal Budgetary Healthcare Institution «Volga District Medical Center», Nizhny Novgorod, Russia

[6] «Medical Laser Company» LLC, St. Petersburg, Russia

kshatilova@mail.ru

Vulvovaginal atrophy, genitourinary menopausal syndrome, and prolapse of the initial degree are the most common female health issues associated with age-related changes in the vaginal tissues. Approximately half of women over the age of 45 y.o. experience them to some extent. The treatment of such conditions is complicated by the fact that physicians do not prescribe timely treatment due to the reluctance to the potential side effects from hormonal treatment, the attitude to the “aging” of the genitourinary system as a natural process, and patients hiding complaints from their physicians. As a result of the lack of prevention, the patient quality of life decreases, and over time, conditions that require surgical intervention develop.

Today, laser technologies are widely used to treat such conditions. Laser technologies that have already become a conventional treatment are ablative fractional photothermolysis with CO_2 and Er:YAG lasers, coagulation fractional photothermolysis with erbium fiber laser, non-ablative treatment with an Er:YAG laser. These methods are based on the principle of stimulating tissue regeneration due to their local damage and heating, by provoking the growth of new vessels and collagen restoration. These methods are well-researched and clinically proven to be effective, but have a few limitations, including a long recovery time due to damaging effects.

A new method is non-ablative and non-destructive impact by Nd:YAG laser radiation. Laser radiation with a wavelength of 1064 nm penetrates deep into the tissues without damaging their surface, heats the tissues without exceeding the coagulation threshold and stimulating a clinical response similar to the methods described above, which leads to painless procedure and rehabilitation period reduction. The report will review the conventional laser technologies, demonstrate the laboratory and clinical studies results of a new method of laser treatment of age-related vaginal changes, and also consider the prospects for its application in the field of gynecology.

S02-4 Oral mucosa fraction laser treatment: from theory to practice

E. Sergeeva, A. Belikov, Yu. Fyodorova, L. Ermolaeva, D. Fedotov

ITMO University, St. Petersburg, Russia

sergeeva_alena_s@mail.ru

The method of laser fractional treatment consists in creating a set of microdamages surrounded by areas of intact tissue using a laser. This treatment effectively stimulates tissue regeneration, which underlies the widespread use of this method in cosmetology and dermatology for skin rejuvenation and scar treatment. The purpose of the work was to evaluate the effectiveness of the use of the oral mucosa laser fractional treatment.

In an experimental study, we assessed the morphological features of the healing of the oral mucosa in rats at different times after fractional treatment of laser "stLase" (Dental Photonics, USA) with wavelength 980nm. As a result, we have determined a set of laser parameters for the clinical study.

The clinical study involved patients with the scars on the oral mucosa and Stillman's cleft. Fractional laser treatment was performed under topical anesthesia using a laser "stLase" (Dental Photonics, USA) with average power 7W, pulse duration 120ms and tip’s diameter 400micrometers. The numbers of treatment were determined individually and ranged from one to three times with interval of 7 days. Throughout the study, photographs were taken of an area of the oral mucosa before fractional treatment, immediately after treatment, and 3-6 months after the last treatment. The results of an objective examination 3-6 months after the last treatment showed a stable decrease in the scars area in all treated patients and the disappearance of Stillman's cleft.

The results obtained allow us to consider that the technique of laser fractional treatment is highly effective. This opens up new possibilities for the application of this method in dental practice.

S02-5 Raman spectroscopy for assessment of the mineral-organic composition of hard dental tissues after in-office teeth whitening procedure

O.O Frolov.[1], P.E. Timchenko[1], E.V. Timchenko [1], L.T. Volova [2], O.A. Magsumova [2], M.A. Postnikov [2], T.V. Kozlova [1]

[1]Samara National Research University, Samara, Russia

[2]Samara State Medical University, Samara, Russia

frolovaleh@gmail.com

The teeth whitening procedure causes qualitative and quantitative change of tooth enamel structural organization disruption, and pulp micro-circulation dynamics, can cause tooth sensitivity.

In this work were studied 24 samples of hard dental tissues (enamel and dentine). All samples were divided in 2 groups: group 1 - tooth enamel and dentin before the office teeth whitening procedure, group 2 - tooth enamel and dentin after the teeth whitening procedure.

For teeth whitening, a chemical method was used with the Opalescence XtraBOOST system containing 40% hydrogen peroxide.

The main method of analysis of the influence of whitening on the hard-dental tissues composition was the Raman spectroscopy method implemented by the experimental stand that included Raman probe RPB-785, combined with the laser module Luxx Master LML-785.0RB-04 and the high-resolution digital spectrometer Shamrock sr-303i providing spectral resolution of 0,15 nm with the build in cooling camera DV420A-OE. Processing of Raman spectra was carried out in Mathematical 12 software environment.

Results of carried studies:

The possibility of using the Raman spectroscopy for noninvasive rapid assessment of efficiency of in-office teeth whitening procedure treatment was shown.

Spectral changes of enamel and dentine composition after the whitening procedure were found in the lines of ~432, ~590, ~959, ~1045 cm^{-1} (hydroxyapatite) and ~1075 cm^{-1} (CO_3^{2-} (ν_1) B-type substitution).

It has been established that the spectral properties of the teeth dentin after the office whitening procedure change slightly, and the main changes after the office whitening procedure are reflected in the tooth enamel. Thus, this method of whitening can be used in dental practice.

Raman spectroscopy can be used to evaluate dental tissues after an in-office whitening procedure.

S02-6 Laser modification of the soft tissues in dental implantation zone

E. Zernitckaia[1], A. Yaremenko[1], A. Zernitskiy[1]
Pavlov First Saint Petersburg State Medical University, St. Petersburg, Russia
zernitskaya_ekaterina@mail.ru

The soft tissue stability around the implants is affected by amount of bone tissue, amount of attached keratinized gingiva, adequate general hygiene of oral cavity and correct positioning of the implant.

The absence of attached keratinized gingiva May lead to mucositis, then to periimplantatis and disintegration of the dental implant.

The LPM treatment concept has been used commercially since 2004 for the treatment of facial wrinkles, acne scars, surgical scars, melasma and photoirradiated. The creation of microscopic thermal wounds representing islets of tissue damage surrounded by normal tissue has been shown greatly regenerative capacity of the tissue, resulting in completely scar-free tissue self-repair. We hypothesized that the gingiva will show fast regeneration and a potential volume increase because of the thermal micro wounds creation analogous to the skin treatment protocols.

The aim of our investigation is to study the effect of fractional laser on the mucosa in implantation zone to increase the area of attached keratinized gingiva or to increase the area of attached mucosa.

Laser therapy was performed ones in two weeks in amount of 4 sessions by diode laser with wavelength 1550 nm.

As a result of analysis, it was found that the greatest increase of the keratinized gingiva in the area of the dental implant during laser therapy usually occurs after the third session and is on average 0.60 mm. At the stage of healing abutment installation, it also increases by an average of 0.90 mm.

The refuse of the extra operation in 60% of cases. And in 40% cases it was recommended to restore the area of attached keratinized gingiva before the healing abutments installation. In the conduction of the laser applications after the topical anesthesia there were no painful effects during the procedure in 81% cases. In 16% cases there were some unpleasant feelings ranging from heat sensation to tingling. And only 1 case were conducted under the local anesthesia all 4 sessions according to the patient demand.

S02-7 Laser based non-contact optical *in-vivo* sensing of cilia motion

D. Duadi[1], N. Shabairou[1], A. Primov-Fever[2], Z. Zalevsky[1]
[1] Faculty of Engineering and the Nano Technology Center, Bar-Ilan University, Ramat-Gan, Israel
[2] Department of Otolaryngology and Head and Neck Surgery, Sheba Medical Center, and Sackler School of Medicine, Tel-Aviv University, Tel-Aviv, Israel
zeev.zalevsky@biu.ac.il

Cilia motion is an indicator of pathological-ciliary dysfunction, however current diagnosis relies on biopsies. In this paper, we propose an innovative optical biopsy approach for sensing cilia motility. We present an endoscopic configuration for measuring the motion frequency of cilia in the nasal cavity. The technique is based on temporal tracking of the reflected spatial distribution of secondary speckle patterns while illuminating on the cilia with a laser. The setup splits the optical signal into two channels; One imaging channel to visualize the area for the physician and another defocusing channel to capture the speckles. Analyzing the spectral responses is the first step toward a simple non-contact detection of cilia abnormalities.

We present *in-vivo* measurements from healthy subjects undergoing endoscopic examination. We found an average motion frequency of around 7.3Hz and 9.7Hz in the antero-posterior nasal mucus (an area rich in cilia), which matches the normal cilia range of 7-16Hz. Quantitative and precise measurements of cilia vibration will optimize the diagnosis and treatment of pathological-ciliary dysfunction. This method is simple, minimally invasive, inexpensive, and enables distinguishing between normal and pathological-ciliary dysfunction.

S02-8 Optical clearing of adipose tissue: *ex vivo* and *in vivo* studies

I.Yu. Yanina[1,2]

[1] Scientific and Educational Institute of Optics and Biophotonics, Saratov National Research State University named after N.G. Chernyshevsky, Saratov, Russia

[2] Interdisciplinary Laboratory of Biophotonics, National Research Tomsk State University, Tomsk, Russia

irina-yanina@yandex.ru

This work discusses the optical clearing (OC) of adipose tissue, which has not yet been described, although it can be useful in optical diagnostics, therapy, and surgery, when the site where it is necessary to carry out light exposure is covered by adipose tissue, which is typical for many important internal organs. The report combines the review of adipose tissue structure, its optical properties and focuses on the study aimed at designing the technology for *in vivo* optical clearing of abdominal adipose tissue using during its physiological heating or as a result of the action of specific optical clearing agents (OCA), or local compression. Evaluation of OC efficiency at the topical application of OCAs in combination with ultrasound action and/or laser fractional microablation was done. The offbeat optical properties of adipose tissue at physiological temperatures are investigated experimentally using optical coherence tomography (OCT) and digital microscopy and theoretically by numerical solution of Maxwell's equations using the finite-difference time-domain (FDTD) and wave Monte Carlo techniques. OCT measurements were performed *ex vivo* for human and rat adipose tissue. *In vivo* digital microscopy imaging of adipose tissue layers was performed in rats when tissue layers were trans-illuminated by a white light source, quasi-monochromatic LED light or monochromatic laser radiation. The computer processing of digital images allowed estimating the light transmission coefficient and the evolution of its spatial and temporal distributions at tissue heating. These measurements made it possible to quantify the thermally induced effect on the structure of adipocytes, to estimate the kinetics of modification of the cell structure, and to propose a model of the observed phenomenon. The effect of optical caustics is discovered. A mathematical model of the propagation of light through the layers of fat cells is proposed. The efficiency of OC correlated with local tissue damage through cell necrosis.

This research was supported by a joint research agreement (1.10.2013) between Olympus Corporation and Saratov State University (SSU), and partly supported by a grant under the Decree of the Government of the Russian Federation No. 220 of 09 April 2010 (Agreement No. 075-15-2021-615 of 04 June 2021); additional optical measurements on SSU equipment were carried out with the support of RSF grant no. 21-72-10057, https://rscf.ru/project/21-72-10057/.

S02-10 Light-Activated Dual-Mode Biocompatible Nanoparticles for Oncology Theranostics

A.O. Orlova[1], F.A. Sewid[1,2], S.A. Kabanov[1], A.V. Veniaminov[1]
[1] ITMO University, St. Petersburg, Russia
[2] Physics Department, Faculty of Science, Mansoura University, Egypt
a.o.orlova@itmo.ru

Nowadays theranostics simultaneously providing diagnostics and therapy of wide-spread social-impact diseases like cancer needs to develop novel materials with perfect biocompatibility and long-term stability. Molecules and nanoparticles called photosensitizes (PSs) with bright photoluminescence (PL) and high quantum yield (QY) of singlet oxygen (SO) generation are in special focus due to their prospects in cancer theranostics [1].

To date nanocomposites based on PSs and various nanoparticles have been actively studied because a combination of PSs with nanoparticles allows significant improvement of PSs' functional properties [2]. Although numerous photosensitizes have already been developed, non-cytotoxic, water-soluble reasonably stable biomaterials with strong PL, high QY of SO generation are still lacking. PSs' challenges can be efficiently overcome using a combination of PS with colloidal quantum dots (QDs) as a platform for developing new and effective drug systems for cancer theranostics [3].

We discuss optical, photophysical and stability properties of new biocompatible chitosan (CS) nanoparticles with water-soluble $AgInS_2/ZnS$ QDs and water-insoluble PS molecules, Tetraphenylporphyrin (TPP). We show that a combination of the QDs with TPP because of CS allows to produce biocompatible stable NPs with bright luminescence and strong SO generation. We demonstrate a huge potential of CS NPs doped with QDs and TPP molecules as a novel candidate for cancer theranostics.

This work was supported by the Ministry of Science and Higher Education of the Russian Federation, goszadanie no. 2019-1080.

1. V. Maslov, A. Orlova, A. Baranov. Combination Therapy: Complexing of QDs with tetrapyrrols and other dyes in Photosensitizers in Medicine, Environment, and Security. Springer. 2012. 351-389. ISBN 9789048138708.

2. Parinaz Fathi and Dipanjan Pan 2020 Current trends in pyrrole and porphyrin-derived nanoscale materials for biomedical applications Nanomedicine 15:25, 2493-2515

3. F.A. Sewid, K.I. Annas, A. Dubavik, A.V. Veniaminov, V.G. Maslov, A.O. Orlova 2022 Chitosan nanocomposites with CdSe/ZnS quantum dots and porphyrin RSC Advances,12 (2), 899-906

S02-11 Research and development both biocompatible and antibacterial covering of the titanium implants

Yu. Karlagina, V. Veiko, M Radaev., G. Odintsova
ITMO University, St. Petersburg, Russia
jujukarlagina@itmo.ru

Improved biocompatible coatings on the surface of metal implants are needed to achieve well bioactivity and get controlled corrosion properties. Antibacterial coatings are created to reduce the formation of a biofilm on the surface of the implant, as well as to prevent bacterial inflammation of the tissues surrounding the implant. However, generally giving some properties, in particular biocompatibility, makes it impossible to give others - antibacterial ones. This work is devoted to research and development of both biocompatible and antibacterial covering of the titanium surface. The prospect of using such a coating is observed for the neck of dental implants, which is in contact with compact bone tissue, and to which bacteria have access due to the adjacent location with soft tissues.

Both biocompatible and antibacterial coating can be created using laser radiation. By laser ablation, we create a biomimetic relief on the titanium surface, which promotes the proliferation and differentiation of MSCs. Using the second stage of processing the same surface, but with a different laser exposure mode, we create a photoactivated oxide layer that exhibits an antibacterial effect. We present the results of an experimental study of the physicochemical properties of the surface after two-stage laser treatment and the results of testing this coating for biocompatibility and antibacterial properties.

The study was supported by the Russian Science Foundation (project № 20-62-46045).

S02-12 Ultrafast laser modification of biomolecules in biologically relevant environment

Vitaly Gruzdev
Department of Physics and Astronomy, University of New Mexico, Albuquerque, NM, USA
vgruzdev@unm.edu

In 1990s, the field of laser chemistry received a significant push from use of ultrashort (femtosecond) laser pulses to drive chemical modifications of various molecules in controlled way. The control was achieved by use of methods of coherent control that employ electronic excitations by ultrashort laser pulses with specifically tailored spectrum [1, 2]. A decade later, several papers [3-6] reported use of the ultrafast coherent control to predictably modify biological molecules, e. g., some proteins. However, all those modifications were performed under quite special conditions [3-6] that prevented influence of environment on the electronic excitations employed for the coherent-control experiments. Moreover, the reported coherent control of biomolecule modification was demonstrated on very few special types of molecules with strong ultrafast photo-response [3-6]. Transfer of those results to arbitrary proteins under real-life conditions met a significant challenge: the reported modifications required coherence of involved electron states with zero perturbations from environment over entire process of laser-molecule interactions. A natural environment for absolute majority of biomolecules is body-temperature water that produces ultrafast de-coherence of electronic excitations and therefore prevents use of the coherent-control methods for modification of biomolecules under biologically relevant conditions. Our research effort [7] demonstrates unique capabilities to modify biomolecules in biologically-relevant conditions by ultrashort laser pulses. Here, we discuss details of those modifications and their mechanisms. We outline potential applications of our results in medicine, pharmacology, biotechnology, and biomedical research.

1. P. Brumer, M. Shapiro, “Laser control of molecular processes”, *Annu. Rev. Phys. Chem.* **43**, 257–282 (1992).
2. A. Assion, et al., “Control of Chemical Reactions by Feedback-Optimized Phase-Shaped Femtosecond Laser Pulses”, *Science* **282**, 919–922 (1998).
3. V. I. Prokhorenko, *et al.*, “Coherent Control of Retinal Isomerization in Bacteriorhodopsin”, *Science* **313**, 1257–1261 (2006).
4. J. L. Herek, et al., “Quantum control of energy flow in light harvesting”, *Nature* **417**, 533 (2002).
5. M. Chergui, “Controlling Biological Functions”, *Science* **313**, 1246–1247 (2006).
6. N. Lambert, *et al.*, “Quantum biology”, *Nature Physics* **9**(1), 10–18 (2013).
7. V. Gruzdev, et al, “Controlled modification of biomolecules by ultrashort laser pulses in polar liquids”, *Sci. Rep.*, v. **7** (1), p. 5550, (2017).

S02-13 Terahertz solid immersion microscopy: Recent achievements and challenges

N.V. Chernomyrdin[1,2], M. Skorobogatiy[3], V.V. Tuchin[4,5], K.I. Zaytsev[1,2]
[1] Prokhorov General Physics Institute RAS, Moscow, Russia
[2] Bauman Moscow State Technical University, Moscow, Russia
[3] Department of Engineering Physics, Polytechnique Montreal, Canada
[4] Science Medical Center, Saratov State University, Saratov, Russia
[5] Institute of Precision Mechanics and Control, FRC "Saratov Scientific Centre of the Russian Academy of Sciences", Saratov, Russia
chernik-a@yandex.ru

Unique effects of THz-wave–matter interaction push rapid progress in THz optoelectronics aimed at bridging the problematic THz gap. However, majority of modern methods of THz spectroscopy and imaging are still hampered by low spatial resolution. Common lens/mirror-based THz optics fails to overcome the Abbe barrier and usually provides resolution larger than a free-space wavelength λ (i.e., hundreds of micrometers or even few millimeters). To mitigate this difficulty, supperresolution THz imaging modalities were introduced recently, among which we particularly underline different methods of THz scanning-probe near-field microscopy. They not only rely on strong light confinement on sub-wavelength probes and provide resolution down to $\sim 10^{-1}$–$10^{-3}\lambda$ but also suffer from small energy efficiency or presume an interplay among imaging resolution, signal-to-noise ratio, and performance. In this talk, we consider reflection-mode THz solid immersion (SI) microscopy that offers some compromise between the high imaging resolution of 0.15λ and high energy efficiency, which is due to the absence of any subwavelength probe in an optical scheme. Recent achievements, challenging problems, and prospects of SI microscopy are overviewed with an emphasis on resolving the inverse problem and applications in THz biophotonics.

S02-14 Moisture adsorption of tissue scaffolds using terahertz pulsed spectroscopy

G.R. Musina[1,2], N.V. Chernomyrdin[1,2], E.R. Gafarova[3,4], A.A. Gavdush[1,2], G.A. Komandin[1,2], I.N. Dolganova[5], K.I. Zaytsev[1,2], P.S. Timashev[3,4,6,7]
[1] Prokhorov General Physics Institute of the Russian Academy of Sciences, Moscow Russia;
[2] Bauman Moscow State Technical University, Moscow, Russia;
[3] Institute for Regenerative Medicine, Sechenov First Moscow State Medical University (Sechenov University), Moscow, Russia;
[4] World-Class Research Center "Digital Biodesign&Personalized Healthcare", Sechenov First Moscow State Medical University (Sechenov University), Moscow, Russia;
[5] Institute of Solid State Physics of the RAS, Chernogolovka, Russia;
[6] Chemistry Department, Lomonosov Moscow State University, Moscow, Russia;
[7] Department of Polymers and Composites, N. N. Semenov Institute of Chemical Physics, Moscow, Russia
guzel-musina12@mail.ru

Interactions between water vapor and tissue scaffolds were studied using terahertz (THz) pulsed spectroscopy. Dielectric features of scaffolds were obtained within 0.4–2.0 THz, while the samples were first dehydrated and then exposed to water vapor atmosphere with 80.0 ± 5.0% relative humidity. In particular, evaluation of the adsorption time constants and an increase of tissue mass of scaffolds is possible thanks to these THz dielectric measurements and the results of their weighting. No statistically relevant differences between the measured properties of the

intact and treated scaffolds were observed. These results are crucial for further optimization of the scaffolds' preparation and treatment technologies. They show the possibilities for THz technology translation to practice as non-invasive instrument for tissue engineering and regenerative medicine.

S02-15 Laser-assisted synthesis of multi-element nanostructures for biomedical applications

Yu.V. Ryabchikov, M. Flimelová
HiLASE Centre, Institute of Physics of the Czech Academy of Sciences, Dolní Břežany, Czech Republic
yury.ryabchikov(at)hilase.cz

The development of laser- and nano-technologies makes a large contribution in many life aspects, especially, in life science. Nanostructured materials play a significant role in biomedicine due to their extremely low sizes and unique physico-chemical properties. One of the most important tasks – the diminution of any side effects caused by undesirable chemical content. For this purpose, a method of pulsed laser ablation in liquids (PLALs) is one of the most useful technique forming nanostructures of high chemical purity. Moreover, PLALs is a promising approach for the formation of multi-element nanoparticles with controlled chemical composition that can further be served as multi-modal nanoagents for simultaneous solving of various biomedical tasks.

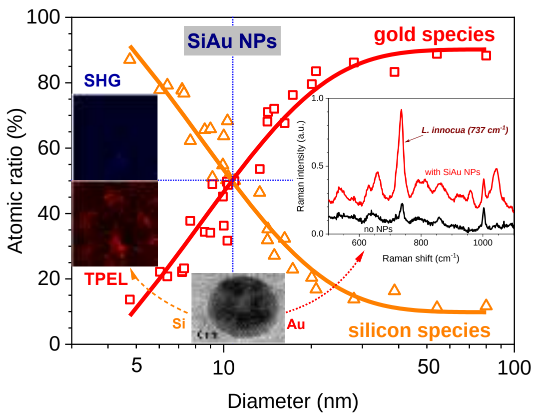


Figure 1. Chemical composition of SiAu NPs formed by pulsed laser ablation in liquids and their possible applications in the field of biomedicine.

In this work, we performed laser-ablative synthesis of both single- and multi-component nanostructures based on semiconductor and metallic materials using ultrafast lasers. Firstly, the dynamics of the formation of single-element silicon and gold nanoparticles as well as their properties were studied. Formed nanostructures showed low cytotoxicity and promising applications in the life science such as hyperthermia or nonlinear optical bioimaging. Further laser-induced structural modification led to the formation of composite nanoparticles, such as silicon-gold nanoparticles (SiAu NPs), whose both chemical composition and properties depended on the time of their modification [1,2]. Moreover, these features were also changed by the variation of the colloidal solution concentration [3]. The laser-synthesized nanocomposites combined modalities of both elements showing, for instance, the high ability of the semiconductor nanostructures for molecule detection using surface-enhanced Raman scattering (SERS) techniques [4].

Acknowledgements:
This research work was financially supported from the European Regional Development Fund and the state budget of the Czech Republic (Project BIATRI: CZ.02.1.01/0.0/0.0/15_003/0000445), from the Ministry of Education, Youth and Sports (Programs NPU I-Project no. LO1602). YuV.R. also acknowledges funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No 897231 (LADENTHER).

1. M. Flimelova and Yu.V. Ryabchikov, A Facile Route of Manufacturing of Silicon-Based Nanostructures with Tuned Plasmonic Properties, Journal of Physics: Conference Series, 2015, 012128 (2021).

2. Yu.V. Ryabchikov and J. Behrends, Expedient Paramagnetic Properties of Surfactant-Free Plasmonic Silicon-Based Nanoparticles, Optical and Quantum Electronics, 52, 177 (2020).
3. Yu.V. Ryabchikov, Facile Laser Synthesis of Multimodal Composite Silicon/Gold Nanoparticles with Variable Chemical Composition, Journal of Nanoparticle Research, 21(4), 85 (2019).
4. M. Kögler, Yu.V. Ryabchikov, S. Uusitalo, A. Popov, A. Popov, G. Tselikov, A.–L. Välimaa, A. Al–Kattan, J. Hiltunen, R. Laitinen, P. Neubauer, I. Meglinski, A.V. Kabashin, Bare Laser–Synthesized Au–Based Nanoparticles as Non–Disturbing SERS Probes for Bacteria Identification, Journal of Biophotonics, 11(7), e201700225 (2018).

S02-16 Core-shell-shell SPION/CdSe/ZnS magnetoluminescent nanoparticles studied by stripe fluorescence recovery after photobleaching technique

L. Borodina, A. Matyushkina, I. Vovk, A. Dubavik, A. Veniaminov, A. Orlova
ITMO University, St. Petersburg, Russia
lborodina141@gmail.com

Nanoscale particles combining luminescent and magnetic properties promise a dramatic impact on bioimaging, theranostics, targeted drug delivery, hyperthermy. The magnetoluminescent nanocomposites comprised of superparamagnetic iron oxide (SPION) core and two shells of CdSe and ZnS were synthesized in our lab. We applied the luminescence technique stemming from Fluorescence Recovery After Photobleaching (FRAP) to observe the nanocomposites' motion and their interaction with a magnetic field. The technique consists in imprinting a photo-induced spatial inhomogeneity (a narrow stripe across the sample) into the photoluminescence pattern ("bleaching") with a scanning focused laser beam, followed by recording and analyzing its post-exposure transformations due to diffusive intermixing of the bleached and intact molecules or particles contributing to the pattern.

We applied the Zeiss LSM 710 laser scanning microscope with a 405 nm diode laser and a low-aperture lens, which ensured the bleaching through and collection of light from the entire thickness of the solution in the 1 mm cuvette. The initial width of the stripe was 50 µm, the 1024x1024 pixels frame covered a 1.7x1.7 mm area. Prior to the bleaching experiment, the exposure dependence of the luminescence intensity was recorded, and the exposure resulting in the intensity decrease by about 15% of the initial value was chosen.

The diffusion coefficient $D = (9.2\pm0.8)\cdot10^{-7}$ cm^2s^{-1} was determined from the time dependence of the profile width, and the corresponding hydrodynamic radius of the nanocomposites (8.1±0.7) nm was found to agree with the DLS data. A pronounced drift as fast as 20 µm/s was observed in the presence of a 0.3 T permanent magnetic field. Thus, the application of the modified FRAP technique to the motion of core-shell-shell composites in colloidal solution proved their ability to manifest both luminescent and magnetic properties.

S02-17 Nanoparticles safety verification for their biomedical applications from microrheologic point of view

A. Lugovtsov[1], E. Shirshin[1], P. Ermolinskiy[1], Chia-Liang Cheng[2], A. Priezzhev[1]
[1]Department of Physics, Lomonosov Moscow State University, Moscow, Russia
[2]National Dong Hwa University, Shoufeng, Hualien, Taiwan
anlug@biomedphotonics.ru

Different types of nanoparticles (NP) have been proposed as biocompatible and promising for various biomedical applications. In particular, iron (iii) oxide nanoparticles (Fe_2O_3) and carbon NP - nanodiamonds (ND), titanium dioxide (TiO_2) and silicon NP, nanotubes and fullerenes have been proposed for using in biomedical imaging and photodynamic therapy, direct drug delivery. It is presumed that to reach the target these particles would be intravenously administered into blood. NP can affect the erythrocytes properties such as their ability to reversibly aggregate and deform in shear flow when propagating along blood vessels and capillaries. These alterations can impair blood rheology and, as a result, increase the risk of development of cardiovascular diseases and even mortality. Basics of laser diffractometry, diffuse light scattering aggregometry, as well as optical trapping techniques and fluorescent microscopy to study various aspects of the interaction of NP with rat and human erythrocytes are discussed. *In vitro* and *in vivo* the effect of NP on blood microrheology aggregation and deformability properties of the cells are demonstrated. Incubation of blood with NP at high concentrations of the latter does negatively affect both aggregation and deformability of the cells, the effect being dependent on the particle concentration, size and surface functionalization. The alterations in the microrheological properties are more significant for higher NP concentrations and more pronounced for non-functionalized particles surface. The effects on blood microrheological properties of NP incubated with blood (*in vitro*) and administrated intravenously into laboratory animals (*in vivo*) are similar. Basing on the results one can conclude that the NP can be administered into blood in ambient conditions at low concentrations (33 µg/ml), without significant complication of the blood rheological conditions. However, under certain conditions, this effect can be very significant, and it is necessary to check the hemocompatibility of each type of nanoparticles *in vitro.*

This work was supported by the Russian Scientific Foundation (Grant No. 20-45-08004) and performed according to the Development program of the Interdisciplinary Scientific and Educational School of Lomonosov Moscow State University «Photonic and Quantum technologies. Digital medicine»

S02-18 Physical aspects of microsecond 1540 nm laser with burst mode application for cataract surgery

A.V.Belikov[1], S.N. Smirnov [1], Yu.N. Batov [2], A.B. Gubin [2], Yu.B. Pirozhkov [2], E.A. Bekryasheva [1], A.K. Lisichnikov[1]

[1] ITMO University, St. Petersburg, Russia,

[2] Nela Ltd., St. Petersburg, Russia

av.belikov@itmo.ru

Cataract is one of the most common ophthalmic pathologies, which leads to eye lens clouding and blindness. Laser cataract extraction (LCE) is a technology that allows to remove cataract lens of any density using only laser radiation energy and is performed without damaging surrounding biological tissues. It consists in the destruction of the clouded lens under the action of laser pulses, the aspiration of the destructed lens substance and inserting an artificial lens.

Since 1997, the technology of LCE using a 1.44 μm Nd:YAG laser has been used in clinical practice. The disadvantage of the existing laser system is its significant weight and size. Small-sized laser sources are being developed, including those based on an ytterbium-erbium glass laser with a wavelength of 1.54 μm.

A new laser system based on an ytterbium-erbium glass laser has significantly different radiation properties. The successful use of this radiation required a significant multivariate optimization of the laser radiation parameters based on a deep study of the processes stimulated by laser radiation in a liquid. The laser operates in the useful-loss modulation mode and emits bursts of microsecond pulses. To increase the efficiency of the lens destruction, laser pulses with a duration of 1.5 μs and with a high-intensity leading spike are used. The pulse energy is limited from above by the damage threshold of the instruments used, including the aspiration tube. The interval between pulses within a burst has a significant impact on the lens destruction performance since it is necessary to match the time of the laser pulse impact beginning and hydroacoustic processes stimulated by the previous pulse. For pulses with an energy of about 100 mJ, the interval between pulses should be more than 700 μs, which ensures that hydroacoustic processes do not overlap. The time of complete lens destruction was found to be 130±10 s, comparable to the time of ultrasonic phacoemulsification and LCE using 1.44 μm Nd:YAG laser radiation.

S02-19 Raman-LIBS for tumor tissue imaging and cells detection

Youyuan Chen[1], Pengkun Yin[1], Zhengying Peng[1], Qingyu Lin[2], Yixiang Duan[2]
[1] College of Life Sciences, Sichuan University, Chengdu, Sichuan, People's Republic of China
[2] Research Center of Analytical Instrumentation, School of Mechanical Engineering, Sichuan University, Chengdu, People's Republic of China
qylin@scu.edu.cn

With cancer seriously hampering the increasing life expectancy of people, developing an instantly diagnostic method has become an urgent objective. we developed a label-free LIBS method for high-throughput recognition of tumor cells based on interpretable deep learning. Saliency maps thus obtained amplified the differences between the spectra of cell lines. The proposed method achieved high accuracy and is seen as an interpretable classification process for cancer cell lines. Moreover, we further focused on the analysis of tumor cells with Raman. We proposed a novel strategy based on signal amplification reaction (i.e. 3D DNA walker and CHA) and SERS for ultrasensitive detection of tumor cells. The tumor cell can be recognized by the corresponding aptamer sequence and can be detected by this SERS method. Our group also proposed LIBS instrument and method for the diagnostic analysis of clinical lung cancer tissues based on label-free imaging. The heterogeneity of multielements and molecular fragments was obtained simultaneously for three types of clinical samples containing different proportions of cancerous tissue by laser-induced breakdown spectroscopy (LIBS) imaging.

S02-20 Rapid measurement of erythrocyte size distribution asymmetry by laser diffractometry of blood smear

S.Yu. Nikitin, E.G. Tsybrov, M.S. Lebedeva
M. V. Lomonosov Moscow State University, Moscow, Russia
tsybrovevgeniy@yandex.ru

The size distribution of erythrocytes is an important rheological characteristic of blood. The main parameters of this distribution - mean cell volume (MCV) and red blood cell distribution width (RDW) are included in the standard blood test. We believe that other parameters of this distribution, such as distribution skewness and kurtosis, may also have diagnostic value. In this paper, we discuss the possibility of measuring the asymmetry of the size distribution of erythrocytes by laser blood smear diffractometry. The advantage of this method is its simplicity and speed of measurements. Our experimental setup includes a laser, a blood smear, an observation screen, and a video camera. A digital photograph of the diffraction pattern from a video camera is fed to a computer, where it is processed using a special program. We measure the average size of erythrocytes, as well as the width and asymmetry of the erythrocytes size distribution. We tested this algorithm by numerical experiment. The results show that for the parameter RDW=14%, which is typical for normal blood samples, the error of the algorithm does not exceed 8%. For RDW =18.8%, the error in determining the parameters of erythrocytes does not exceed 17.5%. In conclusion, we present an algorithm for measuring the characteristics of the size distribution of erythrocytes based on the method of laser blood smear diffractometry. The algorithm makes it possible to measure the average radius of an erythrocyte on a blood smear, as well as the width and asymmetry of the size distribution of erythrocytes. The

advantage of this method is the simplicity and speed of measurements. The numerical simulation shows that the algorithm provides an acceptable measurement accuracy and has a fairly wide range of applicability.

S02-21 Phenomenon of osmotically-induced strain in porous biological tissues and its observation with optical coherence elastography

Yu.M. Alexandrovskaya[1], O.I. Baum[1], A.A. Sovetsky[2], A.L. Matveyev[2], L.A. Matveev[2], V.Y. Zaitsev[2]
[1] Institute of Photon Technologies, FSRC "Crystallography and Photonics" of RAS, Moscow, Russia
[2] Institute of Applied Physics, Russian Academy of Sciences, Nizhny Novgorod, Russia
yu.alexandrovskaya@gmail.com

The application of hydrophilic optical clearing agents (OCAs) is becoming a common practice for improvement of optical diagnostics of biological tissues in vitro and in vivo. The effects of standard OCAs, such as organic alcohols and polysaccharides, were shown to be safe and reversible in a certain range of concentrations and application time. However, some side effects of OCA's action connected with osmotically-induced local strains during diffusion of an agent were not studied. Meanwhile, these local deformations may contribute to the overall toxicity of the used OCA as they affect the microenvironment of cells, and additionally at closer analysis, including the amplitude and sign of a particular strain, they may provide useful diagnostic information about the tissue permeability, structure and integrity. Here we present the capabilities of phase-resolved optical coherence elastography (OCE) for non-contact monitoring of osmotically-induced strains in porous biological tissues during application of various OCAs. The observation of deformations is provided with the spatial resolution of ~50 µm, which fills the gap between macroscopic elasticity measured at millimeter level and nanosize elastic parameters obtained by atomic force microscopy. OCE allowed us to observe the time-resolved evolution of the observed strains and its dependence on the agent type and concentration. The alternating-sign nature of the subsurface strain evolution (within 1 mm depth), including depth ranges of dilatation and shrinkage, induced by the action of strong hydrophilic OCAs, was revealed for the proteoglycan-rich tissues, such as cartilage. Possible mechanisms of the non-uniform spatial strain evolution are discussed.

S02-22 Semiconductor lasers for the mid-wavelength infrared range

K. Mynbaev[1], A. Semakova[1], M. Ruzhevich[2]
[1] Ioffe Institute, St Petersburg, Russia
[2] ITMO University, St Petersburg, Russia
mynkad@mail.ioffe.ru

The middle-wavelength infrared (MWIR) range of the electromagnetic spectrum is considered to cover the 2–12 µm range, which corresponds to energies between 0.62 and 0.1 eV. The main interest in this spectral range is stipulated by the presence of several transparency windows of the atmosphere, but also, many molecules have fingerprint absorption lines in the MWIR. These include such important species as hydrocarbons (methane, ethane, etc.), hydrochloric acid, ethanol, ammonia, etc. The MWIR range, therefore, is well suited for implementing a variety of photonic sensors and devices, yet the deployment of such sensors strongly relies on dedicated laser sources. These lasers theoretically should exhibit continuous wave (CW), tunable, single-

frequency emission with at least a few milliwatts of output power near room temperature (RT), but technical realization of the devices complying with these requirements remains difficult.

In our talk, we will review the development of MWIR interband lasers, i.e., laser diodes (LDs), interband cascade lasers (ICLs), and vertical-cavity surface-emitting lasers (VCSELs) with the emphasis on LDs. First, we will briefly review both old and new material systems used in the development of the MWIR lasers, including interband emitters based on GaSb, InP and InAs, highly mismatched alloys and lead-salt and transition-metal-doped II-VI materials. Many of these emitters employ traditional band structure engineering along the epitaxial growth direction, including separate confinement heterostructures, quantum wells (QWs), strain-balancing, digital alloys and superlattices (SLs). We shall also very briefly discuss the potential for MWIR emitters using utilizing three-dimensional (quantum dot, QDs) confinement for intersubband transitions and so-called type-II transitions, as well as lead-salt epitaxial dots and new classes of nanocrystal and colloidal quantum dots with MWIR. Finally, we will concentrate on the achievements in the development of MWIR lasers at Ioffe Institute, where these technologies have been developed for many decades. The material systems considered in this part of the talk will include well-known III-V semiconductors and also, II-VI materials, such as HgCdTe, which are usually considered less suitable for development of the MWIR emitters and are mostly used in the photodetector technology. We will also present a brief outlook for the next generation of semiconductor lasers for mid-wavelength infrared range, and discuss both the challenges and opportunities for these emitters.

S02-23 Mid-infrared stimulated emission and optical properties of InAs(Sb)-based LED heterostructures

A. Semakova[1], K. Mynbaev[1,2], N. Bazhenov[1], M. Ruzhevich[2]
[1] Ioffe Institute, St Petersburg, Russia
[2] ITMO University, St Petersburg, Russia
semakova@gmail.com

There has been much interest in the studies of the properties of infrared devices based on narrow-bandgap InAsSb alloys. These materials are suitable for opto– and photoelectronic devices operating in the mid-infrared range of the spectrum (2-6 μm), where optical absorption bands of many important chemicals (CH_4, CO_2, NO_2, etc.) are located. Detection systems of such substances are in demand for laser diode spectroscopy of gases, environmental monitoring and non-invasive medical diagnostics.

It is known that InAs possesses excellent emitting properties due to its direct bandgap and strong overlapping of wave functions of electrons and holes. In a number of experiments, enhanced 'stimulated' emission was observed in InAs(Sb)-based heterostructures designed to be used in light-emitting diodes (LEDs). We have studied electroluminescence (EL) of LED heterostructures based on $InAs_{1-x}Sb_x$ films (molar fraction of InSb in the active region x_{InSb}=0-0.09), and multi quantum-well (MQW) structures in the temperature range T=4.2–300 K. The growth of the heterostructures was performed by MOCVD on n^+-InAs substrates. On top of the active layer, a wide-bandgap InAsSb(Ga,P) barrier was formed. At low temperatures 4.2–100 K, stimulated emission was observed in the spectral region 3.0–3.8 μm. For some structures the EL spectrum demonstrated a clearly pronounced mode structure at T ~77 K. With increasing temperature, a transition from stimulated to spontaneous emission was observed, while the temperature of this transition decreased with an increase x_{InSb} in $InAs_{1-x}Sb_x$ active region. For the structure with MQW, a very weak temperature dependence of EL peak was observed at T>150 K, which make it attractive for fabricating temperature-resistant gas sensors. We have studied the effect of the barrier height on the value of threshold current and on the optical power of the

LEDs. The optical cavity was found to be formed normal to the growth plane, which makes such structures promising for the development of mid-infrared vertical-emitting lasers.

S02-24 Low-charged nanostructured metal on a semiconductor for antibacterial application

D.A. Zayarny [1], L.F. Khaertdinova [1], A.A. Nastulyavichus [1], E.R. Tolordava [1,2], S.I. Kudryashov [1]
[1] P. N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia
[2] N.F. Gamaleya Federal Research Centre of Epidemiology and Microbiology, Moscow, Russia
Lilianakhr@yandex.ru

Search for new antibacterial agents has become one of the most popular agenda in nanotechnology. One of these areas of research was the development of antibacterial protective coatings based on metallic films. The correlation of bactericidal efficiency and such a physical parameter as the work of the electron exit for nanoporous captivity made it interesting to try charging them.

The structure was formed on a thin 380 μm plane-parallel n-type single-crystal silicon wafer with a double-sided 500 nm metal (Ag, Au, Pd of 99.99% purity) coating deposited on it by magnetron sputtering in an argon atmosphere. A two-dimensional microscale dot pattern was formed on one side of the metalized silicon wafer by laser ablation in air pulsed from a near-IR femtosecond fiber laser. When an electric current flows through such a laser-treated metal film, a two-dimensional microscale periodic magnetic field is formed near it, which quickly dissipates with distance from the film surface.

The culture of Salmonella enterica was taken for antibacterial tests. A stable high antibacterial effect at a level exceeding five orders of magnitude CFU / ml was detected at exposure times of bacterial cultures from 15 minutes or more, regardless of the polarity of the applied voltage for all metals. A decrease in the exposure time to less than 10 min led to a rapid disappearance of the bactericidal properties of the structures under study.

Thus, a new highly effective bactericidal material was obtained based on electrically weakly charged nanostructured metal films on the surface of crystalline silicon.

S02-25 Long term experience of laser technologies application for studying blood microrheology and microcirculation

A. Priezzhev[1], A. Lugovtsov[1], P. Ermolinskiy[1], A. Semenov[2], Kisung Lee[3], S. Nikitin[1], Yu. Gurfinkel[4]
[1] Department of Physics, Lomonosov Moscow State University, Moscow, Russia
[2] Department of Biology, Lomonosov Moscow State University, Moscow, Russia
[3] Center for Soft and Living Matter, Institute of Basic Science, Ulsan, Korea
[4] Medical Research and Education Centre, Lomonosov Moscow State University, Moscow, Russia
avp2@mail.ru

We describe our more than 20-years long experience in designing and implementing laser technologies (laser tweezers, diffuse light scattering, laser diffractometry and digital capillaroscopy) for studying blood microrheology and microcirculation. We evaluate the feasibility of these techniques to assess microrheological effects of various molecular mechanisms affecting erythrocyte aggregation and deformability. In particular, we show that laser tweezers and diffuse light scattering allow for assessing the changes in erythrocyte aggregation in whole blood samples and cell suspensions both on the level of single cells and on the level of large ensembles of cells. Application of these methods *in vitro* enable one to study the mechanisms of erythrocyte aggregation because they are sensitive to changes in the medium surrounding the cells (i.e., blood plasma, serum or model solutions of blood plasma proteins) and to changes in the cellular properties of the erythrocytes (i.e., effects on the cell membrane due to glycoprotein inhibition). Using the laser diffractometry technique we are able to assess the distribution of the erythrocytes in sizes and deformabilities. Using digital capillaroscopy we are able to monitor *in vivo* the alterations of blood flow parameters on the microcirculatory level where the major exchange of gases between blood and tissues takes place. We have been applying all these techniques to monitor the alterations of blood microrheology and microcirculation in patients suffering from such socially important diseases as arterial hypertention and diabetes mellitus.

This work was supported by the Russian Science Foundation (Grant No. 22-15-00120) and performed according to the Development program of the Interdisciplinary Scientific and Educational School of Lomonosov Moscow State University «Photonic and Quantum technologies. Digital medicine»

S02-26 Developing a lightsheet-based cytometer for the whole undiluted blood with magnetic separation of objects

D. Bratashov[1], O. Grishin[1], I. Kozhevnikov[1], O. Sindeeva[2], O. Mayorova[1], R. Verkhovsky[1], A. Ermakov[1], M. Makarkin[1], E. Prikhozhdenko[1]

[1] Saratov state university, Laboratory of Biomedical photoacoustics, Saratov, Russia

[2] Skolkovo Institute of Science and Technology, Skolkovo, Russia

dn2010@gmail.com

The development of flow cytometry technologies allow us to obtain a lot of valuable information about cells and other objects in the patient’s blood. However, if working the extremely rare populations, even the largest possible blood sample size is too small to catch enough objects for the analysis. It can sample no objects at all if we start sampling in the wrong moment of time. But these rare objects could provide valuable diagnostic insights about severe pathologies. It can be circulating tumor cells that form the metastases, clots-forming aggregates of blood cells, bacteria and other pathogens in acute blood infections and so on. In vivo flow cytometry techniques can solve this problem by measuring the whole blood volume in the single point of blood circulation, usually measuring in some large vessel. The several in vivo cytometer constructions have been developed up to now. The most well-working now are the techniques of photoacoustic flow cytometry and multiple-scattering fluorescence measurements. In our model we extract the blood flow between two large vessels into the external flow cell connecting the arterial vessel and large vein, thus returning the sampled blood inside the body without damaging it. We use multi-wavelength fluorescent lightsheet microscopy to detect and measure objects in the whole undiluted blood inside the flow cell. The objects can be also separated from the flow by the magnetic separator placed nearby the measured area. The developed technique was tested with the artificially-created blood flows (phantoms) and the blood flow of the laboratory animals with the injected targeted drug delivery fluorescent containers. The proof-of-concept experiments proves that the scheme we developed is working, but it requires some fine-tuning of construction parameters. From the all objects injected into the blood flow of the animal 60% were successfully detected and counted by the scheme.

This work is supported by RSF project 18-19-00354.

FT-S02-1 Red blood cell behavior in the laser trapping beam of optical tweezers

P. Ermolinskiy, A. Lugovtsov, A. Priezzhev
Department of Physics, Lomonosov Moscow State University, Moscow, Russia
ermolinskiy.pb15@physics.msu.ru

Laser tweezers allow for the trapping and manipulation of living cells without mechanical contact, thus they are widely used to perform studies on single cell level. In this work, the effect of a sharply focused laser beam with a wavelength of 1064 nm and a power of 10-160 mW on red blood cells (RBC) during their trapping by laser tweezers has been investigated. It is found that the shape of RBC, changes after optical trapping and takes the pear-shape in less than 5 s. No further changes occur if the duration of trapping is shorter than 5 min and laser beam power is less than 60 mW. At beam powers over 80 mW, the RBC folding starts after around 1 min of trapping time, and at power over 100-150 mW, the RBC membrane breaks in 1-3 min after optical trapping. It is also found that the repeated short-term trapping of RBC in the optical trap changes the deformation properties of the membrane, i.e., the membrane becomes stiffer. The obtained results are important both for understanding the mechanisms of interaction of the laser beam with RBC and for optimizing the methodology of optical experiments, especially for measuring the deformation properties of the RBC membrane with laser tweezers.

This work was supported by the Russian Science Foundation (Grant No. 22-15-00120) and performed according to the Development program of the Interdisciplinary Scientific and Educational School of Lomonosov Moscow State University «Photonic and Quantum technologies. Digital medicine».

FT-S02-2 Optimization of parameters of 980-nm laser hair extension

V.M. Ermolaev, Yu.V. Fyodorova
ITMO University, St. Petersburg, Russia
v_m_ermolaev@mail.ru

The paper investigates the possibility of extension (connection) of human hair by a moving laser source with a radiation wavelength of 980 nm without solder. Radiation with a given wavelength is absorbed well enough by the hair, which makes it possible to modify its structure and make a connection.

Computer optical and thermophysical models of human hair have been created in the TracePro Expert and COMSOL Multiphysics programs respectively to optimize exposure of hair to laser radiation for the purpose of their extension. The simulation of light propagation in a computer optical model of hair and temperature distribution in a computer thermophysical model of hair as a result of continuous laser exposure with a wavelength of 980 nm was performed. The Arrhenius function distribution was calculated, that allowed to evaluate the volume of thermal damage to the biological tissue.

When optimizing the parameters of laser hair extension, it was necessary to meet the following conditions:

1. to reach the melting point of the hair;
2. to achieve the value of the Arrhenius function less than one, since with the value of the Arrhenius function no more than one, it is possible to achieve a successful hair connection without irreversible changes.

The parameters that changed during optimization were radiation power and scanning speed. Combinations of these values, under which the described conditions are met, are optimal.

To test the possibility of hair extension and the optimal parameters obtained during computer modeling, experiments were carried out using an Alta-ST diode laser with a wavelength of 980 nm operating in continuous mode in the required power range. The radiation was delivered via optical fiber moving along the sample fixed in the holder at different speeds. A comparison of computer simulation and experiment was carried out.

The study is funded by RPMA grant of School of Physics and Engineering of ITMO University.

FT-S02-3 Investigation of active laser delivery of photosensitizing drugs for the treatment of mycoses

A.V. Belikov, A.D. Kozlova, Yu.V. Fyodorova, S.N. Smirnov

ITMO University, St. Petersburg, Russia
yvsemyashkina@mail.ru

Mycosis is a common disease of the skin and its appendages, including the nail. Since the nail is a barrier to drugs, the rate and efficiency of drug delivery can be increased by creating micropores in the nail. Such micropores can be created by laser radiation, moreover, an addition laser action may be required to deliver water-based drugs. This type of drug delivery method is called active laser delivery. It should be noted that the laser radiation can affect the conformational state of the drug during delivery and change its photodynamic efficiency. Thus, the purposes of current study were to research the active Er:YLF-laser delivery of modern chlorine-containing photosensitizing drugs and to investigate extinction spectra and conformational states of the drugs before and after laser exposure.

In the study, modern chlorine-containing photosensitizing drugs "Chloderm 660" and "Chloderm 660 with hyaluronic acid" (Russia) were used. Er:YLF-laser pulses ($\lambda = 2.81$ µm) with energy from 1.0 to 4.0 mJ at pulse repetition rate of 30 Hz were used to create micropores with a diameter of 200 ± 10 µm in the nail plate and to deliver photosensitizing drugs under the nail plate. Active laser delivery of a chlorine-containing photosensitizing drugs with its various concentrations in water (0.65÷100 %) was carried out immediately after nail plate microporation by applying laser radiation with the same parameters as during microporation. It was established that the rate of active laser delivery of "Chloderm 660" and "Chloderm 660 with hyaluronic acid" decreases with increasing the drug concentration in water.

The extinction spectra of studied drugs in the spectral range 400÷900 nm were studied before and after Er:YLF-laser exposure. The influence of the laser radiation on the conformational state of chlorin e6 in the studied drugs was found to be insignificant.

This work was supported by the Russian Science Foundation (Grant No. 22-25-00468).

FT-S02-4 Optimization of endovasal laser treatment based on the analysis of the IR signal accompanying heating of a titanium-containing optothermal fiber converter

Do Thanh Tung, A.V. Belikov, Yu.V. Fyodorova
ITMO University, St. Petersburg, Russia
tungifmo@gmail.com

Possibility of controlling the temperature of the vein wall during endovasal laser treatment (EVLT) is investigated. The desired medical effect is achieved by the coagulation of the vein wall at the temperature of 80 °C. Heating of the vein wall is mainly due to the efficient conversion of laser radiation into heat in an optothermal fiber converter located at the output end of the optical fiber placed inside the vein. Titanium-containing optothermal fiber converter (TOTFC) is very promising for EVLT application due to its high efficiency in converting laser energy into thermal energy and smooth shape that excludes perforation of the vein wall when the fiber moves inside the vein.

At present study a computer thermophysical model of the EVLT process with TOTFC has been developed in the COMSOL Multiphysics 5.4 program («COMSOL Inc.», USA). The dependence of the TOTFC temperature and the temperature on the vein wall on the traction speed of the optical fiber in the range of 1-7 mm/s with an average laser power of 8-14 W, a laser radiation wavelength of 980 nm, and a constant internal diameter of the vein of 5 mm has been numerically explored. During the EVLT process, TOTFC heats up and emits an IR signal. In accordance with Planck's formula, the dependence of the spectral luminosity density of a blackbody simulating TOTFC (IR signal) on its temperature has been determined. The spectral luminosity density in a wide range (within the wavelength of 0.4-20 μm), as well as in spectral ranges limited by the transmission of the quartz fiber and the sensitivity of Ge and PbS photodetectors was defined. The results obtained can be useful in developing laser medical equipment and materials for use in vascular surgery at endovasal laser treatment.

This work was supported by the Russian Science Foundation (Grant No. 22-25-00468).

FT-S02-5 Investigation of the influence of the intensity and duration of visible range light exposure on the absorption spectrum of chlorine-containing photosensitizing drugs

Yu.V. Fyodorova, A.V. Belikov, A.D. Kozlova, S.N Smirnov
ITMO University, St. Petersburg, Russia
yvsemyashkina@mail.ru

Photodynamic therapy is a promising method of treatment in many areas of medicine, including oncology, immunology, dentistry, dermatology, and others. The method of photodynamic therapy consists in the fact that a photosensitizing drug penetrates into the tissues, followed by irradiation with light with a wavelength absorbed by the photosensitizing drug. The choice of a photosensitizer plays an important role in photodynamic treatment. Currently, chlorine-containing photosensitizers of the second generation based on chlorin e6 are considered optimal. In the process of photodynamic therapy, it is possible to change the conformational state of the photosensitizer and, as a result, change the course of treatment.

At present study the effect of resonant (with a wavelength 660 nm and 405 nm) and non-resonant (with a wavelength 450 nm) light action on the conformational state of chlorine-containing photosensitizing drugs was carried out. Resonant exposure involves irradiation with a wavelength close to the peak of the absorption band of the drug, while non-resonant exposure excludes this process partially or completely. The absorption spectra in the region of 190-900 nm and the conformational states of the photosensitizing drug "Chloderm" (Russia) with or without hyaluronic acid before and after visible range light exposure was analyzed. Non-resonant light exposure should lead to a decrease in the absorption of the photosensitizing drug during the exposure at the excitation wavelength to a lesser extent than resonant light exposure. In this case, during a treatment, for example, a fungal disease in dermatology, to compensate for the loss of photodynamic activity of the drug during non-resonant exposure, less light intensity at the excitation wavelength will be required than in the case of the resonant. It will avoid unnecessary trauma to the skin while maintaining high efficiency of photodynamic action, i.e., will increase the safety of photodynamic therapy.

This work was supported by the Russian Science Foundation (Grant No. 22-25-00468).

FT-S02-6 Refractive properties of healthy and pathologically altered tissues of the kidney and breast, measured at selected laser wavelengths in the visible and near-IR ranges

E. N. Lazareva [1,2], N.A. Shushunova [1], V.V. Tuchin[1,2,3], E.A. Geinina[1,2]
[1] Saratov National Research State University named after N.G. Chernyshevsky Saratov, Russia
[2] National Research Tomsk State University, Tomsk, Russia
[3] Institute of Precision Mechanics and Control RAS , Saratov, Russia
lazarevaen@list.ru

Breast cancer and kidney cancer are the two most common types of cancer in the world, accounting for about 30% of all cancers, according to statistics from the World Health Organization. The main methods for diagnosing and assessing the degree of oncological lesions are biopsy and analysis of histological sections. An urgent task at present is the development of fast and minimally invasive diagnostic methods that allow detecting pathological changes in tissues at an early stage. Optical methods have such possibilities. For this, various methods have already been developed that are used without classical signs, based on both inelastic (spectroscopic) and elastic (scattering) interactions of light and tissues. However, an obstacle to the use of these methods in medicine is insufficient knowledge of the optical properties of tissues, in particular, the refractive index, as one of the most important optical parameters.
In this study, for the first time, data on the refractive index of healthy and pathologically altered tissues of the mammary gland and kidneys of mice were obtained in the spectral range of 480-1550 nm. The dispersion dependences and Raman spectra were analyzed and the obtained results were compared. For the dispersion dependences, the coefficients were obtained using the Sellmeier formula, which make it possible to restore the value of the refractive index in the range of 480–1550 nm.

The study was carried out with the financial support of the Russian Foundation for Basic Research within the framework of scientific project No. 20-52-56005

FT-S02-7 Study of the effect of photodynamic exposure on the optical characteristics of healthy and pathological tissues

E.N. Lazareva,[1,2] D.K. Tuchina,[1,2] A.A. Doronkina,[1] R.A. Anisimov,[1] R.A.Verkhovsky,[1] M.V. Lomova,[1] A.M. Mylnikov,[3] N.A. Navolokin,[3] V.I. Kochubey,[1] I.Yu. Yanina[1,2]
[1] Research Educational Institute of Optics & Biophotonics, Saratov National Research State University named after N.G. Chernyshevsky, Saratov, Russia)
[2] Interdisciplinary Laboratory of Biophotonics, National Research Tomsk State University, Tomsk, Russia
[3] Saratov State Medical University named after V. I. Razumovsky, Saratov, Russia
lazarevaen@list.ru

Photodynamic therapy (PDT) is a non-surgical method of cancer treatment, which is currently being intensively used with high efficiency. The experience of the clinical application of PDT shows that this method belongs to one of the promising areas in modern clinical oncology. The necessary components of PDT are a photosensitizer (PS), localized in the area of the disease, and a source of radiation of the appropriate wavelength. PS include dyes such as methylene blue, rose bengal, organic molecules - chlorin e6, porphyrin and phthalocyanine derivatives, various inorganic compounds. The emission range of the source is limited by the PS absorption spectrum (<600 nm), which, as a rule, does not intersect in the spectrum with the "biological tissue transparency window" that overlaps the region of 750-1000 nm. This determines the shallow depth of therapeutic action. However, there are some problems with the use of PS, such as their non-specific distribution in the body and the hydrophobicity of some drugs. For example, during PDT with preparations based on chlorin e6 and photosens after intravenous administration, the same PS content is observed in tumor structures and in the wall of unchanged vessels 3-4 and 1-2 hours after administration, respectively. As a result, there is a need to use FS carriers. In particular, such carriers can be particles whose surface is functionalized by the addition of PS, ligands that provide water compatibility. Also, targeting agents can be attached to the surface of the nanoparticles, allowing them to be selectively directed to certain cells. The creation of functionalized nanoparticles with PS makes it possible to increase the effectiveness of the therapeutic effect. In this work, a comparative analysis of the optical characteristics of healthy and pathological tissues after photodynamic exposure with the introduction of a classic drug without and with the use of targeted delivery was carried out.

The study was supported by RSF grant no. 21-72-10057, https://rscf.ru/project/21-72-10057/.

FT-S02-8 Inactivation of coronaviruses under the UVA LEDS radiation

A.A. Fronya[1,2], V.A. Gushchin[3], L.I. Russu[3], E.A. Cheshev[1,2], A.V. Kabashin[2,4], I.N. Zavestovskaya[1,2]

[1] P.N. Lebedev Physical Institute, RAS, Moscow, Russia
[2] National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Moscow, Russia
[3] National Research Centre for Epidemiology and Microbiology named after the Honorary Academician N. F. Gamaleya of the Ministry of Health of the Russian Federation, Moscow, Russia
[4] Aix Marseille Univ, CNRS, LP3, Campus de Luminy, Marseille, France
fronyaaa@lebedev.ru

The investigation of the SARS-CoV-2 virus showed its high contagiousness and long survivability on various types of surfaces. To inhibit the spread of the virus in the human population, the challenge is to develop means of safe and environmentally friendly treatment of the virus transfer vectors. An analysis of the works showed that researchers consider ultraviolet radiation as such means. Radiation from the UVC range is not safe radiation for humans, and is not applicable in his presence. UVA radiation is the safest for humans, but the effects of exposure on humans, as well as on pathogens, are determined by the dose of radiation received.

The present work is devoted to investigation of two types of β-coronaviruses (bovine and SARS-CoV-2) sensitivity to UV radiation. Studies on virus-cell systems were carried out using proven protocols at reference center for coronavirus infection of the Gamaleya National Research Center of Epidemiology and Microbiology. In the experiments LEDs with wavelengths and different UV ranges were used - UVC (270 nm), UVB (308 nm), UVA (325, 340, 371, 385, 395, and 401 nm).

At the first stage, experiments were carried out with bovine coronavirus, selected for research as a model virus with a lower degree of pathogenicity compared to SARS-CoV-2. The experiments gave a positive result. At the second stage, experiments were carried out in the "red zone" with SARS-CoV-2.

In the work, the effective inactivation of β-coronaviruses (bovine and SARS-CoV-2) by UVA radiation and dose-dependent decrease in the infectious titer of the virus were shown. UVA radiation provided a reduction in virus titer by at least 2 orders of magnitude, in accordance with the Recommendations of the Pharmacological Committee of the Russian Federation it characterizes as an antiviral means. For example, reduction in virus titer by 2 orders of magnitude was achieved at 6.4 J/cm^2 of 405 nm LED. This is practically important results for the development of technologies for disinfection of coronaviruses in the rooms.

This work was supported by the Russian Foundation for Basic Research (Scientific Project No. 20-04-60292).

FT-S02-9 Antibacterial surfaces, their properties and methods of preparation

E. Lovushkina, K. Mikhailova, G.V. Odintsova, Yu. Karlagina

ITMO University, St. Petersburg, Russia

elizaveta.lovushkina.0@mail.ru

To date, there is a need to impart antibacterial properties to various types of implants, as well as medical instruments. A wide range of such medical devices are made of titanium and its alloys. The most common way to impart antibacterial properties to titanium surfaces is the application of antibiotics and other chemical compounds. However, this method has a number of disadvantages, such as the development of immunity in bacteria to a specific type of antibiotic, as well as the fragility and rapid erasability of the layer when used. We also propose a technology for creating an antibacterial coating using laser exposure to the surface of the product.

To conduct an experimental study, we used samples made of titanium alloy VT6 and a MiniMarker-2 laser complex based on a pulsed fiber ytterbium laser (λ = 1.064 microns; P = 20 W; τ = 200 ns). The processing was carried out by line-by-line scanning of the surface of the product with a laser beam. When exposed to laser radiation on the surface of titanium at conditions below the boiling threshold, an oxide layer appears on the surface in the phases of rutile, anatase, and higher oxides, which, after irradiation with ultraviolet light, exhibits antibacterial properties. We conducted studies on Streptococcus oralis bacteria, which showed high bacterial resistance of the treated surface.

The study was supported by the Russian Science Foundation (project № 20-62-46045).

FT-S02-10 Laser formation of an antibacterial surface on the jaw membrane

A. Zavyalova, M. Radaev, Yu. Karlagina, G.V. Odintsova

ITMO University, St. Petersburg, Russia

znastiaz2002@gmail.com

Osteoplasty is an operation to build up bone tissue, which allows you to create a bed sufficient for implant placement. In modern dentistry, barrier membranes are widely used for osteoplasty, often representing a thin smooth or mesh titanium plate, the shape of which is shaped by the doctor himself during the operation. These membranes have a number of disadvantages: during the installation of the plate, sharp folds and sharp edges can form that injure the gums and provoke infections, and bacterial colonies can form on the surface of the membrane, causing suppuration and rejection. To avoid these problems, we propose to use individual membranes with a laser-structured surface, which have a number of advantages: reduced operating time, restoration of the anatomy of the original bone tissue, and bactericidal properties.

Until recently, the process of creating an individual titanium membrane for osteoplasty was quite laborious and lengthy, requiring a lot of manual labor at the stage of designing a 3D membrane model based on CT data. We propose to optimize the process of creating both a digital model of membrane and the process of post-processing of the created product by creating and applying a neural network, as well as laser processing technologies. Having created and trained such a neural network, we will be able to get a finished 3D model based on the results of a CT image in a few minutes, thereby reducing this stage by 2-3 times. It is also necessary to determine the optimal parameters of laser exposure for the formation of an oxide coating on the membrane surface, which will contribute to its better biocompatibility and bactericidal activity. Since the membrane surface is complex and uneven, we suggest using additional equipment of the laser technological complex - a rotator, for uniform surface treatment.

Authors acknowledge the support of the Ministry of Science and Higher Education of the Russian Federation research agreement No. 075-11-2021-045 of 24.06.2021, project title "Development of high-tech production of equipment and technologies for laser functionalization of the surface of medical products" (within the framework of decree of the Government of the Russian FederationNo. 218 of 09.04.2010).

FT-S02-11 Photodynamic inactivation of bacterial clinical isolates from the tracheobronchial tree using methylene blue

E.V. Akhlyustina[1], I.G. Tiganova[3], G.A. Meerovich[1,2], I.D. Zulufova[4], V.D. Parshin[4], Yu.M. Romanova[3,4], V.B. Loschenov[1,2]
[1] National Research Nuclear University "MEPhI", Moscow, Russia
[2] Prokhorov General Physics Institute of the Russian Academy of Sciences, Moscow, Russia
[3] Gamaleya National Research Center of Epidemiology and Microbiology, Moscow, Russia
[4] I.M. Sechenov First Moscow State Medical University, Moscow, Russia
Katya_ahlyustina@mail.ru

The treatment of patients after mechanical ventilation of lungs suffering from a multi-species infection of the tracheobronchial tree can be complicated. As a multi-species infection result, cicatricial stenosis of the trachea of purulent-inflammatory infectious genesis or infected tracheal stenosis (ITS) may occur. The goal was to estimate the optimal methylene blue (MB) concentration and light dose for antibacterial photodynamic therapy. In this work, we studied the possibility of photodynamic inactivation of pathogenic microbiota typical for patients with ITS using MB. The optical absorption of MB at 664 nm shows linear dependence from its concentration in the wide range, which adheres to Beer's law for non-aggregated photosensitizers. Comparing this dependence with the features of the absorption and fluorescence spectra of MB in these concentration ranges, it can be assumed that the decrease in the efficiency of MB fluorescence at higher concentrations is a result of aggregation, which is relatively weak at concentrations below 30 μM, but increases in the range of 30–50 μM.

The study of the photodegradation rate allows evaluating the light dose that can be used for photodynamic inactivation of bacteria without a significant decrease in efficiency due to the photodegradation of photosensitizer molecules. The rate of photodegration was estimated from the decrease in the fluorescence intensity depending on the light dose density. The results show high photostability of MB—the photodegradation of its molecules does not exceed 30% at irradiation doses up to 30 J/cm^2. It was shown that 30 μM of MB at a light irradiation dose of 25 J/cm^2 and incubation with MB for 15 min was sufficient to completely inactivate bacteria found in the tracheobronchial secretions of patients with ITS.

FT-S02-13 Complex model of accumulative laser heating of metal, semiconductor, and hard biological tissue

A.A. Shamova, D.S. Polyakov, G.D. Shandybina
ITMO University, Saint Petersburg, Russia
alex.shamova94@gmail.com

Ultrafast laser micromachining is usually characterized by excellent quality and control at low processing speeds. One of the factors limiting the increase in processing speed for industrial applications is the heat accumulation, since at high pulse repetition rates it can lead to the formation of: microcracks in brittle dielectrics, re-solidified melt layers in metals and semiconductors, and large heat-affected zones in hard biotissues. Therefore, the problem of express analysis of 3D accumulative heating of various materials is actual. Despite significant differences in the structure of solids and hard biotissues, analytical methods of the theory of thermal conductivity can be used in the development of corresponding models.

The report presents for discussion analytical formulas for the temperature after exposure to N laser pulses at the time of arrival of the N+1th pulse obtained using the Green's function method for heat sources with different spatial forms typical for practically important cases of laser heating taking into account three-dimensional heat removal. For the point source, all spatial dimensions are less than the scale $l_T = \sqrt{4a/f}$ (*a* is the thermal diffusivity of the material, *f* is the pulse repetition rate), for the source-thread, transverse dimensions are less than l_T, for the source-disk, size in depth is less than l_T. It is shown that the point source approximation is applicable for metals in a wide range of repetition rates. For a photoexcited semiconductor, the point source approximation is applicable at low repetition rates, and as the repetition rate increases, it is necessary to use the source-disk approximation. For a hard biotissue, at low repetition rates the point source approximation is applicable, and at high repetition rates the source-thread approximation can be used. Simple dependences of the residual temperature on the number of pulses and their repetition rate are obtained. The case of heating by a source with a Gaussian transverse profile exponentially decreasing with depth is also considered for arbitrary values of the beam radius and the laser penetration depth.

The proposed analytical estimates can be useful for optimizing and analyzing technological regimes of high-performance laser processing of a wide class of materials.

The reported study was financially supported by the Ministry of Science and Higher Education of the Russian Federation research agreement No. 075-11-2021-045 of 24.06.2021 (within the framework of decree of the Government of the Russian Federation No. 218 of 09/04/2010).

FT-S02-14 Mid-IR laser inactivation of pathogenic bacteria

S.N. Shelygina[1], V.O. Kompanets[2], E.R. Tolordava[1,3], ,S.I. Kudryashov[1], Y.K. Yushina[4]

[1] Lebedev Physical Institute RAS, Moscow, Russia

[2] Institute of Spectroscopy RAS, Troitsk, Russia

[3] Gamaleya National Research Center for Epidemiology and Microbiology, Moscow, Russia

[4] V.M. Gorbatov Federal Scientific Center for Food Systems RAS, Moscow, Russia

shelyginasn@lebedev.ru

The emergence of new types of pathogenic microorganisms and the development of their resistance to antibiotics are the reason for the search and development of methods to combat them. Limitations of ultraviolet radiation, traditionally used for disinfection, in view of its carcinogenicity to human cells, lead to the study of the bactericidal activity of other radiation ranges. Thus, the mid-IR radiation is the most promising, since this range contains the characteristic absorption bands of the main structures of bacterial cells that are fundamentally important for their proliferation: C=O, C-N vibrations of amide groups of proteins and nucleic acids in the spectral range of 1500 – 1600 cm^{-1} (~ 6 μm) and C-H vibrations of lipids in the spectral range of 2800 – 3000 cm^{-1} (~ 3 μm). Inactivation by mid-IR radiation is a non-contact, environmentally friendly method. In addition, mid-IR radiation does not have the disadvantages of UV irradiation such as carcinogenicity.

In this work possibility of using of mid-IR femtosecond and nanosecond laser irradiation to inactivation of pathogenic microorganisms was studied. Micrometer-thick layers of Pseudomonas aeruginosa were prepared on fluorite substrates and treated by mid-IR femtosecond and nanosecond laser irradiation that was tuned to achieve the selective excitation of either the stretching C-H vibrations of lipides (3 μm), or stretching C=O, C-N vibrations (6 μm) of amide groups of bacteria. It was shown that 3-μm laser irradiation evenly heats the bacterial cell meanwhile 6-μm laser irradiation leads to selective heating and subsequent denaturation of lipids and proteins in the cell membrane and intra-cell nucleic acids. Viability assays demonstrated more inactivation effectiveness for 6-μm laser treatment. Results of microbiological investigation showed a decrease of the number of colony-forming units depending on peak intensity of laser pulses.

The research was supported by the Ministry of Science and Higher Education of the Russian Federation (Project No. 075-15-2020-775).

FT-S02-15 Analysis of efficiency of photodynamic teeth bleaching assisted with methylene blue and chlorine-containing photosensitizing drug

V.S. Minko, Yu.V. Fyodorova
ITMO University, St. Petersburg, Russia
minko@itmo.ru

With the development of aesthetic dentistry, teeth bleaching became the most common aesthetic dentistry procedure. One of the most progressive methods of teeth bleaching is photodynamic teeth bleaching (PDTB), which is performed by applying a bleaching agent - a photosensitizer (PS) to the teeth and irradiating it with the radiation of laser or LED devices. Traditionally, gels based on a concentrated hydrogen peroxide are used as a bleaching agent, which negatively affects the sensitivity of the teeth after the bleaching procedure.

Various PSs could be used as more comfortable bleaching agents for PDTB. Chlorine e6-containing drugs are mostly mentioned in the articles as PS applicable for the photodynamic bleaching. The PDTB procedures without the use of hydrogen peroxide have great potential, but there are almost no articles on this topic in the literature available to date.

Methylene blue (MB) is widely used for various tasks in dentistry - mainly as a drug for visualization of enamel demineralization or as an antiseptic. The antibacterial properties of MB can also be enhanced by photodynamic therapy. Despite that the properties of MB are well-known, the use of MB as a bleaching agent for PDTB has not yet been considered in the literature.

The aim of performed study was the analysis of the effectiveness of PDTB assisted with an aqueous solution of MB and chlorine e6-containing photosensitizing drug "Chloderm 660". The dependence of the depth of penetration of "Chloderm 660" drug into the hard tissues of the tooth on time has been studied. PDTB was performed on ex vivo tooth samples. The results of the study were evaluated using the LAB color model and the 3M Filtek Z250 Shade Guide.

FT-S02-16 Analysis of diffraction patterns in laser ektacytometry of erythrocytes

M.S. Lebedeva, E.G. Tsybrov, S.Yu. Nikitin
M. V. Lomonosov Moscow State University, Moscow, Russia
2mary.lebedeva@gmail.com

The deformability of erythrocytes, understood as the ability of blood cells to reversibly change their shape under the action of external forces, is an important rheological characteristic of blood. This parameter is difficult to measure, but important for the diagnosis and treatment of many diseases, including ischemic and infectious diseases, diabetes mellitus, malaria, sickle cell anemia, hereditary spherocytosis, sepsis, and others. There are commercial devices for measuring the deformability of erythrocytes - LoRRca (Holland) and RheoScan (Korea). These devices measure only the average deformability of erythrocytes in the studied blood sample, while the distribution function of erythrocytes in deformability is also of interest. In our works, algorithms for measuring the width and asymmetry of the distribution of erythrocytes in deformability are proposed. However, the problem of calibrating the laser ektacytometer remains, which consists in measuring the light intensity on the isointensity line chosen for measurements with respect to the intensity of the central maximum of the diffraction pattern. This task is complicated by the fact that the center of the diffraction pattern is illuminated by a direct laser beam. Therefore, it is expedient to search for indirect calibration methods that do not require photometry of the diffraction pattern in its central part. One such method is proposed in this paper. Here we present a calibration equation that relates the geometric parameters of the isointensity line of a diffraction pattern to the level of light intensity on this line. A simplified algorithm for measuring the spread of erythrocytes in deformability is proposed, which is applicable to blood samples with a symmetrical distribution function in deformability. The algorithm does not require measurement of the relative light intensity on the isointensity line selected for measurements. As input data, only the geometric parameters of the isointensity line are needed: the coordinates of the polar and characteristic points, as well as the radii of curvature of the line at the polar points.

FT-S02-17 One-stage processing technology of laser structuring of the dental implant and the preclinical study results

Yu. Karlagina, M. Radaev, V. Veiko, G. Odintsova, V. Romanov
ITMO University, St. Petersburg, Russia
ionhcik@rambler.ru

A dental implant is a multicomponent structure, the success and durability of which can be improved many times by giving each component certain functional properties. For example, the implant root requires a microrelief providing osteoinductive properties, the neck requires a relief with osteoinductive and antibacterial properties, and the abutment needs a coating with both antibacterial properties and biocompatible for epithelial cells. Existing processing methods often do not allow to impart several properties of the surface of a medical device at the same time, are complex and multi-stage, require consumables, which in some cases provoke deterioration of biocompatible properties. We are developing a number of technologies for the modification of various areas of the implant based on the use of laser radiation. These technologies do not require consumables, are single-stage and eco-friendly.

To implement technologies for single–stage processing of functional areas of a dental implant, we used the MiniMarker-2 laser complex based on a pulsed fiber ytterbium laser. For the experiments, products made of Ti-Al-V titanium alloy, widely used in the manufacture of medical implantation systems, were used.

Based on the results of a series of in vitro and in vivo experiments, the most favorable design for each of the functional zones of the implantation system was determined. Thus, the relief in the form of grooves was chosen for the screw part (apex) - it promotes faster cell proliferation and differentiation, as well as tighter contact of the newly formed bone with the implant surface. For the neck of the implant, a biomimetic relief is proposed that repeats the osteonic structure of the compact bone tissue with which it contacts. The resulting relief is additionally coated with titanium oxide to impart antibacterial properties. This coating is biocompatible for epithelial cells. We use the same titanium oxide coating to impart antibacterial properties to the abutment. A study on Streptococcus oralis bacteria confirmed the presence of this property.

The study was supported by the Russian Science Foundation (project № 20-62-46045).

FT-S02-18 Application of laser diode illumination systems for

rodent tracking purposes

I. Mazanov, K. Ezhova
ITMO University, Saint-Petersburg, Russia
dr.vata1@gmail.com

The problem of creating high-quality video recordings of animal behavior is extremely relevant for tracking purposes. Accurate analysis requires recordings having minimal optical distortion for the more correct operation of the tracking system. One of the methods of quality increasing is providing the system with a powerful light source. This study presents a possibility of implementation of laser diode illumination sources in experiments of rodent tracking in laboratory.

As rodents can be scared by a directional light, a diffuse illumination system was designed to create powerful yet compact construction. Laser diode lighting sources were combined with flat surface panels to provide the tracking system with optimal lighting level. DIALux tools were used to create a model of laboratory environment with a corresponding tracking equipment. In order to recreate illumination conditions, lighting sources were placed. To examine how light is spread throughout the laboratory room using laser diodes, DIALux light calculation functions were utilised.

According to the received data from modeling and projecting illumination, an optimal system was designed to provide the laboratory with an increased quality of video recordings. The level of light emission is enough for both experiment installation and a camera. Another potential advantage of using laser diode systems is their form-factor as the room of laboratory is small and requires the replacement of using cinema floor lamps.

In conclusion, a laser diode illumination system was designed for potential quality increase of tracking purposes and accuracy of laboratory analysis of video recordings. In perspective, it is planned to create a working prototype of laser diode light emission system to implement it in real conditions of experiment conditions.

Laser-based approaches in Art & Science (S03)

S03-1 Modigliani's paintings as a model for Augmented Art Object (AAO)

Vincent Detalle[1,2,3], Anaïs Genty-Vincent[1], Michel Menu[2,4], Ruven Pilay[1]
[1] C2RMF, Palais du Louvre, Paris, France.
[2] Heritage Science laboratory, ITMO University, St. Petersburg, Russia.
[3] ESPADON (21-ESRE-0050), Fondation des Sciences du Patrimoine, Paris, France
[4] Cyprus Institute, STARC- APAC, Aglantzia, Nicosia, Cyprus

A comprehensive analysis of 25 paintings from Amedeo Modigliani associated with an exhaustive documentation provided by art historians, conservators and documentalists provide a set of hybrid data. Merged with the object proper, this build an augmented art object what must be interpreted in an original way with new and innovative tools and means.

After presenting a summary of the results achieved what were presented in a colloquium celebrating the end of the project, *Modigliani's secrets,*(1) a tentative of interpreting the hybrid different results of diverse origins will show the role of an AAO as it is developed in the ESPADON project.

Research carried out with the support of a grant under the Decree of the Government of the Russian Federation No. 220 of 09 April 2010 (Agreement No. 075-15-2021-593 of 01 June 2021).

1. Anaïs Genty-Vincent, Michel Menu, Marie-Amélie Sénot (Éd.), *Les secrets de Modigliani*, 2022, Ed. LAM, Lille Métropole, musée d'art moderne, d'art contemporain et d'art brut et Éditions Invenit.

S03-2 Terahertz C-scans of the museum test-object in the spectral range from 0.1 to 2.5 THz

O.A. Smolyanskaya[1], S.V. Sirro[1,2], A.A. Lykina[1], O.A. Malaya[1], I. Andreev[1,2], A.V. Minin[2], V.Yu. Toropov[2], O.V. Kravtsenyuk[1], A.A. Smolyanskaya[1,2], M. Menu[1]
[1] Heritage Science lab, ITMO University, Saint-Petersburg, Russia
[2] The State Russian Museum, Saint-Petersburg, Russia
smolyanskaya@itmo.ru

One of the most difficult problems for museum restorers and technologists is non-destructive studies of multilayer coatings. Traditional museum methods, such as x-ray radiography, infrared reflectography, give an integrated picture of all layers and it is almost impossible to determine the sequence of layers and highlight the layer of interest. For this purpose, the terahertz time-domain spectroscopy (THz-TDS-based) object visualization system can be useful. Due to non-invasive properties of THz radiation, such a system allows to be applied for investigation of an object of art. The main goal of this study was to test the detecting capacity of such a system to identify layers of paint below the surface. We have used a unique test-object, mimicking the most common tasks for painting investigation. The image of paints on canvas was recorded using the TeraPulse LX (TeraView, UK) system with a spectral range 0.06 THz – 6.00 THz. Due to the high sensitivity of THz radiation to the distinction between the optical properties of painting materials, this experiment allowed us to obtain detailed information about the structure of layers of test-object and determine the shape of invisible elements without damaging the canvas. Thus, the THz imaging method can be very useful in restoration work designing, determining defects in the structure of paintings materials, as well as when searching for hidden objects under layers of paint.

S03-3 An example of the reconstruction of the author's color

solution of the monument of ancient Russian carved polychrome sculpture, based on natural science data

S. Sirro, A. Zhuravleva
The State Russian museum, St. Petersburg, Russia

The large carved polychromic warship cross, located in the chapel of Uspensky Cathedral in the city of Kem, is the monument of the second half of XVII century. The cross was found in 2021 by the expedition of specialists of the State Russian Museum. The aim of this work was to perform the first integrated research of the monument whereby the results allowed to indentify precisely both the materials and the technics applied to create the carved base and the polychromy. Upon the initial UV examination in line with the detailed UV-photos made solely in the Chapel, further X-Ray fluorescence spectroscopy revealed several types of metal coatings, as well as certain chemical pigments in paint layers. This work was continued in the Russian Museum laboratory using the methods of micro chemical tests, Fourier-transform IR-spectroscopy and polarizing microscopy. The results obtained did not contradict with the XVII-century attribution of the monument by art experts. Thus, the research result is the introduction to the open sources of another monument of Belomorie area with the exact date attribution, while the integrated material analysis permitted to make the probable reconstruction of the author's color approach while creating this monument.

The research was carried out with the support of a grant under the Decree of the Government of the Russian Federation No. 220 of 09 April 2010 (Agreement No. 075-15-2021-593 of 01 June 2021).

S03-4 Technological aspects of yellow glazed tiles of Kievan Rus'

V.A. Aseev[1], Yu. Mironov[1], D.S. Prokuratov[2], M.A. Isaeva[1], N.A. Bulygina[1], D.D. Jolshin[2], N.V. Nikonorov[1]
[1] Heritage Science lab, ITMO University, St. Petersburg, Russia
[2] The State Hermitage Museum, St. Petersburg, Russia
Aseev@oi.ifmo.ru

Since the end of the 10th century to the middle of 13th century, active construction of stone structures had been taking place in Kievan Rus'. During this time, more than 200 stone structures, which are mainly represented by churches and cathedrals, were built [1]. The architecture of churches was largely influenced by Byzantium tradition traditions [2]. Orthodox cathedrals Byzantine churches of this period were often decorated with mosaic stone floors. The lack of a suitable stone for mosaic floors in Kievan Rus' led to the use of mosaic floors made of glazed ceramic tiles. Thus, the local architectural tradition was formed. To decorate the floors, glazed tiles of different shapes and different colors (yellow, red (brown), green, and polychrome) were used. The use of ceramic tiles has been archeologically identified in more than 80 architectural monuments of Kievan Rus'. The geography of mosaic floors covers all the architectural and political centers of that period. The study of glazed ceramic floors allows to date the production (with an accuracy of 50 years), since the construction time is documented in the Russian chronicles.

The main goal of this work is to study the production technology of glazed ceramic tiles in the territory of Kievan Rus' in the 10-13th century AD. Samples were acquired from the collection of the State Hermitage museum. It is supposed to determine the specifics of the tiles production in the main cultural centres and the technological links between them. To do this, it is planned to analyze data on the chemical composition of the glaze and pigment of yellow tiles from Kiev, Galich, Polotsk, Vladimir-Volynsky, Pereslavl-Zalessky, and Novgorod.

Analysis of the data obtained by Raman spectroscopy and XRD has shown that the tile samples contain crystalline phase of lead tin yellow pigment. In addition, some samples contain secondary phases of silicon and tin oxides as well as lead carbonate. We either assume that the secondary phases are undissolved batch residues or were formed over time under the influence of external factors.

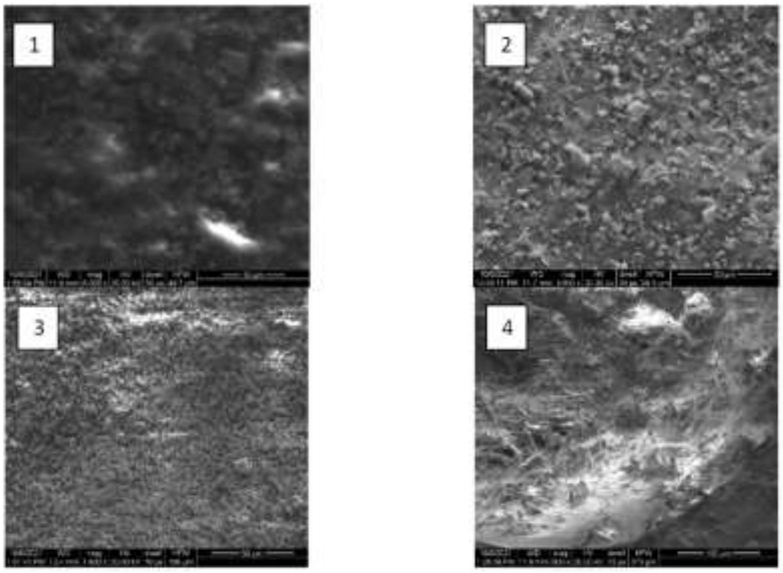


Figure 1. SEM images of ceramics tiles. 1 - Kiev (The St. Sophia Cathedral), 2 - Galich (The church of the Savior), 3 - Vladimir-Volynskii (The church of the St.Theodore), 4 – Pereslavl'-Zalessky (The Transfiguration church).

Lead-tin yellow pigment has two different types (Type I - Pb_2SnO_4 and Type II - $PbSn_{1-x}Si_xO_3$), which are difficult to distinguish analyzing complicated X-ray diffraction data from historical samples.

Raman spectroscopy is well suited for type identification since different types of lead-tin yellow have clearly different bands [3]. Local analysis of glaze pigments was performed with μ-Raman scattering. It was found that distribution of pigments over the tiles is very heterogeneous. Thorough study of tile samples in several places from the different sites revealed the presence of characteristic lead-tin yellow type 2 intense band at 138 cm^{-1}. Also, broad and weak characteristic bands at 324 cm^{-1} additionally confirm the type of a pigment. Some samples also have an intense band at 1054 cm^{-1}, corresponding to lead carbonate. The band of white lead was appearing only in several spots, while other spots of the same sample had only bands of lead-tin yellow. The results of phase identification were also supported by the appearance of corresponding peaks in XRD data.

Further, using the energy-dispersive x-ray fluorescence spectroscopy, the composition of the glass was analyzed and photos of the glaze surface were obtained on a scanning electron microscope. All glazes are based on alkaline-lead-silicate glass. Alkalis are represented by potassium or calcium and their total content does not exceed 10 wt.%. Three groups of ceramic tiles can be distinguished from the photographs. In the first group, the dye crystals are distributed in the volume of the glass (Fig 1.1), in the second and third crystals are observed on the surface. The difference is that crystals on the surface can be covered with glass (Fig 1.2) or not (Fig 1.3). The sample from Pereslavl-Zalessky does not contain glass, since there is practically no silicon oxide in the analysis data; a polycrystalline structure of lead oxide is observed (Fig 1.4). The typical crystal size of lead-tin yellow does not exceed 10 micrometers. This may indicate that the dye was synthesized during glass synthesis or secondary heat treatment, since it is difficult to obtain a mechanically grinded crystalline powder with a grain size of less than 10 micrometers. The location of the powder on the surface or in the bulk may be related to the temperature at which the glazed ceramics were made. Lead-silicate glass has high density and at low viscosity of the melt (at temperatures above 900°C) the dye can float to the surface of the melt.

The research was carried out with the support of a grant under the Decree of the Government of the Russian Federation No. 220 of 09 April 2010 (Agreement No. 075-15-2021-593 of 01 June 2021).

1. P. Rappoport, Building the Churches of Kievan Russia. Variorum, Cambridge, 1995.
2. R. Ousterhout. Eastern Medieval Architecture. The Building Traditions of Byzantium and Neighbouring Lands. Oxford University Press, New York, 2019. Pp. 540-550.
3. R. Clark, L. Cridland, B. Kariuki, K. Harris and R. Withnall. Synthesis, structural characterization and Raman spectroscopy of the inorganic pigments lead tin yellow types I and II and lead antimonate yellow: their identification on medieval paintings and manuscripts, J. Chem. Soc. Dalton Trans, Issue 16, 1995, 2577-2582

S03-5 Green glazed architectural ceramics of Kievan Rus'

V.A. Aseev[1], Yu. Mironov[1], D.S. Prokuratov[2], N.A. Bulygina[1], A Frolova[1], D.D. Jolshin[2], N.V. Nikonorov[1]
[1] Heritage Science lab, ITMO University, St. Petersburg, Russia
[2] The State Hermitage Museum, St. Petersburg, Russia
Aseev@oi.ifmo.ru

Glazed ceramics was a unique element of floor decoration in Kievan Rus in the 10th-13th centuries. Several primary colors were used in the decoration: yellow, brown, red and green. These colors can be obtained by adding various pigments to the glass. In this paper, green glazed ceramic tiles from various cities of Kievan Rus are studied. Studies of the body of ceramic tiles and glazes were carried out using X-ray diffractometry, X-ray energy-dispersive spectroscopy, and reflection spectra were measured. It is shown that divalent iron or a mixture of iron and copper is used as dye. Comparison of glazed tiles was carried out in order to find the features of production technology in various architectural centers and in different periods.

S03-6 Creation and investigation by FT-IR spectroscopy of a test object based on a copy of a 19th century painting by I.K. Aivazovsky

I.I. Andreev[1,2], S.V. Sirro[1,2], A.A. Lykina[1], A.A. Smolyanskaya[1,2], A.V. Minin[2], O.V. Kravtsenyuk[1], M. Menu[1], O.A. Smolyanskaya[1]
[1] Heritage Science lab, ITMO University, St. Petersburg, Russia
[2] The State Russian Museum, Saint-Petersburg, Russia
iiandreev@itmo.ru

The emergence of new research methods in the field of Heritage Science always raises a large number of questions related to their applicability, reproducibility of results on similar objects, complementarity with other methods, as well as the development of new research methods. To solve such problems, a multi-layered test object was created and described based on a fragment of a copy of a 19th-century painting by I. Aivazovsky. As part of the use of a single research method (FT-IR), differences in the picturesque layers of the 19th and 21st centuries were revealed, consisting in different composition of whitewash, the absorption intensity of hydroxyl groups in the high-frequency region of the IR spectrum. The aim of the work was to create and describe a test object using the FT-IR method in order to further work on the development of research methods using new methods such as OCT and THz tomography.

The research was carried out with the support of a grant under the Decree of the Government of the Russian Federation No. 220 of 09 April 2010 (Agreement No. 075-15-2021-593 of 01 June 2021).

S03-7 Laser paintbrush as a new tool of modern art: from a color laser marking to a laser painting

V. Veiko, G. Odintsova, D. Lutoshina
ITMO University, Saint Petersburg, Russia
vadim.veiko@mail.ru

Light is the main source of art around us. It allows us to see colors, and moreover, light itself can be a tool for creating unique pieces of art and designs. Here we demonstrate that a laser acts as a multifunctional and effective tool for creation of masterpieces in a way similar to that of classical paints and brushes. To make analogies between the processes of an artist creating a canvas and laser painting an artwork, we investigate the interaction between focused laser irradiation and metallic surfaces and analyze deeply the optical effects in thin oxide films. For this, we describe the nature of three main artistic operations, which are color making, multiple color change, and erasing managed by a nanosecond laser. These processes are possible due to the material heating above the evaporation point and are proved to be dependent on the cooling rate according to the obtained experimental and theoretical results. Therefore, our work is the first attempt to present the concept of interference-based laser paintbrush, which sets new perspectives for modern art and design.

S03-8 Laser paintbrush. Traditions of innovations in art

A.I. Bagautdinov, A.A. Alexandrova
[1] Saint Petersburg Stieglitz State Academy of Art and Design, Saint-Petersburg, Russia
[2] Peter the Great St. Petersburg Polytechnic University, Saint-Petersburg, Russia
crocodile_aa@mail.ru

- Postmodernism is a new surge of interest in the symbiosis of science and art (Neo-Renaissance of modernity). Even the geniuses of the Renaissance Leonardo Da Vinci, Michelangelo Buanorotti, Albrecht Dürer, Filippo Brunelleschi and others declared a close connection between science and art.
- Contemporary art adopts the latest achievements of science.
- Science art: Educational format; Liberal Arts Education; Research by Thomas Cech.
- Modern world-famous artists such as Ai Wei Wei, Damien Hirst, Jan Fabre and others use new materials and technologies for their work.
- Tom Wesselman is the first artist to use a laser in his art.

Our experiences with engraving laser. The use of laser engraving, along with etching and enameling, has greatly expanded the range of possibilities for decorating metal.

Anvar Bagautdinov, Anastasia Alexandrova
«Bug» Hot enamel on cooper, brass, laser engraving.

Anvar Bagautdinov, Anastasia Alexandrova
«Bug» Hot enamel on cooper, brass, laser engraving.

The laser paintbrush undoubtedly opens up a fundamentally new approach to the problem of laser metal processing, due to ergonomics and direct contact between the artist and the tool, it allows you to introduce an element of improvisation into the creative process. Which, in turn, can give impetus to a rethinking of the use of a laser tool in contemporary art in general, bring this problem to a new level and, as a result, allow high-tech equipment to take its rightful place among the fine art tools in the art industry.

FT-S03-1 Using a laser as an artist's brush

D.S. Lutoshina, V.P. Veiko
ITMO University, St. Petersburg, Russia
ld3282@ itmo.ru

The use of a laser for painting metal surfaces is based on the technology of color laser marking. The technology makes it possible to obtain local thin oxide films on the treated surface.

Laser radiation is focused on the surface of the sample. The surface is heated to the melting point. And at the stage of cooling, as a result of exposure to air, a thin oxide film is formed.

The resulting color depends on the interference effects in the upper oxide layer and the color of the lower oxide layers. To obtain a certain color, the oxide film must have a certain thickness. This can be achieved by controlling the exposure temperature.

The thickness of the oxide film increases with increasing temperature.

This technology allows you to get stable colors, and the resulting images have high contrast and high-quality detail.

The technology has been improved recently. The possibility of a controlled change in the color of an already painted surface was shown, as well as the possibility of laser removal of a drawn element. All this made it possible to proceed to the creation of a universal laser device for drawing by artists.

The paper presents the first results of drawing by the developed laser device, which has the form of a laser brush. This device allows you to draw color images on metal surfaces.

FT-S03-2 Development of the "ITMO" installation using laser coloring technology

A.A. Morozova, V.V. Romanov, L.A. Okman, G.V. Odintsova

ITMO University, St. Petersburg, Russia
aamorozova@itmo.ru

Contemporary art is at a stage when the priority is the use of non-standard materials and tools, as well as interdisciplinary knowledge. This causes the emergence of such a direction of contemporary art as "scientific art". One of its promising areas is laser art, which is determined by the characteristic properties of a laser source. The most interesting application of the laser in this direction is its use to change the color of metal objects. The existing technologies for coloring metals were originally developed for industrial use, therefore they do not provide for the specifics of use in the creation of art objects, and therefore need to be improved. The colors obtained on the surface of titanium with the help of color laser marking have a glossy sheen, which means that their optical properties change depending on the illumination and the viewing angle.

In this work, the optimal angle of scanning, lighting, and viewing was selected for the use of CLM technology in art. The use of the obtained results is demonstrated on the developed and put into practice art installation “ITMO” of metal parts.

Titanium plates VT1-0 were used as samples. An ytterbium fiber laser with a nanosecond pulse duration was used as a laser source. Laser coloring of the surface of metals subject to oxidation is based on the formation of an oxide film on their surface because of heating in air. Resulting color of the coatings depends on both the film thickness and the intrinsic color of the oxide film. Dyeing at temperatures above the evaporation temperature is preferred for art applications, as it allows it to be erased or overwritten when reprocessed if necessary. However, the resulting colors have a glossy sheen, which limits the viewing angle of the recorded image.

The optical properties of the previously developed palette were studied and recorded using optical microscopy at various recording and illumination angles. For each of the modes, the optimal scanning angle was chosen, at which the color had the highest saturation. For the optimal choice of the location of the object of art in space, the optical properties of the corrected modes were studied with a change in the vertical viewing angle.

With the help of a corrected palette, the metal details of the installation were created, the sketch of which was created by his own hand. Based on the results obtained, lighting and location in space were chosen.

S03-9 Laser cleaning of archaeologically corroded copper

D.S. Prokuratov[1,2], O.S. Vereshchagin[3], N.S. Kurganov[4,5], A.A. Samokhvalov[6], D.V. Pankin[7], A.V Povolotckaia[7], A.A. Shimko[7], A.A. Mikhailova[7]
[1] Heritage Science laboratory, ITMO University, St. Petersburg, Russia
[2] The State Hermitage Museum, St. Petersburg, Russia
[3] Mineralogical Department, Institute of Earth Sciences, Saint-Petersburg State University, St. Petersburg, Russia
[4] Conservation Department, Faculty of Arts, Saint Petersburg State University, St. Petersburg, Russia
[5] Institute of the History of Material Culture of the Russian Academy of Sciences, St. Petersburg, Russia
[6] International laboratory "Laser micro-and nanotechnologies", ITMO University, St. Petersburg, Russia
[7] Center for optical and laser materials research, Saint-Petersburg State University, St. Petersburg, Russia

Objects made of copper-based alloys are among the first metal objects of material human history. A lot of museums around the world have in their storage number of such items of archaeological origin. Restoration of archaeological objects is a complex and multistep work, including the object's analysis, strengthening its surface and internal structure, stabilization of corrosion processes, conservation, reconstruction of fragments, and replenishment of losses. Cleaning from corrosive layers plays a significant role due to its possibility to remove pollutions, to reveal the shape of the object being restored and its technological and decorative features. Currently, there are many methods of cleaning metal objects, among which are mechanical, chemical, electrochemical ones and so on.

Mechanical cleaning methods are based on the use of brushes, scalpels, scrapers, hand-piece drills, and other tools. The mechanism of used chemicals is based on the principle of chemical conversion and dissolution of corrosion products for their subsequent removal. Electro-chemical cleaning is a rather gentle technology that allows cleaning the object from corrosion, however, it can takes a long time, and cannot be used for items containing inlays.

Our paper presents the results of several years of research on the possibility of using a laser for the controlled layer-by-layer removal of copper underground corrosion. Lasers generating radiation at wavelengths of 355, 532, 1064 nm were tested. A comparison of pulse durations of 100 μs, 100, 10 ns, 75 ps, 100 fs was made. The performed analyses allow us recommending the parameters of laser radiation, which can provide the process of layer-by-layer ablation of archaeological corrosion without any structural modification of the underlying layers and their discoloration.

S03-10 Sampling of paint layers using laser ablation

A.E. Dedova, I.A. Balakhnina, N.N. Brandt, A.Yu. Chikishev
Lomonosov Moscow State University, Faculty of Physics, Moscow, Russia
dedova.ae19@physics.msu.ru

Laser methods are employed in the analysis and restoration of paintings [1]. In several studies laser ablation of real paint layers was carried out, for example, during UV laser ablation surface-enhanced Raman microspectroscopy (LA-SERS) [2] or laser-induced breakdown spectroscopy (LIBS) [3], etc. Although the accuracy of the methods is relatively high the probe (ablated part of the object) disappears during measurements and cannot be further study with the aid of alternative techniques. In contrast, an experimental technique of the laser ablation for the sampling from the paper was proposed [4]. Extending the application of the technique to paintings can be useful as an alternative to traditional mechanical sampling methods. The advantage of the laser ablation method lies in the relatively small size of the samples obtained and the damaged area of the sample. Optimal parameters of radiation results to the craters be invisible.

The aim of the study was verifying sampling by laser ablation on model system (paint layer on primed linen canvas) that is close to a real painting, and to study the physical parameters of the microprobes (ablated part of the object). Six oil paints prepared as a mixture of linseed oil binder and color pigment were used as a paint layers. The size of each paint fragment was 2x2 cm^2. The thickness of the paint layer ranged from 0.1 to 0.4 mm.

For the sampling and diagnostics, we used the experimental setup from [4]. A horizontal laser beam is incident on a vertical sample. Ablation products fall under the action of gravity on a horizontal glass plate placed in the immediate vicinity of the sample below the laser beam. A Q-switched Nd:YAG laser with frequency doubling generated 15-ns pulses at λ = 532 nm (in the single-pulse mode). The laser spot diameter on the sample was about 50 μm. The laser pulse energy was varied from 0.02 to 1.9 mJ.

The physical parameters of microprobes were diagnosed by original procedure of photographing and image processing.

The ablation thresholds of paint layers were determined, and the parameters of the obtained microprobes were studied. A Thermo Scientific DXR confocal Raman microspectrometer was used to discuss possible changes in the chemical composition after interaction with laser radiation.

This work was supported by the Russian Foundation for Basic Research (project no. 20-02-00987). The DXR Raman microscope was purchased with the help of Lomonosov Moscow State University Program of Development.

1. Kautek, W., “Lasers in Cultural Heritage: The Non-Contact Intervention,” [Laser-Surface Interactions for New Materials Production], A. Miotello and P. M. Ossi, Eds., Springer Berlin Heidelberg, Berlin, Heidelberg, 331–349 (2010).
2. Cesaratto, A., Leona, M., Lombardi, J. R., Comelli, D., Nevin, A. and Londero, P., “Detection of Organic Colorants in Historical Painting Layers Using UV Laser Ablation Surface-Enhanced Raman Microspectroscopy,” Angew. Chem. Int. Ed. **53**(52), 14373–14377 (2014).
3. Hamed, S. A. E.-K. M., “A comparative study on the color change of pigments due to the consolidation of conventional spectroscopic techniques and laser-induced breakdown spectroscopy,” Applied Physics A: Materials Science and Processing(125), 559 (2019).
4. Balakhnina, I., Brandt, N., Chikishev, A., Rebrikova, N. and Yurchuk, Y., “Laser ablation of paper: Raman identification of products,” Appl. Phys. A **117**(4), 1865–1871 (2014).https://onlinelibrary.wiley.com/doi/full/10.1002/ange.201408016 - nss

Physical foundations of laser technologies for nanophotonics and nanoscale systems (S04)

S04-1 Optics of micrometer dielectric spheres

B.S. Lukiyanchuk
Faculty of Physics, Lomonosov Moscow State University, Moscow, Russia
lukiyanchuk@nanolab.phys.msu.ru

Scattering of transparent sphere depends on the refractive index of the sphere, n and relation between the size of the sphere (R is the radius sphere) and the radiation wavelength λ, given by the so-called size parameter, $q = 2\pi R / \lambda$. It is given by the Mie theory. The history of classical optics is associated with lenses, with a size of about one centimeter (Galileo's telescope, microscope, etc.). The corresponding size parameter in such optical systems is quite large, $q > 10^5$. The geometrical optics approximation is in good agreement with the Mie theory for $q > 10^2$. Research on the optics of nanostructures in plasmonics and nanophotonics refer to the systems where the size parameter is of the order of unity, $q \sim 1$. In this area, progress has been made in the study of optically resonant dielectric nanostructures with a high refractive index [1]. At the same time, structures with the size parameter of the ten, $q \sim 10$, are in the region between the wave and geometric optics turned out to be a "blank spot" on the map of optics due to the reason that lenses of the size of a few micrometers for a long time had no particular interest.

However, over the past twenty years, discover a number of unusual phenomena, including photonic nanojets [2], optical nanovortices [3], Fano resonances [4], magnetic light [5], the effects of overcoming the diffraction limit in the virtual image [6], effects associated with the excitation of anapole modes [7-9] and the excitation of giant magnetic fields [10,11]. The report gives an overview of these phenomena and discusses the physical mechanisms underlying these phenomena.

1. A.I. Kuznetsov et al.// *Science* **354**, aag2472 (2016).
2. B. Luk`yanchuk et al.// *Optical Materials Express* **7**, 1820 (2017).
3. B. S. Luk`yanchuk et al.// *Journal of Optics* **15**, 073001 (2013).
4. B. Luk`yanchuk et al.// *Nature Materials* **9**, 707 (2010).
5. A.I. Kuznetsov et al.// *Scientific Reports* **2**, 492 (2012).
6. Z.B. Wang et al.// *Nature Communications* **2**, 218 (2011).
7. A.E. Miroshnichenko et al.// *Nature Communications* **6**, 8069 (2015).
8. B. Luk`yanchuk et al.// *Phil. Trans. Roy. Soc*. A **375**, 20160069 (2017).
9. B. Luk`yanchuk et al.// *Phys. Rev*. A **95**, 063820 (2017).
10. Z.B. Wang et al.// *Scientific Reports* **9**, 20293 (2019).
11. B. Luk`yanchuk et al.// *Scientific Reports* **11**, 23453 (2021).

S04-2 Strong optical dichroism of laser-modified self-assembled silver nanostructures

I.A. Gladskikh, D.R. Dadadzhanov, G. Alexan, N.A. Toropov, A.A. Starovoytov, R.A. Zakoldaev, T.A. Vartanyan
ITMO University, St. Petersburg, Russia
tigran.vartanyan@mail.ru

2D metal nanostructures with strong optical dichroism have been fabricated via a novel method based on the spectral hole burning technique [1,2]. The essence of the method lies in the selective heating and reshaping of metal nanoparticles by pulsed laser irradiation with linear or circular polarization.

Silver nanostructures were obtained by PVD on the surface of glass slides at room temperature.

Such deposition leads to the formation of a complex labyrinth structure. To study the laser irradiation effect on individual nanoparticles with a shape close to spherical some of the samples were annealed at a temperature of 200°C for 1 hour. The samples were irradiated with the focused 2-nd harmonic beam of a pulsed picosecond Nd:YAG laser with linear or circular polarization. The laser fluence varied from 8 mJ/cm^2 to 50 mJ/cm^2.

In all cases, as a result of irradiation, the extinction spectra exhibit the spectral hole at the wavelength of laser radiation caused by a change in the shape and/or size of the particles. After irradiation by linearly polarized light, the samples exhibited linear dichroism caused by the metal nanoparticles that predominantly absorb light polarized in the direction orthogonal to laser light polarization. The maximum value of linear dichroism for samples with the irradiated silver nanostructures reaches 4%. In the case of laser irradiation with circular polarization, similar spectral holes in circular dichroism spectra at the wavelength of laser radiation were observed. The maximum value of circular dichroism of the silver nanostructures was 0.1 deg, which is comparable to the values characteristic for 2D chiral plasmonic metasurfaces obtained by much more complicated and costly lithographic methods [3].

The study was supported by the Russian Science Foundation grant No. 21-72-10098, https://rscf.ru/en/project/21-72-10098/.

1. F. Stietz, J. Bosbach, T. Wenzel, T. Vartanyan, A. Goldmann, F. Träger. Phys. Rev. Lett.,v. 84, Iss. 24, pp. 5644-5647 (2000)
2. Toropov N.A., Gladskikh I.A., Parfenov P.S., Vartanyan T.A. Fabrication and laser-assisted modification of the Ag particles ensembles supporting quadrupole plasmon oscillations // Optical and Quantum Electronics - 2017, Vol. 49, No. 4, pp. 154
3. Kong X.T., Besteiro L.V., Wang Z., Govorov A.O. Plasmonic chirality and circular dichroism in bioassembled and nonbiological systems: theoretical background and recent progress //Advanced Materials. – 2020, Vol. 32, No 41, pp. 1801790.

S04-3 Simulation of an intrafiber sensor structure obtained by optical breakdown

Yu. A. Konin [1], V.A. Shcherbakova [2], N.A. Grachev [2]
[1] ITMO University, Saint Petersburg, Russia
[2] Perm National Research Polytechnic University, PJSC PNPPK, Perm, Russia
yuri-konin@yandex.ru

Analyzing the results of studies on measuring the reflection spectra of a prototype scatterer made on the basis of single-mode fiber type Corning SMF-28e, it was concluded that the micro-cavities (scattering centres) formed in the scattering part of the fiber represent a sensitive Fabry-Perot interferometer. To be able to control the process of selecting the characteristics of sensors based on scatterers with microcavities, it is necessary to consider a mathematical model of radiation scattering in such a fiber with scattering centres.

The scatterer was simulated in the finite element package COMSOL Multyphysics.

The model was calculated in the radiation wavelength range λ_0 = 1540...1560 nm, which corresponds to the range of experimental data. In this wavelength range, the reflection coefficient for several wavelength values within this range was calculated in order to obtain the spectral dependence of the reflection coefficient of this model.

The geometric dimensions of the fiber were specified in the model according to the specification of the fiber under study: the fiber core has a diameter 8.2 µm and the fiber envelope has a diameter 125 µm. The length of the fiber section L = 200 µm was taken from the considerations of modeling sections of undamaged fiber along the course of propagating radiation along the fiber before and after microcavities to obtain a picture of radiation scattering on microcavities.

The characteristic dimensions of the micro-cavities were set according to the real dimensions of the micro-cavities measured in the prototype scatterer. Thus, diameter of the micro-cavity "tip" is d_m = 2.576 µm, length of the micro-cavity "body" l_m = 6.589 µm and distance between "tips" l_d = 12.756 µm.

Visualization of electric field strength distribution for the emission wavelength value λ_0 = 1550 nm was simulated near the first microcavity. The interference of the wave incident on the microcavity and reflected from it is observed on it.

S04-4 Terahertz opal nanocomposites with a wide refractive index range

V.E. Ulitko[1], G.M. Katyba[1,2], G.A. Komandin[2], G.A. Emelchenko[1], V.N. Kurlov[1], V.M. Masalov[1], K.I. Zaytsev[2,3,4]
[1] Institute of Solid State Physics of RAS, Russia
[2] Prokhorov General Physics Institute of RAS, Russia
[3] Institute for Regenerative Medicine, Sechenov University, Russia
[4] Bauman Moscow State Technical University, Russia
ulitko.vl@gmail.com

In our previous articles, it was shown [1,2], that opal-based nanostructures could be very promising terahertz (THz) optical materials with low absorption and dispersion and quite a unique ability to choose refractive index in a wide range (1.6-1.95) only by heat treatment regimes. In this work, we fabricate different opal-based nanocomposites possessed various refractive indexes and insignificant absorption. Thus, fabricated PMMA-inverted opals (IO) have refractive index of 1.15 and opal matrix contained Fe_2O_3 up to 30% by volume has refractive index up to 2.87. Materials obtained in this way could possess refractive indices in the whole wide range in these two extreme values by varying the volume fraction of the material in the initial opal matrix. This feature, combined with no dispersion in the material show that artificial opals have a great potential for THz applications.

This work was partially supported by the Russian Science Foundation (RSF), Project # 19-12-00402.

1. Ulitko, V.E. et. al. Nanoporous SiO_2 based on annealed artificial opals as a favorable material platform of terahertz optics, Optical Materials Express, 10(9), 2100, 2020. DOI:10.1364/OME.402185;

2. Ulitko, V.E. et. al. Opal-based terahertz optical elements fabricated by self-assembly of porous SiO_2 nanoparticles, Optics Express 29(9), 13764, 2021. DOI:10.1364/OE.422637.

S04-5 Sapphire shaped crystals: from THz-wave delivery to super-resolution imaging

G. M. Katyba[1,2,3], K. I. Zaytsev[2,3], N.V. Chernomyrdin[2,3], D.G. Melikyants[3], V.N. Kurlov[1,3]
[1] Institute of Solid State Physics of the RAS, Chernogolovka, Russia
[2] Prokhorov General Physics Institute of the RAS, Moscow, Russia
[3] Bauman Moscow State Technical University, Moscow, Russia
katyba_gm@issp.ac.ru

During the past few years, we introduced different elements and instruments of THz waveguide and fiber optics based on sapphire shaped crystals [1–4]. Such crystals are fabricated using the Edge-defined Film-fed Growth technique in ISSP RAS. The EFG method allows for producing crystals with a complex cross-section geometry, as well as high surface and volumetric quality, directly from the Al_2O_3 melt, without any mechanical processing operations. In this way, flexible sub-wavelength-diameter sapphire fibers were successfully implemented in the THz scanning-probe near-field optical microscopy [5,6]. Sapphire optical fiber bundles were applied for the THz imaging with the spatial resolution beyond the ~0.5λ Abbe diffraction limit [7]. More recently, we developed a sapphire fiber-based "THz focon" [8], that captures the THz near-field with the resolution as high as 0.25–0.3λ and, then, scales it by a factor of 3. This makes possible to read out the THz near-field from the output end of the focon using conventional diffraction limited optics. Thus developed "THz focon" allows to overcome the Abbe diffraction limit and to perform the THz near-field imaging using common diffraction-limited lens- or mirror-based THz optics.

1. IEEE Transactions on Terahertz Science and Technology, 6(4), 576 (2016).
2. Advanced Optical Materials, 6(22), 1800573 (2018).
3. Progress in Crystal Growth & Characterization of Materials 67(3), 100523 (2021).
4. Progress in Crystal Growth & Characterization of Materials 64(4), 133 (2018).
5. Applied Physics Letters, 114, 03110 (2019).
6. Optical Engineering 60(8), 082010 (2021).
7. Advanced Optical Materials, 8(18) 2000307 (2020).
8. Journal of the Optical Society of America 51(1), 32 (1961).

S04-6 Terahertz endoscope based on the solid immersion effect with subwavelength spatial resolution

A.S. Kucheryavenko[1,2], V.A. Zhelnov[2,3], G.M. Katyba[1,2], N.V. Chernomyrdin[2,3], K.I. Zaytsev[2,3], V.N. Kurlov[1]
[1] Institute of Solid State Physics of the RAS, Chernogolovka, Russia
[2] Prokhorov General Physics Institute of the RAS, Moscow, Russia
[3] Bauman Moscow State Technical University, Moscow, Russia
ans.kucher@mail.ru

Terahertz (THz) technology went through rapid development during the past few decades [1]. Nowadays, it offers novel opportunities in the label-free diagnosis of malignant and benign neoplasms with different nosologies and localizations [2–8]. Nevertheless, it is still far from clinical applications. There are a number of problems in this area, namely: relatively low spatial resolution of most focusing systems, difficulties with the delivery of THz radiation to hard-to-reach areas of the objects under study, especially *in vivo*, biocompatibility of materials.

In this work, an original design of the THz endoscope was proposed. The THz endoscope consists of two parts:

1. hollow sapphire waveguide with PTFE sheath [9];
2. focusing element consisting of a lens and a plane window made of High-Resistivity Float-Zone Silicon featuring a high refractive index in the THz region [10].

This design provides delivery of THz radiation with low losses and focusing on the rear surface of the plane window.

THz waveguides made of sapphire feature optical transparency in a wide spectral range, high refractive index in the THz range, mechanical resistance, chemical inertness, and biocompatibility [11]. Subwavelength resolution in the system is achieved due to solid immersion effect, which makes it possible to reduce the dimensions of the beam caustic by focusing it at a small distance (compatible with the radiation wavelength) on the rear surface of the focusing element [10].

For numerical simulation of sapphire waveguides, the full-vector method of finite-difference eigenmode was used, taking into account the terahertz optical properties of sapphire. The design of the focusing element was calculated using the finite difference time domain method and demonstrated a subwavelength resolution up to 0.15 λ, where λ is a free-space wavelength.

Thus, the developed design of the THz endoscope has a high spatial resolution, is compact, and expands the range of applications of THz radiation. This opens up new horizons in the development of THz biophotonics and medical diagnostics [2].

1. H. Guerboukha et al., Adv. Opt. Photonics 10(4), 843–938 (2018).
2. K. Zaytsev et al., J. Opt. 22(1), 013001 (2020).
3. P. Ashworth et al., Opt. Express 17(15), 12444–12454 (2009).
4. M. Konnikova et al., Biomed. Opt. Express 12(2), 1020–1035 (2021).
5. G. Musina et al., J. Biomed. Photonics Eng. 6(2), 020201 (2020).
6. Yamaguchi et al., Sci. Rep. 6(1), 30124 (2016).
7. Y. Ji, et al., Sci. Rep. 6(1), 36040 (2016).
8. L. Wu et al., Biomed. Opt. Express 10(8), 3953–3962 (2019).
9. G.M. Katyba, Prog. Cryst. Growth Charact. Mater. 67(3), 100523 (2021).
10. N.V. Chernomyrdin, Appl. Phys. Lett. 113(11), 111102 (2018).
11. G.M. Katyba, Prog. Cryst. Growth Charact. Mater. 64(4), 133–151 (2018).

S04-7 Design of a laser sensor for detection and resolution of small-sized objects

A.A. Chebotarev [1], V.A. Komisarov [1], R.M. Akhmadullin [2], D.E. Kukushkin [1], D.A. Sinev [1]
[1] ITMO University, Saint Petersburg, Russia
[2] AO NPP Signal, Saint Petersburg, Russia
greentrent@mail.ru

With the development of technical vision methods, the number of ways to highlight and detect objects on the assembly line is growing, and, accordingly, an ever-wider range of radiation wavelengths is used to identify objects. This means that for the simultaneous operation of an optical sensor and technical vision, it is necessary to use a various range of solutions, and understand the features when identifying objects from different materials with various geometries. The purpose of this work is to select a component base for a laser sensor for detecting and resolving small-sized objects to solve the problem of controlling the presence of a bending spring (200 μm thick) with a galvanized coating in a product when assembling an arc-flash protection device (AFPD). To achieve this goal, the reflectance spectrum of AFPD parts (bending springs and adjacent parts) in the range of 350–900 nm was studied, and the deformation thresholds of AFPD parts were determined. By modeling several optical circuits in the Zemax OpticStudio software, the optimal sensor components, and the required distance to the bend spring of 105 mm were determined. Assembled and test device layout. A 3D model of the device prototype was built using the KOMPAS-3D software. The theoretical study of the temperature dynamics of the bending spring under laser exposure in the SolidWorks software is proposed to prevent imperceptible overheating of the steel under the galvanized coating.

The authors are grateful to the Faculty of Physics and Technology at ITMO University for the grant support of scientific and research work of masters and graduate students (NIRMA).
The reported study was financially supported by the Ministry of Science and Higher Education of the Russian Federation research agreement No. 075-11-2021-045 of 24.06.2021, project title "Development of high-tech production of equipment and technologies for laser functionalization of medical devices" (within the framework of decree of the Government of the Russian Federation No. 218 of 09/04/2010)

S04-8 Dye's fluorescence amplification by nanostructures on the AlZnO:Ag films: fabrication and application

A.D. Dolgopolov, V.R. Gresko, M.M. Sergeev
ITMO University, St. Petersburg, Russia
addolgopolov@itmo.ru

Fluorescence is used in the life sciences generally as a non-destructive way of tracking or analysing biological molecules by means of fluorescence. However, with constant dwarfing of measurements scale, it is also important to keep our analizing method updated, via inventing new technics, or reviewing existing ones with a different approach.

One of the modern materials, hugely tied with biomedical applications are thin sol-gel films. This is especially true for transparent semiconductor films modified by laser emission. Therefore, the study of alterations in the optical properties of such films after laser influence becomes more and more important for the applications of such materials in the field of spectrophotometry, and by addition, fluorescence.

In this work, we observe properties of nanostructures with a submicron period and a several tens of nm relievo depth on the surface of AlZnO sol-gel films that are obtained by the method of two-beam interference processing by pulsed laser emission. Such nanostructures were used to enhance the luminescence signal from organic compounds. In this work, it was suggested that the period of nanostructures can affect the luminescence intensity in the case when the spectral range of the luminescent emission is commensurate with the period. This study shows the effect of the resulting gratings on the luminescent properties of the dye rhodamine G6 and bromocresol purple. The nanostructure amplified the signal of rhodamine intensity several times, while the maximum amplification occurred at a wavelength near the grating period. At the same time, both the luminescence spectra of a solution of rhodamine and rhodamine on the initial untreated AlZnO film differed from each other only slightly and had a maximum at a longer wavelength

The study was supported by the NIRMA grant from ITMO University

S04-9 Laser technologies: nanoparticle production and shock peening

N.A. Inogamov [1,2,3], V.V. Zhakhovsky [2,3], V.A. Khokhlov [1], E.A. Perov [3], V.V. Shepelev [4], Yu.V. Petrov [1], S.V. Fortova [4]
[1] The Landau Institute for Theoretical Physics of RAS, Chernogolovka, Russia
[2] Dukhov All-Russian Scientific Research Institute of Automation, Rosatom, Moscow, Russia
[3] Joint Institute for High Temperatures of RAS, Moscow, Russia
[4] Institute of Computer Aided Design of RAS (ICAD RAS), Moscow, Russia
nailinogamov@gmail.com

Numerical modeling of ablation into a liquid has been performed. Molecular dynamics and hydrodynamics codes have been applied. Laser radiation passes through a transparent liquid and illuminates a metal target. The light is absorbed and reflected from the target. The range of absorbed energies Fabs of the order of 1 J/cm^2, which is of interest for technology, is considered: below these values few nanoparticles are formed per laser pulse, above - the optical breakdown of the liquid. A theory has been developed, which, using modeling data and thermodynamic information (equations of state of matter), allows us to estimate the mass and composition of nanoparticles formed by laser action [1].

Powerful laser exposure causes irreversible changes in the crystal structure of the target. These changes are the basis of laser shock peening (LSP) technologies. The processes determining the thickness of the residual strain layer and related residual stresses are investigated in this work. It is known that the termination of pinning is associated with the attenuation of laser shock wave. In this work, new information was obtained concerning the transformation of the wave from the elastic-plastic to the elastic mode of propagation in the case of picosecond impact. The elastic wave is useless for pinning. It turns out that during the transformation, the classical configuration with a plastic jump and an elastic precursor before it disappears. The leading edge of the expanding plastic layer gradually reduces its velocity below the volume speed of sound, smears inside the rarefaction wave, and stops [2,3].

1. Inogamov N.A., Zhakhovsky V.V., Khokhlov V.A. // JETP Letters. 2022. Volume 115. Issue 1. Pages 16-22. DOI 10.1134/S002136402201009X
2. Inogamov N.A., Perov E.A., Zhakhovsky V.V., Shepelev V.V., Petrov Yu.V., Fortova S.V. // JETP Letters. 2022. Volume 115. Issue 2. Pages 71-78. DOI 10.1134/S0021364022020047
3. Shepelev V.V., Petrov Yu.V., Inogamov N.A., Zhakhovsky V.V., Perov E.A., Fortova S.V.// J. Opt. and Laser Techn., accepted (20/3/2022)

S04-10 Polynomial and machine-learning interatomic potentials for laser excited solids

B. Bauerhenne, P. Plettenberg, M.E. Garcia
Theoretical Physics, Department of Mathematics and Natural Sciences, University of Kassel, Kassel, Germany
m.garcia@uni-kassel.de

In laser excited solids, the produced hot electrons are usually described in the canonical ensemble in terms of the Helmholtz free energy, which in turns determines the potential energy surface (PES) for the ions U(Te) = Ee − TeSe, where Te, Ee and Se are the electronic temperature, total energy and entropy after laser excitation and thermalization, respectively. On the other hand, the motion of the ions on the laser excited PES fulfills energy conservation as long as Te does not change and can be treated in the microcanonical ensemble. Now, when the electron-phonon coupling is active and there is energy exchange in both directions, the mixed canonical-microcanonical usually leads to inconsistencies and wrong results. So far, different approximate approaches have been used to overcome this problem, but a microscopic theory is still lacking. In this talk, we present a theory for the coupled description of the laser induced ultra- fast dynamics of the electronic temperature and the ions from first principles. The theory yields and generalizes the equations of the two-temperature-model-molecular-dynamics (TTM-MD) method in a natural way and can be used either in ab-initio simulations or in large- scale MD simulations based on Te-dependent force fields.

For performing large-scale TTM-MD simulations using this method we developed different methods to construct interatomic potentials depending on the electronic temperature. Recently, we proposed a self-learning algorithm [1] based on the expansion of metallic and covalent bonding terms into polynomials. Using this approach, we constructed potentials for laser excited silicon, antimony and graphite. Remarkably good agreement with experiments is obtained. Results will be discussed during the talk.

Finally, a Machine Learning interatomic potential for laser excited silicon will be presented. We extended the concept of “high-dimensional“ neural network potentials (HDNNP), introduced by Behler and Parrinello in 2007 [2], to the laser excited case in which the interatomic forces are dependent on the electronic temperature. Excellent agreement with ab-initio simulations is obtained, so that we could implement this neural-network potential into large-scale MD simulations.

1. B. Bauerhenne, V. P. Lipp, T. Zier, E. S. Zijlstra and M. E. Garcia, Self-Learning Method for Construction of Analytical Interatomic Potentials to Describe Laser-Excited Materials, Phys. Rev. Lett. 124 (8), 085501 (2020).
2. J. Behler and M. Parrinello, Generalized Neural-Network Representation of High- Dimensional Potential-Energy Surfaces, Phys. Rev. Lett. 98, 146401 (2007).

S04-11 Structural coloring and anti-counterfeiting enabled by direct femtosecond laser printing

A.A. Kuchmizhak [1,2]
[1]Far Eastern Federal University, Vladivostok, Russia
[2]Institute of Automation and Control Processes, Far Eastern Branch, RAS, Vladivostok, Russia
alex.iacp.dvo@mail.ru

Laser-matter interaction provides facile and high-performing way for surface nano-structuring. Tightly focused femtosecond laser pulse interacting with thin noble-metal films are of special practical interest owing to ability to produce unique 2D and 3D surface nanostructures in a well-controlled and reproducible manner. Fabricated laser-printed nanostructures can resonantly interact with incident optical radiation allowing to locally tune optical properties of the surface opening pathways for various applications as structural coloring, marking, sensing, etc. Here, we justify direct femtosecond-laser printing, a simple and scalable technology, for fabrication of high-resolution (25 000 dots per inch) and durable physically unclonable one-way function labels with a substantially large encoding capacity of 10^{895} and a simple spectroscopy-free optical signal readout. The proposed tags are comprised of laser-printed plasmonic nanostructures exhibiting unique light scattering behavior and unclonable 3D geometry. Uncontrollable stochastic variation of the nanostructure geometry in the process of their spot-by-spot printing results in random and broadband variation of the scattering color of each laser printed "pixel", making laser-printed patterns unique and suitable for PUF labeling. Moreover, direct femtosecond laser nanopatterning of metal-insulator-metal (MIM) sandwich designed to support Fabry-Perot mode in the visible spectral range was carried out to demonstrate high-resolution multi-color printing of structural colors in reflection. By varying the applied pulse energy, the type of the surface modification (evolving form hollow nanobumps and nanojets to through holes and spallative craters) can be controlled to tune the local surface reflectivity resulting in variation of the surface color observed in reflection with ordinary optical microscope. Moreover, we demonstrated facile single step printing of multi-color images at resolution up to 25,000 dots per inch justifying the applicability of the developed approach for structural color marking and optical information encryption.

S04-12 Laser-induced processes to control functional characteristics of thin-film topological nanoclusters on solid surface

D. Bukharov, A. Antipov, O. Butkovsky, T. Khudaiberganov, S. Arakelian
Stoletovs Vladimir State University, Vladimir, Russia
arak@vlsu.ru

By our presented technique, used a laser ablation as an initial procedure, it is easy to form a cluster work-Net topological system of both the different and many elements composition with any optimal concentration in thin films on solid surface being an analogue of a simple polycrystalline metallic sample with the element distribution in localized areas of the high configurational mixing entropy material.

The surface topology map in the thin film nanocluster metallic system is a key parameter to perform different characteristics (both optical and electrophysical) of the photonic devices created on new physical principles by presented laser-induced processes. A new branch for the subject is to study the quasi-particle states in low-dimensional solid system resulting in unique quantum states and behavior.

We describe mathematical and computer modeling and approach to obtain the fractal nanocluster systems on solid surface. Formation of conductive coatings is considered experimentally, and the study of the electrophysical properties of the deposited layer (Cu, Ni, Cu+Ni) is presented. Coherent migration of charges in the topological thin film cluster structures is under discussion with analysis of the electron energy states in frame of several models. Modeling of the optical properties for bimetallic (Ag/Au) nanocluster system is carried out.

We study experimentally the dynamics of the phase composition in micro-regions of the zone of laser radiation exposure to the surface of stainless steel, and discuss the parameters for increase of the entropy mixing.

Finally, we focus our attention on the problems being under intensive study in modern physics and technologies in connection with developed by us approach. In particular, in the problem of superconductivity in similar multilayer surface structures of different dimensions and shapes/sizes of their constituent nanoobject (from 0D to 3D), being organized into certain spatial configuration with the corresponding elemental composition and surface relief in contact layers and heterostructures of different types (e.g. with the Berry curvative and Berry connecture) are the principal directions in modern study in the field, and discuss by us.

S04-13 Micro and nano powder production with conical laser beams and inert gas flow condensation

Yu. Chivel
Additive Technologies Lab , Minsk, Belarus
yuri-chivel@mail.ru

A process is presented for obtaining a spherical powder in a wide range of sizes 50 nm - 50 μm, in which a continuous near-surface optical discharge with a temperature of 20 kK is formed using conical laser beams in an argon flow, into which material is introduced in the form of a wire or powder stream. The condensation of particles are strongly and rapidly quenched by an inert gas flow, producing high supersaturation. The process capacity is 0.5 kg/kWh with a laser power of 10 kW.

The process of nanoparticle formation using inert gas condensation of metal vapour produced by conical laser beam vaporization of micropowder 40-60 μm stream with a particle concentration of 10^4-10^6 cm $^{-3}$ has been investigated. Obtained nanoparticles 20-50 nm are collected in the form of conglomerates up to 100 nm in size. The productivity of the process reaches 0.2 g/Wh

S04-14 Laser radiation impact on pseudoisocyanine J-aggregates deposited on an Al_2O_3/Ag hybrid film

R.D. Nabiullina, I.Yu. Nikitin, L.N. Borodina, I.A. Gladskikh, A.A. Starovoytov
ITMO University, St. Petersburg, Russia
rezida2105@mail.ru

The studies of organo-inorganic composites have gained a lot of attention recently. Molecular nanoclusters, such as J-aggregates, with high absorption, fluorescence cross-sections and nonlinear optical characteristics may be used in these nanocomposites. Organic dyes incorporated into nanoporous material are considered as an attractive alternative to pure organic materials due to their mechanical, thermal and optical stability. The nanoclusters, embedded in nanoporous matrices, can demonstrate an optical excitation transfer. This fact makes fabrication of scattering feedback lasers or so-called random lasers possible. It is known that near field of plasmonic metal nanoparticles contribute to an increase of the quantum yield of nanoclusters. Thus, the introduction of molecular nanoclusters into the pores of anodized aluminum, grown on a substrate of metal nanoparticles, will allow to obtain a laser media with higher emission intensity.

The effect of laser radiation on the J-aggregates deposited on hybrid Al_2O_3/Ag film has been studied. The hybrid film, based on anodized aluminum and silver island film has been synthesized, using a novel method, based on physical vapor deposition and electro-chemical one-step anodisation. J-aggregates of pseudoisocyanine dye were obtained according to the original method of thermostimulated self-assembly of the dye in ethanol without the use of salts. Molecular nanoclusters were deposited on an Al_2O_3 hybrid film by immersion of the film in a dye solution.

The optical properties of samples were investigated by absorption and fluorescence spectroscopy. The dependence of the optical properties of the hybrid film on the anodizing time was obtained. When films with dye are excited by laser radiation in the band of oxygen vacancies of aluminum oxide (405 nm), the transfer of optical excitation energy from them to J-aggregates is observed, which is confirmed by fluorescence spectra. Laser radiation impact on J-aggregates of a dye deposited on an Al_2O_3/Ag hybrid film was considered.

Mr. Nikitin and Ms. Nabiullina are grateful to RPMA grant of School of Physics and Engineering of ITMO University and Babkina A.N. and Aseev V.A. for the provided laser installation.

S04-15 Creation of quasi-regular nanodomain structures in ferroelectrics by pulse IR laser irradiation

M. Kosobokov, V.Ya. Shur, A. Makaev, D. Kuznetsov, M. Nebogatikov
Institute of Natural Sciences and Mathematics, Ural Federal University,
Ekaterinburg, Russia
mihail.kosobokov@urfu.ru

Uniaxial ferroelectrics lithium tantalate $LiTaO_3$ (LT) and lithium niobate $LiNbO_3$ (LN), are the most popular materials for the implementation of domain engineering for the creation of effective frequency converters of laser light.

We studied the formation of nanodomain structures under pulse irradiation and scanning of single-domain LN and LT wafers of congruent composition 0.5 mm thick using VLS3.50, Universal Laser System (λ = 10.6 μm, 40 W). Scanning was done by sample movement at a speed of 2.5 m/s. The domain imaging at the surface was realized after chemical etching by optical microscope Olympus BX51 and by scanning electron microscope Auriga CrossBeam Workstation, and in the bulk by Cherenkov-type second harmonic microscopy.

The irradiation of LN wafer by two consecutive pulses leads to transformation of the stripe domains appeared at the surface after the first pulse into the regular arrays of isolated round domains after the second one. The domain imaging in the bulk allows to reveal the 1D to 2D transformation of the comb-like domain to array of isolated conical domains. The obtained new effect has been attributed to the action of the pyroelectric field pulses with alternating signs.

The multiple IR laser scanning of LT wafers results in formation of quasi-regular structure of round domains. It was shown that the domains appeared after the second scan grew by merging with small domains. The revealed ordering of the domain structure was attributed to domain interaction. The finite element method was used to simulate the time dependence of the pyroelectric field for explaining the ordering. The obtained results present interest for the further development of domain engineering methods in LT crystals.

The equipment of the Ural Center for Shared Use “Modern nanotechnology” Ural Federal University (Reg.№ 2968) was used with the financial support of the Ministry of Science and Higher Education of the Russian Federation (Projects № 075-15-2021-677). The research was made possible by Russian Science Foundation (Project №19-12-00210).

Ultrafast Laser-Matter Interaction & Technologies (S05)

S05-1 Unexpected pulse repetition rate effect on femtosecond laser-induced birefringent structures in alkali-containing glass

S.V. Lotarev, A.S. Lipatiev, S.S. Fedotov, A.I. Pomigueva, V.N. Sigaev
Mendeleev University of Chemical Technology, Moscow, Russia
lotarev.s.v@muctr.ru

Nanogratings are birefringent periodical nanostructures written by a series of ultrafast-laser pulses in the bulk of oxide glasses and some other materials. They are regarded as the first optically induced structure with a regular period multiply smaller than the wavelength of light. Their controllable form birefringence and reduced chemical durability have already been applied in ultrastable data storage, polarization converters, and microfluidics [1]. Nanogratings written in multicomponent glasses can exhibit some specific features such as the nanoperiodic variation of chemical composition inside a nanograting and is much less investigated so far. In this study, we investigated formation of nanogratings and the effect of the pulse repetition rate (PRR) on their birefringence in alkali-containing glass by the example of $22Na_2O{\cdot}77GeO_2$ composition. FEMTOLAB laser microfabrication setup based on PHAROS SP femtosecond laser operating at 1030 nm wavelength was applied in the experiments.

We have revealed, that at a PRR below ~250 kHz, the laser-induced form birefringence is observed under series of 10^5 to 10^6 pulses, whereas a higher PRR promotes precipitation of $Na_2Ge_4O_9$ microcrystals due to the thermal effect of ultrashort pulses. At some exposure conditions, these effects take place simultaneously We also showed the unexpected growth of optical retardance of the laser-written nanogratings with the PRR starting from 110-125 kHz, which principally differs from stability or slow gradual decrease of retardance with increasing PRR earlier reported for some fused silica and some multicomponent glasses [2]. The revealed phenomenon can be presumably attributed to local variation of chemical composition due the thermal diffusion of Na^+ cations increasing with the thermal effect of the femtosecond laser pulses at higher repetition rate.

This study was funded by RFBR and DFG (project 21-53-12026).

1. B. Zhang, X. Liu, and J. Qiu, Single femtosecond laser beam induced nanogratings in transparent media - Mechanisms and applications, J. Materiomics, vol. 5, pp. 1-14 (2019).
2. J. Cao, L. Mazerolles, M. Lancry, D. Solas, F. Brisset, and B. Poumellec, "Form birefringence induced in multicomponent glass by femtosecond laser direct writing," Opt. Lett. 2021, V.41, P. 2739.

S05-2 Single-shot compressed optical field topography

Zhengyan Li
Huazhong University of Science and Technology, Wuhan, China
zhengyanli@hust.edu.cn

Femtosecond lasers are powerful tools to detect and control ultrafast phenomena. The ability to diagnose the femtosecond optical field in three-dimensional (3D), including two dimensions in transverse spatial directions and one dimension in the longitudinal temporal direction, in a single shot is the cornerstone of understanding ultrafast dynamics. Some quasi-3D solutions that sample a finite number of discrete 2D spectral or temporal slices have been proposed to resolve the intensity of optical field in absence of phase information. Conventional ultrafast phase measurement techniques are limited by detection dimensions.

By combing recent advances in compressive imaging techniques and phase retrieval techniques, compressed optical field topography (COFT) is proposed to draw a 3D topographic “map” for an arbitrary ultrafast optical field in a single shot. Two global 3D phase retrieval procedures are presented, one is based on wave front recovery and non-collinear FROG, and the other is based on 3D spectral holography. Both implementations succeed in visualizing the optical field of femtosecond laser pulses with spatiotemporal coupling, and the former one is applied to study the light-speed propagation of a plasma channel ionization front, illustrating the versatility of COFT.

COFT can further promote the development of ultrafast imaging or photography techniques in two aspects. First, COFT incorporating 3D phase information has a nearly multi-quadrillion imaging frame rate, theoretically only limited by geometric smearing in the non-collinear FROG system. Second, optical compressed imaging and a global 3D phase retrieval applied in COFT can be extended to short-wavelength ranges in principle. Short wavelength COFT is expected to reveal sub-nanometer spatial and attosecond temporal structures.

S05-3 Peculiarities of UV ultrashort laser radiation interaction with dielectrics

V.S. Makin [1,2], R.S. Makin [3]
[1] Peter the Great St. Petersburg Polytechnic University, Nuclear Energy Institute, Sosnovyi Bor, Leningrad Oblast, Russia
[2] “Kometa” corporation – NPC OEKN, Saint-Petersburg, Russia
[3] National Nuclear Research University, MIFI, Moscow, Russia
vladimir.s.makin@gmail.com

The analysis of series of experimental results on the interaction of linear polarized ultrashort (λ = 450 fs) pulses of UV (τ = 248 nm) laser radiation (LR) with ZnO and TiO_2 crystals [1, 2] was made. The energy of photon of LR is higher the energy gap of ZnO and TiO_2, respecrively, 3.2 eV and 3.0 eV (rutil structure). The used energy densities were sufficiently to create the crytical conduction band currier concentration to support the existance of surface plasmon polariton (SPP) at the crystal-vacuum boundary. The analysis was made on the base of universal polariton model (UPM) and nonlinear mathematical model (NMM) formation of spatial periods of nanostructures.

The action of series of N = 5000 pulses (Q = 20 mJ/cm^2) on (0001) ZnO causes the production of dissipative microstructures - microcrystals and their boundaries of 10 nm width. The boundaries were modulated by the nanograting with period d = 30 nm and the size of nanopit is 30 nm [1]. To elucidate the grating formation we consider the intercrystalline boundary as guiding structure to support the propagation of channel surface plasmon polaritons (CSPP). So, the mutual nonlinear interference of spatial harmonics of CSPP of opposite propagation directions produces the nanograting with period $d = \lambda/2k\xi = 30$ nm, k = 4, $\xi \approx 1.03$. Here k is the number of spatial harmonic of CSPP, ξ is the real part of refractive index of the excited crystal-vacuum boundary for channel SPP’s.

At higher energy density (50-200) mJ/cm^2, the formation of nanostructures of normal orientation $\mathbf{g}||\mathbf{E}$ with $d = \lambda/\eta$, $2\lambda/3\eta$ and $\lambda/2\eta$ due to SPP’s participation in nonlinear interference were identified. (Here $\eta \geq 1$). The gratings of normal orientation are modulated by orthogonal ones with $D = \lambda/2\xi$ and $D = \lambda/\xi$ and are identified as nonlinear interference with CSPP participation. The capital letter D is introduced to mark the participation of CSPP in interference. Similar results were obtained for TiO_2 surfaces.

So the experimental results of series of publications on UV short pulsed laser irradiation of dielectrics are well explained in framework of UPM and NMM.

1. Museur L., Manousaki A., Anglos D., Chauveau T., Kanaev A. Effect of laser polarization and crystalline orientation on ZnO surface nanostructuring in the regime of high-density electronic excitation // J. Opt. Soc. Am. B. 2014.V. 31. №11. P. C44-C47.
2. Museur L., Tsibidis G.D., Manousaki A., Anglos D., Kanaev A. Surface structuring of rutile TiO2 (100) and (001) single crystals with femtosecond pulsed laser irradiation // J. Opt. Soc. Am. B. 2018. V. 35. № 10. P. 2600-2607.

S05-4 Femtosecond laser treatment of transparent glass-ceramics

A.S. Naumov, A.S. Lipatiev, G.Yu. Shakhgildyan, S.S. Fedotov, S.V. Lotarev, V.N. Sigaev
Mendeleev University of Chemical Technology, Moscow, Russia
andreynaum13@mail.ru

To date, transparent glass-ceramics have found application in a variety of spheres of our life, from cooking plates to airspace facilities operating in an extreme environment [1]. The ZnO-MgO-Al_2O_3-SiO_2 (ZMAS) system is of special interest for applications in photonics among other glass-forming systems in which it is possible to obtain glass-ceramics with improved mechanical characteristics. Very recently, transparent glass-ceramics has also become an object of laser-induced micromodification studies. In particular, we have shown the fabrication of channel waveguides with a laser-written depressed cladding, also known as Type III waveguides, in Li_2O-Al_2O_3-SiO_2 (LAS) glass-ceramics possessing ultra-low thermal expansion coefficient [2]. Laser-induced space-selective amorphization has been proposed as the main mechanism responsible for the laser-induced decrease of the refractive index in LAS glass-ceramics.

In the present study, we report on direct femtosecond-laser writing of tracks in transparent ZMAS glass-ceramics. The tracks were written by the focused beam emitted by Pharos SP laser (Light Conversion Ltd.) at the wavelength of 1.03 µm, the pulse duration of 180 fs, the pulse energy of 200-500 nJ, the pulse repetition rate of 10-500 kHz, and the scanning speed of 500 µm/s. The diffraction pattern registered for the glass-ceramic region clearly shows reflections typical for nanocrystallites. On the other hand, the diffraction pattern obtained for the core of the laser-inscribed track confirms its complete amorphism which is most likely due to remelting of nanocrystals in the area absorbing the laser energy. As a result, the effect of femtosecond laser pulses on a ZMAS glass-ceramic induces an increase of the refractive index which depends on the pulse energy of the laser pulses, reaching a value of 0.0013. It is expected to give an opportunity for direct laser writing of Type I channel waveguides in ZMAS glass-ceramics.

This work was supported by the Russian Science Foundation (grant #19-19-00613-П).

1. E. D. Zanotto. Bright future for glass-ceramics. Am. Ceram. Soc. Bulletin. 2010. Vol. 89 (8). P. 19-27.
2. A S. Lipatiev, S. S. Fedotov, S. V. Lotarev et al. Direct laser writing of depressed-cladding waveguides in extremely low expansion lithium aluminosilicate glass-ceramics. 2021. Opt. Laser Technol. Vol. 138. P. 106846.

S05-5 Molecular dynamics simulation of structural evolution inalloys under ultrafast laser irradiation

D. Iabbaden[1], C. Fusco[2], J. Amodeo[2], F. Garrelie[1], and J.P. Colombier[1]
[1] Univ Lyon, UJM-Saint-Etienne, CNRS, Institute of Optics Graduate School, Laboratoire Hubert Curien UMR 5516, F-42023 St-Etienne, France
[2] Univ Lyon, INSA Lyon, CNRS, MATEIS, UMR 5510, F-69621 Villeurbanne, France
djafar.iabbaden@univ-st-etienne.fr

Surface structuring of amorphous and crystals materials may find interest in many leading technological applications. The one we target is related to laser-driven surface topography modification, however, so far, no exhaustive study was made to really give a clear picture of the different mechanisms involved in this complex process. The main originality of this work is to investigate the ultrafast phenomena and the subsequent structural modifications triggered by femtosecond laser pulses. In this context, classical molecular dynamics approach is proposed to capture solid-solid phase transformations in alloys. To manage our investigations, we have used LAMMPS to lead atomistic simulation, which is adapted to catch phenomena occurring at a picosecond scale. To model this laser-matter interaction a suitable hybrid simulation combining Molecular Dynamics and Two Temperature Model is used to predict the involved dynamics of the electrons and ions. This combination allows us the control of laser most important processing parameters, namely the fluence and pulse duration. We have to highlight that this work deals with metallic and amorphous based alloys structures. Dealing with such structures is motivated by two reasons, the experimental evidence that this alloys compositions are stable and the availability of a robust Embedded Atomic Method potential which faithfully reproduces the properties required to determine the thermodynamic path for laser-induced polymorphic phase transition.

S05-6 Influence of band filling effects on optical properties of semiconductors under the action of intense femtosecond laser pulses

D.S. Polyakov, G.D. Shandybina, A.A. Shamova
ITMO University, Saint Petersburg, Russia
polyakovdmitry1988@gmail.com

Action of intense femtosecond pulses on band gap materials lead to the generation of dense and hot electron-hole plasma with concentration of above 10^{21} cm^{-3} with following relaxation. The corresponding dynamics of the changes of the optical properties of excited materials can be detected using pump-probe technique by analyzing the reflection (for highly absorbing materials) or transmission (for semi-transparent materials) of probe pulses for different time delays. It was usually assumed that generation of dense electron hole plasma should increase the absorption coefficient after excitation. However, recently it was shown theoretically for semiconductors [1,2] and experimentally for dielectrics [3,4] that for some conditions the transmission coefficient can rapidly increase after excitation by femtosecond laser pulses (and even the amplification of probe pulse can be achieved). Such unusual behavior can be explained by band filling effects during relaxation of electron subsystem, that may lead the creation of population inversion state.

In this report the results of our works [1,2] devoted to the theoretical studying of the influence of band filling effects on optical properties of semiconductor materials (Si, GaAs) under the action of short and ultrashort laser pulses will be presented. It was shown that after excitation of a semiconductor by an intense femtosecond laser pulse one should expect a rapid increase in the transmittance at the wavelength near the edge of interband absorption caused by cooling of electron-hole plasma during electron-phonon relaxation and the optimal condition for its experimental observation was found. Such effect can be used for the experimental determination of the electro-phonon relaxation time in semiconductors. Also, it was shown that taking into account the influence of band filling effects on heating and photoexcitation of Si at wavelength 1.06 μm allows to achieve a good agreement with the experimentally measured melting thresholds in the wide range of the pulse duration (from 100 fs to 100 ns).

The reported study was financially supported by the Ministry of Science and Higher Education of the Russian Federation research agreement No. 075-11-2021-045 of 24.06.2021 (within the framework of decree of the Government of the Russian Federation No. 218 of 09/04/2010).

1. D.S. Polyakov, E.B. Yakovlev, Influence of Burstein–Moss effect on photoexcitation and heating of silicon by short and ultrashort laser pulses at wavelength 1.06 μm, Appl. Phys. A 124 (2018) 803
2. D.S. Polyakov, G.D. Shandybina, A.A. Shamova. Ultrafast changes of optical properties of semiconductors at wavelength near the edge of interband absorption after excitation by femtosecond laser pulse, Optik 256 (2022) 168751
3. T. Winkler, L. Haahr-Lillevang, C. Sarpe, B. Zielinski, N. Gotte, A. Senftleben, P. Balling, T. Baumert, Laser amplification in excited dielectrics, Nat. Phys. 14 (2018) 74–79
4. T. Winkler, P. Balling, B. Zielinski, C. Sarpe, N. Jelzow, R. Ciobotea, A. Senftleben, T. Baumert, Unveiling nonlinear regimes of light amplification in fused silica with femtosecond imaging spectroscopy, Phys. Rev. Res. 2 (2020), 023341

S05-7 Modeling of nanoparticles formation process due to pulsed laser ablation in liquids

D.S. Ivanov[1,2], S.M. Klimentov[2], I.N. Zavestovskaya[1], A. Popov[2], P. Shahov[2], and A.V. Kabashin[2]

[1] P. N. Lebedev Physical Institute of Russian Acad. Sci., Moscow, Russia
[2] MEPHI, Institute of Engineering Physics for Biomedicine Moscow, Russia

Pulsed Laser Ablation in Liquids (PLAL) has proven itself as a pow-erful and efficient method of NPs [1] generation for industrial and bio-medical applications [2]. However, due to a number of interrelated pro-cesses involved into the laser ablation phenomenon, the final character-istics of the resulting particles are difficult to control. Thus, one of the most important properties of the produced NPs such as their mean size and size distribution, depending on the irradiation parameters, frequent-ly have a broad and multimodal distribution [3]. In this work, we inves-tigate the mechanism of NPs generation in liquids as a function of the pulse duration, the indecent fluence, and the irradiation regime (single- multi-pulse). For that purpose we applied the combined atomistic-continuum model to simulate ultrashort laser pulse interaction with gold sample under water layer confinement [4]. The model described non-equilibrium laser-induced phase transitions at atomic level and accounts for the effect of free carriers in continuum. The simulation results are directly compared with the experimental data. The preformed study suggests the methodology for generation of NPs due to PLAL with pre-designed morphology, size, and size distribution demanded in bio-medical applications [5].

1. S. Lal Pal, U. Jana, P. K. Manna, G. P. Mohanta, and R. Manavalan, *Journal of Applied Pharmaceutical Science* **01 (06)**, 228-234 (2011).
2. K. McNamara and S.A.M. Tofail, *Phys. Chem. Chem. Phys.* **17**, 27981-27995 (2015).
3. A.V. Kabashin, M. Meunier, C. Kingston, and J.H.T. Luong, *J. Phys. Chem. B* **107**, 4527 (2003).
4 D.S. Ivanov, Th. Izgin, A.N. Mayorov, V.P. Veiko, B. Rethfeld, Y.I. Dom-brovska, M.E. Garcia, I.N. Zavestovskaya, S.M. Klimentov, and A.V. Kabash-in, *Molecules* **25**, 67 (2020).
5 D.S. Ivanov, S.M. Klimentov, I.N. Zavestovskaya, B. Rethfeld, M.E. Gar-cia, A. Popov, P. Shahov, and A.V. Kabashin, submitted *Molecules* (2022).

S05-8 Mechanisms of surface structuring by short and ultrashort laser pulses in axial magnetic field

Vitaly Gruzdev
Department of Physics and Astronomy, University of New Mexico, Albuquerque, USA
vgruzdev@unm.edu

Recently reported enhancement of nanosecond laser ablation of semiconductors by axial (i. e., directed parallel to laser beam and normal to a target surface) magnetic field [1, 2] stimulated increased attention to use of the magnetic field to enhance laser ablation by femtosecond laser pulses [3-5]. Those publications [3-5] have claimed quite non-trivial modification of laser-induced surface structures by axial magnetic fields. Here we summarize the major features of the reported modifications of surface nano-structuring by linearly polarized femtosecond laser pulses in axial magnetic field and interpret them in terms of modification of structure of surface electromagnetic waves. Our theoretical analysis is based on modeling of free-carrier generation in semiconductors by ultrashort laser pulses and modification of the free-carrier optical response by the magnetic field. The optical response is evaluated by the Lorentz-Drude model with time-dependent density of free carriers. The model predicts slight modification of the optical response in the direction parallel to the polarization of laser pulses compared to the usual mechanisms of surface nano-structuring by ultrafast lasers. The major feature is generation of the optical response and related propagation of surface waves in the direction normal to the polarization. The latter component of the optical response provides transversal shift of the laser-generated structures and formation of 2D surface patterns. Based on obtained results, we discuss potential applications of magnetic fields to generate advanced multi-scale surface structures by single laser beam.

1. H. Farrokhi. V. Gruzdev, et al., “Magneto-absorption effects in magnetic-field assisted laser ablation of silicon by UV nanosecond pulses”, *Appl. Phys. Lett.*, v. **108** (25), 254103 (2016).
2. H. Farrokhi, et al., “Fundamental mechanisms of nanosecond-laser-ablation enhancement by axial magnetic field”, *J. Opt. Soc. Am. B*, v. **36** (4), pp. 1091-1100 (2019).
3. J. Maksimovic, et al, “External Field-Controlled Ablation: Magnetic Field”, *Nanomaterials* **9**, 1662 (2019).
4. J. Maksimovic, et al., “Ablation in Externally Applied Electric and Magnetic Fields”, *Nanomaterials* **10**, 182 (2020).
5. M. Schäfer, et al., “Magnetic-field assisted laser ablation of silicon”, *JOSA B* **38** (12), E1-E6 (2021).

FT-S05-1 Differentiated contribution of relaxation and recombination processes to silicon heating under the action of femtosecond laser radiation

A.A. Shamova, D.S. Polyakov, G.D. Shandybina
ITMO University, Saint Petersburg, Russia
alex.shamova94@gmail.com

Knowledge of the heating regularities of monocrystalline silicon is of great practical interest and allows justifying the choice of highly efficient regimes of femtosecond laser fabrication of multifunctional surfaces, which can be used to create modern solar cells, highly sensitive photodetectors, biosensors, biochips, as well as biomimetic scaffolds for regenerative medicine.

Laser heating of silicon occurs as a result of several successive stages: electron-phonon relaxation (a few ps), relaxation of high-energy Auger electrons (~ 10 ps), and nonradiative recombination (~ 100 ns). Previous studies have been performed for short pulses, and the significance of nonradiative recombination has been shown. For femtosecond pulses, the influence of Auger recombination on lattice heating was taken into account together with electron-phonon relaxation and mainly in the single-pulse irradiation regime. However, the question of the relative contribution of recombination processes to the heating of the crystal lattice of the semiconductor under femtosecond laser irradiation remains not fully clarified.

The report presents for discussion the results of numerical modelling of the differentiated contribution of relaxation and recombination processes to the heating of the silicon surface under the action of femtosecond laser radiation at fluences near and below the melting threshold. It is shown that recombination processes not only slow down the cooling process, but are also an influential factor in increasing the temperature of the silicon surface. The results obtained expand the understanding of the regularities of silicon heating by femtosecond laser radiation and allow explaining the development of activation-type processes that usually accompany laser modification of silicon surface, which is especially important for biomedical applications.

S05-9 Laser direct writing waveguide with variable cross section and its application in on-chip mode conversion

Zhong Lijing [1], Wang Yuying [1], Yang Yi [2], Chen Zhi [1], Tan Dezhi [1], Qiu Jianrong [2]
[1] Zhejiang Lab, Hangzhou, China
[2] State Key Laboratory of Modern Optical Instrumentation, College of Optical Science and Engineering, Zhejiang University, Hangzhou, China
zlight.optics@gmail.com

Laser direct writing waveguide has attracted widely research interests in numerous transparent materials, such as, glass [1], crystal [2] and polymer [3], due to their great potential in constructing 3D on-chip photonic circuits [4]. In previous works, the heat-accumulation effect outside the laser focal volume was fully developed to obtain waveguides with large cross-sectional diameter for the purpose of reducing the coupling loss with the commercial single-mode fiber [5,6]. However, large-sized waveguides usually result in asymmetric cross-sections and rough control of its refractive index distribution. In order to obtain a circularly symmetric waveguide, complex beam shaping methods, such as, SLM beam shaping method [7], and slit shaping method [8], are attempted. However, waveguides with complex cross-sectional shapes (such as ring-shaped waveguide in our work) are rarely reported in previous results. This shortcoming fundamentally increases the difficulty in controlling the guiding mode and polarization characteristics of the laser direct writing waveguide and further limits the expansion of the waveguide functionalities.

In order to harness this issue, we have proposed a method by constructing waveguide's core at sub-micron resolution, namely, "photonic-like lattice waveguide (PLLW)" [9]. The PLLW conceived the design of waveguide refractive index profile at sub-micron resolution, which was impossible in previous work. As an interesting demonstration (Fig. 1), a PLLW with circular input and ring-shape output was implemented to converse Gaussian mode to doughnut-like mode, showing high conversion efficiency while keeping a very low insertion loss of 1.65 dB (wavelength: 976 nm).

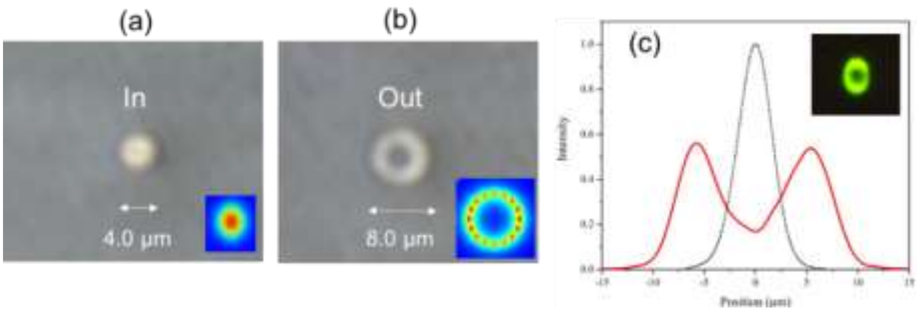


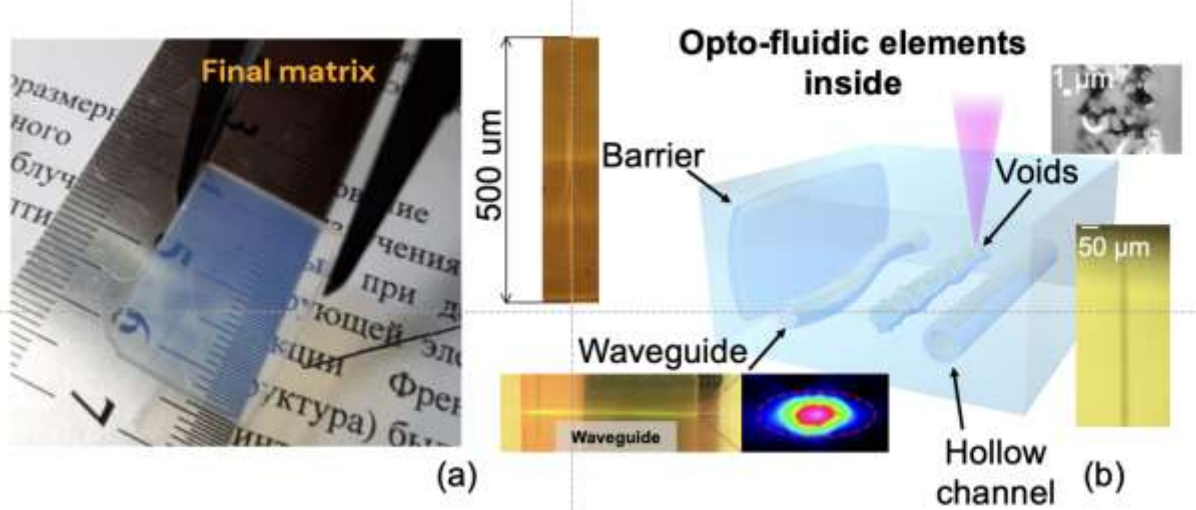
Figure 1. Microscopic cross-section images of the waveguide with circular input (a) and ring-shape output (b). The near-field distributions of the guiding mode (c).

1. Dezhi Tan, Zhuo Wang, Beibei Xu, Jianrong Qiu, Photonic circuits written by femtosecond laser in glass: improved fabrication and recent progress in photonic devices, Adv. Photonics 3, 2 (2021) 024002.
2. Yuechen Jia, Shixiang Wang, Feng Chen, Femtosecond laser direct writing of flexibly configured waveguide geometries in optical crystals: fabrication and application, Opto-Electronic Advances 3, 10 (2020) 190042.
3. Gian-Luca Roth, Stefan Kefer, Steffen Hessler, Cemal Esen, Ralf Hellmann, Polymer photonic crystal waveguides generated by femtosecond laser, Laser Photonics Rev. 15, 11 (2021) 2100215.
4. Xu-Lin Zhang, Feng Yu, Ze-Guo Chen, Zhen-Nan Tian, Qi-Dai Chen, et al., Non-Abelian braiding on photonic chips, Nat. Photonics (2022).
5. Dezhi Tan, Bo Zhang, Jianrong Qiu, Ultrafast Laser Direct Writing in Glass: Thermal Accumulation Engineering and Applications, Laser Photonics Rev. 15, 9 (2021) 2000455.
6. Shane M. Eaton, Haibin Zhang, Peter R. Herman, Fumiyo Yoshino, Lawrence Shah, et al., Heat accumulation effects in femtosecond laser-written waveguides with variable repetition rate, Opt. Express 13, 12 (2005) 4708.
7. A Ruiz De La Cruz, Andrés Ferrer, W Gawelda, D Puerto, M Galván Sosa, et al., Independent control of beam astigmatism and ellipticity using a SLM for fs-laser waveguide writing, Opt. Express 17, 23 (2009) 20853.
8. Martin Ams, GD Marshall, DJ Spence, MJ Withford, Slit beam shaping method for femtosecond laser direct-write fabrication of symmetric waveguides in bulk glasses, Opt. Express 13, 15 (2005) 5676.
9. Yuying Wang, Lijing Zhong, Zhi Chen, Dezhi Tan, Zaijin Fang, et al., Photonic lattice-like waveguides in glass directly written by femtosecond laser for on-chip mode conversion, Chinese Optics Letters 20, 3 (2022) 031406.

S-05-10 Femtosecond laser fabrication of optofluidic elements in nanoporous silicate matrices

R.A. Zakoldaev [1], V.A. Yakimuk [1], Y.I. Yandybaeva [1], A.S. Shishkina [1], A.E. Rupasov [1,2], P.A. Danilov [2], N.A. Smirnov [1,2], S.I. Kudryashov [2], O.V. Andreeva [1], V.P. Veiko [1]
[1] ITMO University, St. Petersburg, Russia
[2] P.N. Lebedev Physical Institute of RAS, Moscow, Russia
zakoldaev@gmail.com

Femtosecond laser writing of three-dimensional structures in glass is a key technology for fabrication of chip scale devices - molecular sensors, waveguide lanterns, phase optical elements and microfluidics elements. Various structural modification depending on the intensity of laser radiation, can be formed [1] - an increase in material density, generation of point defects, nanogratings, and material decompaction. The utilisation of nanoporous silicate matrices [2] expands the thresholds for laser processing, the functionality of structures and thus suggest the novel optofluidic structures fabrication.



We propose LDW inside of a nanoporous silicates matrices (NPSM-17) in the form of plane-parallel plate (20x20x1mm) with free volume of pores 25%. For this a femtosecond laser (Avesta, Antaus) operating at 1035 nm wavelength with a pulse duration of 220 fs and repetition rate up to 1 MHz was utilized. As a results, a set of structures were fabricated - waveguides of several types, microfluidic channels and barriers. We considered the application of some structures in the manufacture of waveguide sensors for liquids and gas components (Figure).

The study is funded by the grant of Russian Science Foundation (project № 20-71-10103)

1. K. Sugioka et al. Ultrafast lasers—reliable tools for advanced materials processing. Light: Science & Applications, 3(4), e149 (2014).
2. Z. Lijing, et al. Optical Sensitivity of Waveguides Inscribed in Nanoporous Silicate Framework, Nanomaterials 11.1 (2021).

S-05-11 Laser induced of periodic nanostructures in the bulk and on the surface of dielectrics

A.E. Rupasov [1,2], P.A. Danilov [1], N.A. Smirnov [1,2], S.I. Kudryashov [1], R.A. Zakoldaev [2]
[1] P.N. Lebedev Physical Institute of RAS, Moscow, Russia
[2] ITMO University, St. Petersburg, Russia
rupasovan@lebedev.ru

The interaction of femtosecond laser pulses with dielectrics is of great interest from the point of view of fundamental physics and applications. When intense laser pulses interact with a dielectric, permanent structures can form in the volume of the material, which arise due to near-field scattering and plasmonics. Bulk structures in this case are defects from subwavelength periodic structures resembling LIPSS (laser-induced periodic surface structures) with a changed refractive index. The most promising technologies include information recording, optical elements, waveguides, diffraction gratings, etc.

To date, the mechanism of formation of bulk periodic structures in dielectric materials is not completely clear. The question of the formation of an electron-hole plasma and interaction with electromagnetic fields near the focal plane remains open. In a transparent material, there is no linear absorption of the incident laser radiation. The question of the mechanisms of defect formation also remains; in the case of silica materials, the formation mechanisms can be associated with photoinduced breaks of strained Si-O-Si bridge bonds, as a result, the material becomes denser due to the migration of oxygen and silicon into the region of laser interaction. In fluorite, the mechanisms may be related to Frenkel pairs, where the F- ion migrates through the crystal lattice. Therefore, the fundamental mechanism of mass transfer, which precedes the formation of bulk nanorefractive nanocoatings in silicon dielectrics, is necessary for wide tuning and optimization of the optical characteristics of such nanophotonic structures.

These and other additional studies shed light on subsequent microscopic processes underlying the formation of birefringent structures in the bulk dielectrics.

The study was supported by a grant from the Russian Science Foundation (project no. 20-71-10103).

S05-12 Laser-induced optical activity of porous glass impregnated with metal nanoparticles

D.R. Dadadzhanov, A.A. Sapunova, Y.I. Yandybaeva, R.A. Zakoldaev, I.A. Gladskikh, T.A. Vartanyan
ITMO University, St. Petersburg, Russia
daler.dadadzhanov@gmail.com

Chirality is an essential characteristic that describes the property of an object incompatibility with its mirror image under any combination of rotations and displacements in three-dimensional space. The synthesis of chiral nanoparticles is usually based on chemical methods using chiral amino-based precursors as template on metal seed nanoparticles. Another method, such as electron beam lithography, allows the formation of two-dimensional chiral structures of any given shape. However, these methods are either expensive or require multi-step procedures for the synthesis of chiral nanostructures. Consequently, the development of new accessible methods for creation of nanostructures with strong chirality is an important goal of scientific researches.

Here, we propose a new approach to induce chirality in gold nanoparticles embedded into nanoporous glass. CTAB-stabilized gold nanoparticles were synthesized by applying the two-step seeding – growth approach. Then, gold nanoparticles were incorporated into nanoporous silica matrices with the average pore size of 17 nm and subsequently irradiated by the focused 2-nd harmonic beam of a pulsed picosecond Nd:YAG laser with circular polarization. The laser induced chirality was revealed via circular dichroism of the obtained nanostructure. The observed transformation of the achiral samples into optically active media can be attribute to the spectral hole burning effect [1] consisting in selective heating of resonant gold nanoparticles that leads to their melting, shape changing and fusion.

The complex nature of the observed phenomena is stressed by the fact that the strength of the circular dichroism of gold nanoparticles inside the porous glass showed a sharp difference under illumination from opposite directions. This difference may be understood in the framework of a theory that combines the conventional description of optical activity of chiral objects with the currently achieved understanding of planar chirality [2].

This possibility of light controlling by chiral nanoparticles opens up new horizons for the development of active and passive optical devices.

The study was supported by the Russian Science Foundation grant No. 21-72-10098, https://rscf.ru/en/project/21-72-10098/.

1. T. Vartanyan, J. Bosbach, F. Stietz, F. Träger. Appl. Phys. B, v. 73, pp. 391 - 399 (2001)
2. A. Papakostas, A. Potts, D.M. Bagnall, S. L. Prosvirnin, H. J. Coles, N. I. Zheludev. Optical Manifestations of Planar Chirality. Phys. Rev. Lett.,v. 90, Iss. 10, P. 107404 (2003)

FT-S05-2 Direct laser writing of microchannel inside transparent optical material

A.S. Shishkina, R.A. Zakoldaev, O.V. Andreeva
ITMO University, St. Petersburg, Russia
shishka2001.shishkina@yandex.ru

Ultrashort laser micromachining of optically transparent materials has long been a proven technology due to fabrication of different structure micro- and nanoscale inside and on the surface of the material [1]. Such fabrication of microstructures finds wide application in manufacturing [2, 3]. One of the most promising applications of femtosecond lasers for microstructuring of materials is microfluidics. This field implies the fabrication of hollow microchannels inside the dielectric, which have a lot of functions: supply, mixing, separation of the reagent and analyte. This is enough to conduct a laboratory study on a millimeter-scale chip [4].

The purpose of this study is to laser direct writing (LDW) prototypes of microchannels inside nanoporous silicate matrix (NPSM) [5] and cleaning these structures in water under the action of ultrasound.

In the course of experimental studies, using femtosecond ytterbium fiber laser Antaus-20W-20u/1M (1030 nm, 0.22-3 ps) and NPSM with an average pore size of 17 nm and a porosity of 50%. Focusing of laser radiation was carried out using an objective (20X, NA=0.4; 60X, NA=0.85). As a result of laser exposure, areas of decompression of the porous structure of the sample were formed. In the cross section of the formed track, glass destruction products are formed, which are cleaned in water under ultrasound action (150 min, 31°C). It should be noted that this method does not use acid/alkali to clean the channels.

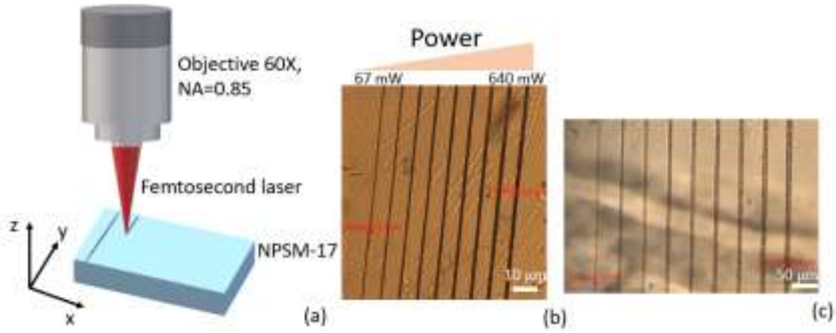


Fig.1. Schematic image of laser direct writing (a), microchannels after laser processing of the material (b) and after cleaning in water under ultrasound action (c)

The study is funded by the grant of Russian Science Foundation (project № 20-71-10103).

1. Liu, Z., Xu, J., Lin, Z., Qi, J., Li, X., Zhang, A., ... & Cheng, Y. (2021). Optics & Laser Technology, 141, 107118.
2. Cheng, Y. (2017). Micromachines, 8(2), 59.
3. Lapointe, J., Gagné, M., Li, M. J., & Kashyap, R. (2014). Optics express, 22(13), 15473-15483.
4. Schaap, A., Rohrlack, T., & Bellouard, Y. (2012). Lab on a Chip, 12(8), 1527-1532.
5. Andreeva, O. V., Obyknovennaya, I. E., Gavrilyuk, E. R., Paramonov, A. A., & Kushnarenko, A. P. (2005). Journal of optical technology, 72(12), 916-922.

FT-S05-3 Structuring and permeability control of nanoporous silicate matrices by femtosecond laser pulses

Y.I. Yandybaeva, A.A. Sapunova, R.A. Zakoldaev, O.V. Andreeva
ITMO University, St. Petersburg, Russia
yulia.yandybaeva@gmail.com

During recent years materials with micro-sized pores have been widely used, for example, microfluidic devices based on porous paper or nitrocellulose [1] and chemical sensors with porous glass blank [2]. However, in most cases, such devices are disposable, chemically and mechanically unstable, or have a pore size not enough for large molecules penetration. We are researching a more resistant nanoporous silicate matrix (NPSM) to fabricate such chips. Due to the high content of SiO2, NPSM has high transparency in the visible and IR range, increased chemical and thermal resistance [3]. Its additional advantage is a system of connected nanopores with a controlled size (5-50 nm) and porosity (50%).

To fabricate multifunctional chips based on the NPSM there is a technology of physical and chemical separation of a porous glass plate using impermeable or partially permeable molecular barriers [4]. In NPSM the formation of such barriers occurs due to the fabrication of local densification under the femtosecond laser radiation (ANTAUS-20W-20u/1M, Avesta Ltd., Moscow, Russia) with λ = 1030 nm, τ = 220 fs and ν up to 1 MHz. There are 2 ways to form a barrier: multi-step using a short-focus lens (Fig.1, a) and single-step using a long-focus lens (Fig. 1, b).

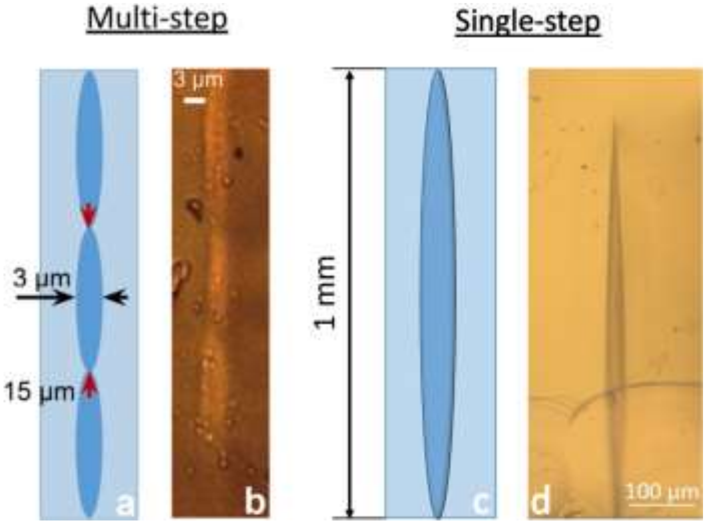


Figure 1 – multi-step mode: a) scheme and b) microphoto of the barrier in the cross section of the NPSM plate [4]; single-step mode: c) scheme and d) microphoto of the barrier in the cross section of the NPSM.

The next step in the fabrication of microfluidic devices is the impregnation of the NPSM sample with dyes which have different molecule's sizes, for example, thionine and rhodamine 6G, whose luminescent properties change in solutions in ethanol and acetone in different concentrations. Nowadays, research is being conducted on the integration of noble metal nanoparticles into NPSM plates, also the effect of pore size on spectral characteristics and the fabrication of independent cells on a single plate are being considered.

The study is funded by RPMA grant of School of Physics and Engineering of ITMO University.

1. Iles, A. H., et al. (2022) Talanta, 237, 122944.
2. Maruo, Y. Y., et al. (2018) Microchemical Journal, 141, 377-381.
3. Andreeva, O. V., et al. (2021) Optics and Spectroscopy, 129(4), 418-426.
4. Itina, T. E., et al. (2019) Optical Materials Express, 9.11, 4379-4389.

FT-S05-4 Laser-induced micromachining inside solid glass to fabricate micro-structures for microfluidics

K. Barhoum, A.S. Shishkina, R.A. Zakoldaev
ITMO University, St. Petersburg, Russia
khaledbarhoum590@gmail.com

As technologies that depend on the usage of microfluidics are receiving growing attention, it's of high importance to investigate and explore new methods for the fabrication of the structures that can be used to optimize microfluidic practice and simplify the fabrication process to realize the optimum result. Ultrashort laser pulses direct writing has proven to be a promising tool to construct precise and controllable structures with a variety of shapes inside transparent materials [1].

In this work, we investigate a new method of microchannels fabrication inside solid glass (DV-1) using femtosecond laser with numerous writing conditions and different ranges of parameters (laser power, writing speed, pulse duration and channels depth under the surface of the glass) to compare and determine the parameters for the favorable outcome. Subsequently, an etching step in hydrochloric acid solution was performed to shape the channels into their final form and provide the solid glass with porous properties, which can widen the applicability of the resulting device. A set of parameters that showed distinguished results has been studied separately to thoroughly understand the dependency of the properties of the fabricated channels on each parameter of the writing procedure.

Channels that have been fabricated using the new technique showed remarkable results in both shape and size, as well as the consistent behavior in response to the etchant along the edges, with the absence of the conic shape of the etched channels that usually appears using other methods. This technique can be used to give a boost to the process of fabrication of structures with complex shapes and 3D geometries inside glass.

The study is funded by RPMA grant of School of Physics and Engineering of ITMO University.

1. Maruo S., Fourkas J.T. Recent progress in multiphoton microfabrication // Laser and Photonics Reviews. 2008. Vol. 2, № 1–2. P. 100–111.

FT-S05-5 Femtosecond direct laser writing of optical channel bulk waveguides in nanoporous silicate matrix

V.A. Yakimuk, D.O. Valkov, R.A. Zakoldaev, O.V. Andreeva
ITMO University, St. Petersburg, Russia
yakimuk2001@mail.ru

Optical waveguides are structures which transmit radiation due to total internal reflection. This is the reason why waveguides are the key element in fabrication of integral photonic devices such as interferometers, sensors of molecules and gas analysis [1]. Femtosecond direct laser writing is a promising tool for channel bulk waveguides fabrication in optical materials [2]. Nanoporous silicate matrix is a prospective base for waveguides inscription, which has shown promising results in small molecules sensing [3]. Symmetrical, low loss and waveguides of several types are in great demand in this matrix. That is why we hold an investigation of femtosecond laser inscription of waveguides in nanoporous silicate matrix.

In our experiment we compared two different ways of waveguides fabrication: without a slit and with one. Using optical microscopy we estimated the waveguide's cross section and aspect ratio of its cross section (with slit we obtained aspect ratio equals to 1-2, without slit - from 5 to 9). The near-field intensity distribution is shown in Figure 1. The experimental scheme consists of red laser (λ = 635 nm), fiber-optics connection with core diameter of 4 µm (Thorlabs, FS-SN-3224), 6-coordinate system which allows to connect fiber with waveguides in different angles and distance, output objective (10X, 0.25 NA), camera (Gentec 3M).

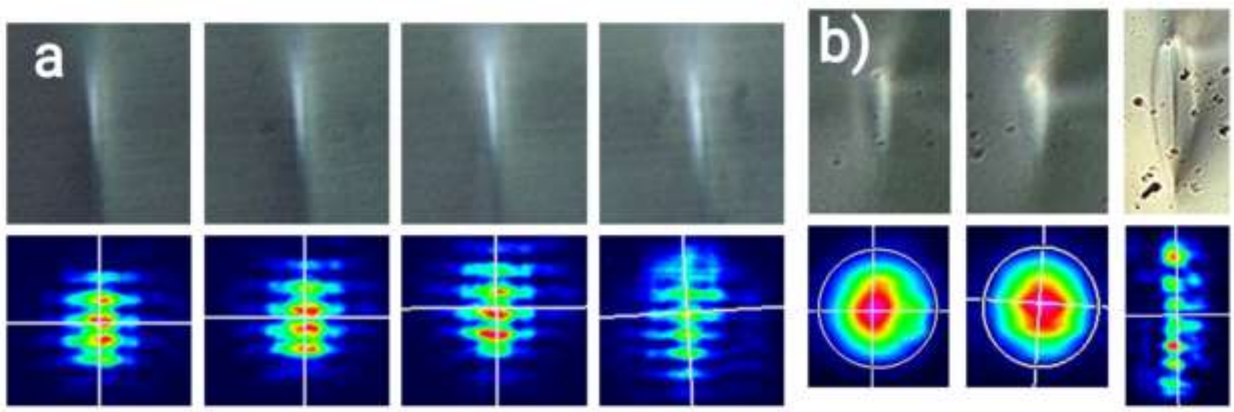


Figure 1 – Near-field intensity distribution: a) waveguides fabricated without slit, b) waveguides fabricated with slit

The study is funded by the grant of Russian Science Foundation (project № 20-71-10103).

1. Schaap, A., Rohrlack, T., & Bellouard, Y. (2012). Optical classification of algae species with a glass lab-on-a-chip. *Lab on a Chip*, *12*(8), 1527-1532.
2. Macias-Montero, M., Muñoz, F., Sotillo, B., Del Hoyo, J., Ariza, R., Fernandez, P., ... & Solis, J. (2021). Femtosecond laser induced thermophoretic writing of waveguides in silicate glass. *Scientific reports*, *11*(1), 1-12.
3. Lijing, Z., Zakoldaev, R. A., Sergeev, M. M., Petrov, A. B., Veiko, V. P., & Alodjants, A. P. (2021). Optical Sensitivity of Waveguides Inscribed in Nanoporous Silicate Framework. *Nanomaterials*, *11*(1), 123.

FT-S05-6 Laser direct writing of volume diffraction elements in glass: design, fabrication, and testing

R.A. Zakoldaev, Li Chunyu, **,** *O.V. Andreeva*
ITMO University, St. Petersburg, Russia
zakoldaev@gmail.com

The development of femtosecond pulsed laser direct writing (LDW) technology has offered the possibility to fabricate phase converter such as optical waveguides, spiral phase plates and photonic chips inside optical materials [1]. Grating or volume phase grating (VPG) as a typical diffractive optical element has also been fabricated inside silicate glass [2]. Traditional VPG consists of two glass plates sandwiched by a layer of dichromate gelatin (DCG) film [3]. However, DCG materials are subject to degradation, which affects the diffraction efficiency. To solve this problem, we suggest the LDW technique to fabricate VPGs, which is based on linear tracks of glass refractive index modification. This method inherits the advantages of traditional VPG, as well as extending the service life of VPG and simplifying the manufacturing process.

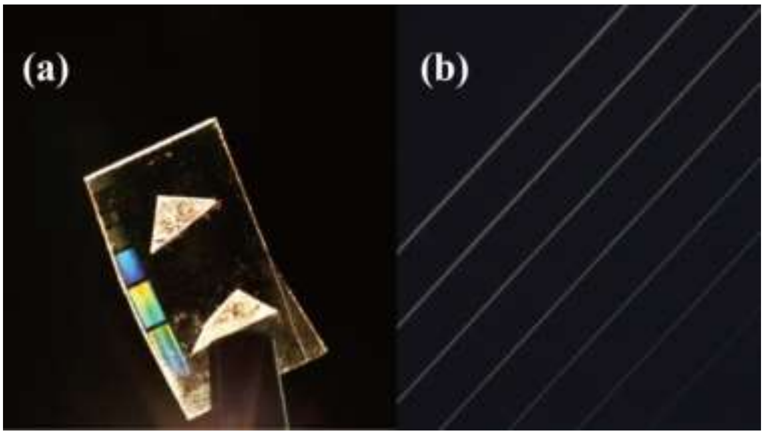


Fig1.(a)VPGs were successfully fabricated inside glass by LDW technique, and diffraction phenomena were observed.
(b)VPG structure was observed with polarized light exposure.

We present the fabrication of VPGs (Fig.1) with different structures in solid and porous glasses by LDW technology and investigate the optical properties of these VPGs, such as optical loss, diffraction order, diffraction efficiency, etc. Based on the experimental results, the optical properties of VPG were found to be closely related to the characteristics of the laser used for fabrication and the period of the grating, while the diffraction efficiency of VPG in double-layer structure was found to be higher than that in single-layer structure. The diffraction efficiency of VPG in porous glass is higher than that of solid glass.

The study is funded by the grant of Russian Science Foundation (project № 20-71-10103);

1. Lijing, Z., Zakoldaev, R. A., Sergeev, M. M., Petrov, A. B., Veiko, V. P., & Alodjants, A. P. (2021). Optical Sensitivity of Waveguides Inscribed in Nanoporous Silicate Framework. *Nanomaterials*, *11*(1), 123.
2. Efimov, O.M., Glebov, L.B., Glebova, L.N., Richardson, K. C., & Smirnov, V. I. (1999). High-efficiency Bragg gratings in photothermorefractive glass. *Applied optics*, *38*(4), 619-627.
3. McCartney, D.J., Sheat, D.E., Leggatt, J.S., & Chamberlin, G. R. (1990, May). Volume phase gratings: reflection filter applications for 1200-1600 nm. In *Computer and Optically Formed Holographic Optics* (Vol. 1211, pp. 200-205). International Society for Optics and Photonics.

S05-13 Femtosecond laser anisotropic structuring GST225 thin films

A. Kolchin[1], S. Zabotnov[1], D. Shuleiko[1], M. Martyshov[1], L. Golovan[1], D. Presnov[1,2,3], V. Glukhenkaya[4], P. Lazarenko[4], T. Kunkel[5,6], S. Kozyukhin[6], P. Kashkarov[1]
[1] Faculty of Physics, Lomonosov Moscow State University (MSU), Moscow, Russia;
[2] Skobeltsyn Institute of Nuclear Physics, Lomonosov MSU, Moscow, Russia;
[3] Quantum Technology Center, Lomonosov MSU, Moscow, Russia;
[4] Institute of Advanced Materials and Technologies, National Research University of Electronic Technology, Zelenograd, Russia;
[5] Moscow Institute of Physics and Technology, Dolgoprudny, Russia;
[6] Kurnakov Institute of General and Inorganic Chemistry RAS, Moscow, Russia
avkolchin@physics.msu.ru

Femtosecond laser-induced periodic surface structures (LIPSS or ripples) with the wavelength and subwavelength periods attract attention not only from the fundamental point of view [1], but may be used in developing novel memory devices with artificial anisotropy [2]. In particular, chalcogenide semiconductor $Ge_2Sb_2Te_5$ (GST225) seems promising to realize rewritable memory on LIPPS [3].

In our work amorphous GST225 thin films with thickness 230 nm on dielectric SiO_2/Si substrates have been irradiated by femtosecond laser pulses (1250 nm, 135 fs, 10 Hz, 0.2 J/cm^2). Optical and scanning electron microscopy revealed LIPSS formation on irradiated area with the size 3×3 mm^2. These lattices possess the period 1100±50 nm which is close to the radiation wavelength, and the orthogonal orientation to the laser polarization. Such structural properties may indicate about the surface plasmon-polariton mechanism of ripples fabrication [1, 3].

A Raman spectrum of the initial sample show an asymmetric broadband from 110 cm^{-1} to 300 cm^{-1} which is responsible for short-range order of the amorphous phase. In turn, Raman spectra of the irradiated sample demonstrate two explicit lines at 125 cm^{-1} and 158 cm^{-1} which indicates laser-induced transition to the face-cubic crystalline (fcc) phase.

Electrophysical measurements of GST225 thin films were provided in the temperature range from 200 K to 400 K. The conductivity of irradiated sample in the direction along scanlines formed by the structuring laser beam is on 1–5 order greater than the same value for the orthogonal direction in plane of the sample. Artificial electrophysical anisotropy can be explained by formation of periodical relief with amorphous and partially crystallized regions as a result of femtosecond laser treatment.

Thus, the results show new opportunities to control electrophysical properties of GST225-based devices with laser-induced artificial anisotropy.

This work was supported by Russian Foundation for Basic Research (grant №20-32-90111).

1. J. Bonse, S. Gräf, Laser Photon. Rev. 2020, 14, 2000215.
2. R. Drevinskas, M. Beresna, M. Gecevičius, et al., Appl. Phys. Lett. 2015, 106, 171106.
3. S. Zabotnov, A. Kolchin, D. Shuleiko, et. al, Micro 2022, 2, 88–99.

S05-14 Modeling ultrafast laser ablation of aluminum films

J.C.D. Bustamante[1], D. Ivanov[2], D. Biasetti[3], G.M. Bilmes[4]
[1] Centro de Investigaciones Ópticas (CONICET-CIC-UNLP) and Universidad Nacional de La Plata, Buenos Aires, Argentina
[2] P. N. Lebedev Physical Institute of RAS, Russia
[3] Comisión Nacional de Energía Atómica, Gerencia LASIE, Argentina
[4] Centro de Investigaciones Ópticas (CONICET-CIC-UNLP) and DCB-FI-Universidad Nacional de La Plata, Buenos Aires, Argentina
camilod@ciop.unlp.edu.ar

With the aim to understand the dynamics of laser ablation surface cleaning processes, the kinetics and microscopic mechanisms of ultrafast laser ablation of thin Al films irradiated by a 120 fs laser pulse was analyzed.

The ablation of condensed matter under exposure to subpicosecond laser pulses has a number of peculiar properties which distinguish this process from ablation induced by nanosecond and longer laser pulses. At high laser fluences, significantly exceeding the threshold for the melting onset, a collapse of the crystal structure overheated above the limit of crystal stability takes place simultaneously in the whole overheated region within a couple ps, skipping the intermediate liquid-crystal coexistence stage. The dynamics of the relaxation of the laser-induced pressure has a profound effect on the temperature distribution in the irradiated films. Lattice distortions and stress gradients associated with the relaxation of the laser-induced pressure destabilize the crystal lattice. High tensile stresses generated in the middle of an irradiated film can also lead to the mechanical disintegration of it.

By using a coupled atomistic-continuum computational model (TTM-MD) we present simulations performed at different laser fluences to, by one hand, determine the ablation threshold. On the other hand analyze the material and its physical features involved in the laser-matter interaction <u>under</u> the ablation threshold. Finally we characterize the ablation process <u>above</u> the ablation threshold. By comparing the obtained results with experimental data performed with the same parameters used in the simulation, we discuss the modeling accuracy.

S05-15 Femtosecond laser-induced structural and electrophysical anisotropy of the amorphous silicon films

D.V. Shuleiko[1], S.V. Zabotnov[1,2], M.N. Martyshov[1], D.E. Presnov[3,1,4], P.K. Kashkarov[1,2]
[1] Lomonosov Moscow State University, Faculty of Physics, Moscow, Russia
[2] National Research Centre «Kurchatov Institute», Moscow, Russia
[3] Lomonosov Moscow State University, Skobeltsyn Institute of Nuclear Physics, Moscow, Russia
[4] Quantum Technology Centre, Faculty of Physics, Lomonosov Moscow State University, Moscow, Russia
dmitriy1815@gmail.com

Femtosecond laser pulses are a powerful tool for modifying the amorphous silicon (a-Si) films on micro- and nanoscale. Nanocrystallization of a-Si films by femtosecond laser radiation increases the conductivity and reduces the photodegradation of this material which is perspective in photovoltaics [1]. Additionally, due to the excitation of plasmon polaritons, the laser-induced periodic surface structures (LIPSS) [2] possessing birefringence and dichroism on amorphous silicon can be formed and potentially applied in polarization optics [3].

In this work, a-Si films with thickness from 400 to 1200 nm and different types of doping (phosphorous-doped n-a-Si or boron-doped p-a-Si) were irradiated by femtosecond laser pulses (λ = 1250 nm, τ = 150 fs, ν = 10 Hz) with fluence 0.15 – 0.3 J/cm^2 in scanning mode at various moving speeds.

In all cases LIPSS orthogonal to laser polarization on the irradiated surfaces were observed. The LIPSS period was close to λ and varied from 840±70 to 1100±100 nm with increasing scanning speed from 50 to 200 μm/s. Simultaneously the LIPSS relief increased from 100 nm up to 400 nm. The Raman spectra demonstrated formation of crystalline silicon (c-Si) phase within irradiated films with the volume fraction up to 82±13% for p-a-Si, and up to 19±3% for n-a-Si.

Dark conductivity of irradiated a-Si films increased by up to 7 orders (up to $1.2\cdot10^{-2}$ S/cm) compared to initial films, due to the crystalline Si phase formation. The conductivity dependence of irradiated a-Si films was nonlinear due to nonuniform c-Si phase distribution within film depth, which was confirmed by Raman measurements. Electrophysical anisotropy was induced by LIPSS formation on all sample's surfaces: the dark conductivity was up to 10 times higher along the LIPSS ridges. Observed anisotropy may be explained by LIPSS depolarizing influence, ablated surface relief and uneven crystalline phase distribution within a-Si films.

The work was supported by the Russian Science Foundation (project 22-19-00035).

1. Hong L., Wang X.C., Zheng H.Y., et al. 2013 J. Phys. D Appl. Phys. 46, 195109
2. Shuleiko D., Martyshov M., Amasev D., et al. 2020 Nanomaterials 11, 42
3. Drevinskas R., Beresna M., Gecevičius M., et al. 2015 Appl. Phys. Lett. 106 171106

FT-S05-7 Nanostructuring of chromium and germanium nitrides films with near-IR and Vis femtosecond laser pulses

K. Bronnikov[1], S. Gladkikh[1], K. Okotrub[1], E. Mitsai[2], A. Kuchmizhak[2,3], A. Dostovalov[1]
[1] Institute of Automation and Electrometry SB RAS, Russia
[2] Institute of Automation and Control Processes of the FEB RAS, Vladivostok, Russia
[3] Pacific Quantum Center, Far Eastern Federal University, Vladivostok, Russia
bronnikovkirill@gmail.com

Irradiation of solids with high-energy ultra-short laser pulses leads to the formation of laser-induced periodic surface structures (LIPSS). LIPSS may appear as periodic grooves or protrusions relative to the initial surface with a period equal or less than the wavelength of the incident light. In this way, multiple lines form simultaneously within the focal spot and can be produced over indefinitely large area by lateral scanning, which is attractive as a technologically simple high-performance method of surface structuring. While LIPSS formation on metals, semiconductors and their alloys has been studied in detail, metal and semiconductor nitrides have not received this much of attention. Metal nitrides are considered as a promising material platform for plasmonics due to high melting point, hardness, carrier mobility in near-IR range in comparison to classical materials in this field, such as silver and gold. Here, we present the results of LIPSS formation on thin films of CrN (25 nm) and Ge_3N_4 (40 nm) by fs laser pulses with linear polarization and the central wavelength λ of 1026 and 513 nm. In the case of CrN film, uniform thermochemical LIPSS with a period of ≈700 nm oriented along the polarization direction are obtained at scanning speeds of up to 500 μm/s for λ = 1026 nm. Reduction of irradiating wavelength down to λ = 513 nm leads to the formation of uniform structures with a period of ≈300 nm at scanning rates of up to 100 μm/s. In the case of Ge_3N_4 film, at scanning rates of 100-1000 μm/s weakly ordered ablative LIPSS with a deeply subwavelength period of ~230 nm and ~110 nm are formed at λ = 1026 and 513 nm, respectively. Raman analysis revealed appearance of CrO_2 and Cr_2O_3 oxides for the CrN film and crystalline Ge for the Ge_3N_4 film after laser treatment.

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

Surface functionalization and related phenomena

(S06)

S06-1 Methods for the formation of computer-generated diffractive structures based on superresolution thermochemical laser writing

V.P.Korolkov[1], V.P.Veiko[2], D.A. Sinev[2], R.I. Kuts[1], A.G. Sedukhin[1], R.V. Shimansky[1]
[1] IA&E SB RAS, Novosibirsk. Russia
[2] ITMO, St. Petersburg, Russia

The search for cost-effective methods for the formation of nanostructured optical elements having minimum sizes of structural elements down up to 100-200 nm is currently rather relevant. In this regard, studies of various types of laser micro-/nanostructuring of thin films of inorganic materials have been actively developed in recent years.

Thin films of transition metals (chromium, titanium and zirconium) are very promising for high-resolution laser writing. The combination of these metals with dielectrics and semiconductors in one multilayer medium can also provide additional technological capabilities for fabrication of new types of diffractive structures.

The contour writing mechanism has been discovered for laser writing on zirconium films. The combination of this mechanism with the plasma treatment of the formed nanostructures gives “dry” process of the formation of binary phase structures. Determining the relationship between the key parameters of this method is important for the subsequent practical realization.

The local formation of laser-induced periodic surface structures and competing interference lithography can also become the basis for the fabrication of new optical elements.

The latest achievements of the joint group of researchers from IA&E SB RAS and ITMO in these areas are highlighted in the proposed report.

S06-2 Periodically poled ferroelectric crystals for laser light frequency conversion and diffractive optical elements

V.Ya. Shur[1], A.R. Akhmatkhanov[1], M.A. Chuvakova[1], A.A. Esin[1], O.L. Antipov[2], A.A. Boyko[3], D.B. Kolker[3], V.S. Pavelyev[4]
[1] Institute of Natural Sciences and Mathematics, Ural Federal University, Ekaterinburg, Russia
[2] Institute of Applied Physics of RAS, Nizhny Novgorod, Russia
[3] Novosibirsk State University, Novosibirsk, Russia
[4] Samara University, Samara, Russia
vladimir.shur@urfu.ru

We present the recent achievements in fabrication of nonlinear frequency converters and tunable diffractive optical elements by domain engineering in single crystals of lithium niobate, lithium tantalate and potassium titanyl phosphate. The promising applications of bulk waveguides created in periodically poled nonlinear crystals by femtosecond laser irradiation are discussed.

The domain structure evolution under application of electric field was systematically studied in uniaxial crystals of lithium niobate (LN) and potassium titanyl phosphate (KTP) families. The created precise periodical domain structures allow to realize the highly effective optical parametric oscillation (OPO) and out-of-cavity second harmonics generation [1]. We demonstrate the possibility to enhance spectroscopic capabilities of mid-infrared pulsed OPOs based on fan-out periodically poled lithium niobate by combining their own wavelength tunability with tunable continuous-wave injection seeding.
Ferroelectric domains with opposite orientation of spontaneous polarization possess the opposite

sign of the linear electrooptic effect, which allowed to create the electrical field-controlled diffraction optical elements (DOE) in LN single crystals. By creation of tailored stable domain structures, we have created DOEs for obtaining Hermite–Gaussian mode (1,0) and mode with orbital angular momentum from Gaussian beam. The continuous tuning of diffraction efficiency has been demonstrated. It was shown that DOE response time is less than 200 ns.

The equipment of Ural Center for Shared Use "Modern Nanotechnology" Ural Federal University (registration number 2968) was used. The reported study was funded by the Ministry of Science and Higher Education of the Russian Federation (projects 075-15-2021-677 and FEUZ-2020-0054).

1. V.Ya. Shur, A.R. Akhmatkhanov, I.S. Baturin, Micro- and nano-domain engineering in lithium niobate, Appl. Phys. Rev., 2, 040604 (2015).

S06-3 The laser source developing trend in accuracy processing

Zhu Xiao[1,2]

[1] National Engineering Center for laser Processing, Huazhong University of Science and Technology

[2] Wuhan Laser Association of Optics Valley of China

With the average power of CW fiber laser and peak power of fs & ps laser higher and higher, a new concept of digital industry laser were developed. What is digital industry laser? The average power, pulse width, peak power, pulse periods, pulse exergy, etc. of the laser are digitized. That means the key parameters (for example laser energy and peak power) of laser interacts with matter are accuracy controlled in the laser. A acoustic optical modulator can realized digital industry laser(Fig.1).

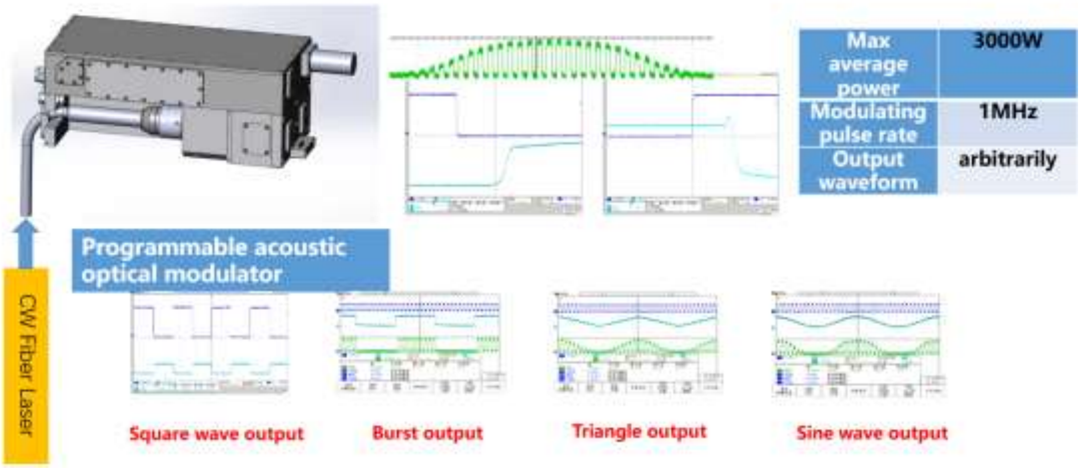


Fig.1 Programmable acoustic optical modulator used in high power fiber laser

For example, drilling a 0.5mm thickness Al2O3 ceramic. If using 500kHz modulated pulses, the recast of the ceramic surface are much better than using a long width pulse drilling. The modulated pulses and non modulated one laser pulse have the same peak power and pulse energy for drilling a hole.

Figure 2 – 500kHz modulated pulses drilling

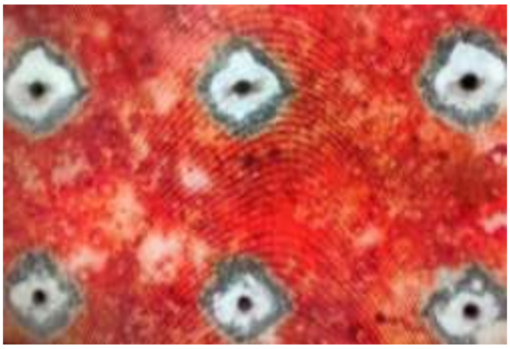


Figure 3 – A long width pulse drilling

S06-4 About the models for regular surface structures formation on semiconductors under interaction with long duration laser radiation

V.S. Makin [1,2], R.S. Makin [3]
[1] Peter the Great St. Petersburg Polytechnic University, Nuclear Energy Institute, Sosnovyı Bor, Leningrad Oblast, Russia
[2] "Kometa" corporation – NPC OEKN, Saint-Petersburg, Russia
[3] National Nuclear Research University, MIFI, Moscow, Russia
vladimir.s.makin@gmail.com

The results of experimental data causing the interaction of polarized laser radiation (LR) of long durations ($\tau > \tau_{e\text{-}ph}$) and normal incidence with semiconductors (Si, Ge) were analyzed [1-5]. Here $\tau_{e\text{-}ph}$ is the electron-phonon interaction time. The formation of grating structures with periods (d) multiplied to λ was shown. The main attention was devoted to structures with d > λ. Such gratings are out of the frame of simple interference models [6]. We show that such gratings are well described by nonlinear mathematical model (NMM) for the formation of spatial periods of structures based on the processes of nonlinear interference. Our analysis allow to show that production of number of structures the mechanisms of creation of which were not related to polaritonic one, or were unclear, are well explained in the framework of universal polariton model (UPM) [1, 7]. In particular, this is one of the first series of experiments with c-Si (thickness 0.3 mm) and millisecond pulse durations [2, 3]. In this case the surface plasmon polaritons (SPP) excitation is realized on the produced dynamic deformation-dislocation gratings, from the spectrum of which the resonant gratings are selected with periods $3\lambda/\eta$, $4\lambda/\eta$, $5\lambda/\eta$ (and fixed as the remnant) and on which the efficient transformation of LR into SPP occurs.

Dynamic periodic surface structures have been formed on silicon film on sapphire substrate under interaction with cw linear polarized CO_2 LR [4, 5]. The sequence of periods with power density is λ/η, $2\lambda/\eta$, $3\lambda/\eta$, $4\lambda/\eta$ and have normal orientation $\mathbf{g}||\mathbf{E}$, where $\mathbf{E}$ is tangential component of LR electric field vector. The large area of solid surface was covered by small scale microgratings $\mathbf{g}\perp\mathbf{E}$ with d ~ λ/n ~ 3.3 μm. They are the result of dynamic thermal waveguide modes (dn/dT > 0) of TE-type interference with incident wave [5].

UPM and NMM are well confirmed by variety of reviewed experimental data and predict the formation of larger periods from the Sharkovsky order [7], for instance, the d = 32 λ/η and thus have predictable force. The reviewed data expand the area of application and justifies UPM and NMM for spatial surface periodic structures formation in this earlier practically unconsidered range of periods d > λ for long duration pulses.

1. Bonch-Bruevich A.M, Libenson M.N., Makin V.S., Trubaev V.V. Optical Engineering. 1992. V. 31. № 4. P. 718-730.
2. Вейко В.П., Дорофеев И.А., Имас Я.А., Калугина Т.И., Либенсон М.Н., Шандыбина Г.Д. Письма в ЖТФ. 1984. Т. 10. Вып. 1. С. 15-20.
3. Banishev A.F., Banishev A.A. AIP Advances. 2012. V. 2. P. 012156.
4. J.S. Preston, H.M. van Driel, J.E. Sipe. Phys. Rev. B. 1989. V.40. № 6. P. 3942.
5. W.A. Hawkins, D.K. Biegelson. Appl. Phys. Lett. 1983. V.42. P.358.
6. Bonse J., Holm S., Kirner S., Rosenfeld A., Kruger J. IEEE J. Selected Topics in Quantum Electronics. 2017. V. 23. № 3. Article 9000651.
7. Макин В.С., Макин Р.С., Воробьев А.Я., Гуо Ч. в сб. Нелинейность в современном естествознании, под ред. Малинецкого Г.Г. М.: изд. ЛКИ, 2009. С. 303-322.

S06-5 Quantitative analysis of the laser-induced periodic surface structures regularity

N.A. Afanasev[1], M.K. Moskvin[1], E.V. Prokofev[1], D.A. Belousov[2], V.P. Korolkov[2], D.A. Sinev[1], G.V. Odintsova[1]
[1] ITMO University, St. Petersburg, Russia
[2] Institute of Automation and Electrometry of the SB RAS, Novosibirsk, Russia
sinev@itmo.ru

Laser-induced periodic surface structures (LIPSS) appear as ripples on a surface of solids, typically with micrometric or sub-micrometric spatial periods. The proper control of LIPSS morphology enables surface functionalization for promising technical, biological, photonic, and medical applications [1-4]. There is however a problem in assessing and comparing the ordering properties of the structures, which complicates standardization and industrialization of the method in the areas, where the coating reproducibility is crucial for its performance. The most common procedure for assessing LIPSS ordering is based on analysis of Fourier images, which allows to determine the dispersion of the LIPSS orientation angle (DLOA), their spatial periods Λ and deviations $\Delta\Lambda$. In addition to the DLOA the parameter Ξ was proposed in [5], which characterizes the parallelism of the structure, and which is estimated as the area under the normalized graph of the angular distribution of pixels at Fourier spectra. Additional parameters, which are not covered by the Fourier analysis, are the quantification of the number of branch points per unit area and bifurcation length [6]. Researchers in [7] proposed a method for evaluation the LIPSS branching type and bending angles, or by convergence of structures. Moreover, it is possible to analyze the deviation of the system (structures) by the estimation of the Gini coefficient on a discrete Lorenz curve [8].

This report describes a comprehensive quantitative clustering analysis of LIPSS ablated on the surface of stainless steel AISI 304. The samples were structured in the air, using a nanosecond pulsed ytterbium fiber laser at a wavelength λ = 1064 nm, pulse duration 100 ns. The laser beam was focused using an F-theta lens (focal length – 216 mm) into a spot with a $1/e^2$-diameter $D_{1/e}{}^2$ = 50 µm. A description of the LIPSS pattern ramification was carried out, and ordering parameters were determined depending on the ellipticity (linear or circular polarization) of the laser radiation. Results show the decrease of the structure clusters with increasing polarization ellipticity. The method for control, creation, and predefinition the values of topological characteristics of regular reliefs based on LIPPS is proposed.

The study was supported by the Russian Science Foundation (project No 21-79-10241) in part of LIPSS recording and bifurcation studies, and by the Ministry of Education and Science of the Russian Federation (IA&E project № 121041500060-2) in part of microimages processing.

1. Gräf, Stephan, et al. "Mechano-responsive colour change of laser-induced periodic surface structures." Applied Surface Science 471 (2019): 645-651.

2. Rathmann, L., et al. "Friction and wear characterization of LIPSS and TiN/DLC variants." Applied Surface Science 584 (2022): 152654.
3. Martínez-Calderon, Miguel, et al. "Surface micro-and nano-texturing of stainless steel by femtosecond laser for the control of cell migration." Scientific reports 6.1 (2016): 1-10.
4. Yamada, Itsunari, Takaaki Ishihara, and Junichi Yanagisawa. "Reflective waveplate with subwavelength grating structure." Japanese Journal of Applied Physics 54.9 (2015): 092203.
5 Belousov, Dmitrij A., et al. "Thermochemical Laser-Induced Periodic Surface Structures Formation by Femtosecond Laser on Hf Thin Films in Air and Vacuum." Materials 14.21 (2021): 6714.
6. Reif, Juergen, Olga Varlamova, and Florenta Costache. "Femtosecond laser induced nanostructure formation: self-organization control parameters." Applied Physics A 92.4 (2008): 1019-1024.
7. He, Shutong, et al. "Surface structures induced by ultrashort laser pulses: Formation mechanisms of ripples and grooves." Applied Surface Science 353 (2015): 1214-1222.
8. Lechthaler, Björn, Christoph Pauly, and Frank Mücklich. "Objective homogeneity quantification of a periodic surface using the Gini coefficient." Scientific Reports 10.1 (2020): 1-17.

S06-6 Lateral effects in laser oxidation for thermochemical recording on thin metallic films

Quang Dung Nguyen, Dmitry A. Sinev, Elena A. Shakhno
ITMO University, St. Petersburg, Russia
elena.shakhno@mail.ru

Laser thermochemical recording on thin Cr films has been successfully implemented to form submicron protective oxide structures, where a sequential chemical etching of metallic films is then applied to create useful photonic devices (for instance, DOEs – Diffractive Optical Elements). Recently, a single-step laser oxidation on thin metallic films with the formation of optically transparent oxides (Ti, Sn, Zr, etc.) have become increasingly an importantly promising topic due to the advantages it provides, such as time and errors reduction, direct high-resolution and high-contrast writing, eco-friendliness, etc. In this work, we experimentally and theoretically present the lateral effects which appear during sequential recording of parallel tracks on thin Ti films. It is shown that size of the recorded tracks drops depending on the distance to the previously recorded ones due to lateral optical non-linearity appearing dynamically during the recording process. To experimentally study the degree of their influence, we've successively recorded three closely located to each other parallel tracks, using scanning cw Yb-laser beam with Gaussian profile on 10nm-Ti films. The third track was recorded in the middle of the first and second one, and as a result of a decrease in the total amount of absorbed energy (on the "wings" of the Gaussian intensity distribution in the irradiated region of the previously recorded tracks), the width of the third recorded track turns out to be much smaller than the width of the previously recorded tracks (80% smaller if located at a distance less than $2.35r_0$, r_0 – radius of the laser beam). This recording scheme helps demonstrate the effect more clearly. We have also proposed a complex mathematical model based on the reduction of film absorptance to predict the recording parameters (laser power density, distance between the tracks) for a desired element's size of the sequential recording tracks.

This work was supported by the grant #21-79-10241 from the Russian Scientific Foundation.

S06-7 Controlled formation of thermochemical laser-induced surface periodic structures for modern photonic devices

D.A. Sinev, G.V.Odintsova, M.K. Moskvin, Ya.M. Andreeva, A.R. Suvorov, N.A. Afanasev, E.V. Prokofev, E.A. Shakhno, V.P. Veiko
ITMO University, St. Petersburg, Russia
sinev@itmo.ru

One of the most promising results in functional materials surface microstructuring are shown by the directed self-organization of regular microreliefs, so-called laser-induced surface periodic structures (LIPSSs). However, direct and utter control of the LIPSSs formation stays unachieved in all the experimental results obtained so far, where the problematics of stochasticity and locality remains, as it is inherent in the processes of formation of ablative LIPSSs. Since the directed formation of regular LIPSSs (long-range order) is usually limited in space by the dimensions of the laser beam, and the control of the parameters of structures is complicated by their sensitivity to the parameters of laser action, the use of low-temperature, thermochemical regimes of LIPSSs formation is of interest, as it allows reducing thermally induced stresses and increasing the ordering of structures.

Presented work shows the results of the implementation of direct (one-step) laser recording the planar objects of arbitrary topology, the outer surface layers of which will be modulated by periodic gratings with a design resolution of up to 1400 lines per mm, which will make it possible to control the spectral and functional properties of these objects. Reproducible, stable, ordered LIPSSs are shown to be a promising foundation for creation the functional elements, such as security signs and holographic elements on steel samples, and photonic structures based on 1D and 2D periodic gratings on titanium films.

This work was supported by the grant #21-79-10241 from the Russian Scientific Foundation.

S06-8 Optimization of scanning thermochemical laser writing of crossed diffractive gratings on circular writing systems

R.I. Kuts, V.P. Korolkov, A.G. Sedukhin, A.R. Sametov, V.V. Cherkashin, A.I. Malyshev, D.A. Belousov

Institute of Automation and Electrometry SB RAS, Novosibirsk, Russia

r.i.kuts@mail.ru

The implementation of the technology of direct laser thermochemical writing of diffractive structures on lithographic systems with a polar coordinate scanning system has a number of features compared to X-Y writers. Due to finite rate of the thermochemical oxidation process, the geometry of the crossed structures (having parallel boundaries along two coordinates) is distorted depending on the laser track entry angle. In places where the laser track is shortly interrupted near points of contact between the corners of the exposed rectangles, merging of the corners is observed. In addition, in places of a too short turn on the laser beam, the expected oxidation is not observed. These distortions introduce errors into the diffraction pattern formed by the grating.

A technique for optimizing the direct laser writing of crossed gratings depending on the angle of entry of the beam trajectory was developed. The study was carried out on the example of Dammann phase gratings, which multiply an incoming beam into a 7x7 beam matrix diverging at an angle of 3° relative to the optical axis. The diffraction structures were written on thin chromium films ~50–60 nm thick. The minimum size of a chromium element in such a grating was ~5.5 μm. As a key quality parameter of the formed diffraction pattern, the root-mean-square deviation of the intensity of diffraction orders inside the 7x7 matrix was recorded. It is shown that by correcting the dimensions of the microelements of the crossed grating, it is possible to obtain a root-mean-square deviation of orders of about 7-8% for any angle of entry of the circular laser beam trajectory.

FT-S06-1 Laser-induced oxidation of titanium: specifics of chemical composition

D.A. Rud’, D.A. Sinev, D.A. Zuev, E.Y. Ponkratova, A.M. Kuzmichev
ITMO University, St. Petersburg, Russia
Luxxmorn@gmail.com

Optimization the photocatalytic properties of the solutions by microstructuring the surface layers of underlying substrates offer new possibilities in the field of photochemistry. Usual photocatalysts are provided in a powder form, mixing into the target reaction mass, but this process requires an ineffective high number of consumables. Structuring and tailoring the geometry and chemistry of the contact surfaces on nanolevel specifically for the reaction of certain type seems to be a promising way to enhance the speed and yield of the photocatalytic reaction. Creation the nano structures required can be achieved by well-known methods of laser structuring, where the wide range of morphologies can be acquired, for instance, by irradiating titanium sample in air. This work shows the phase-structural and chemical analysis of bulk grade 2 Ti and thin Ti films modified by pulsed fiber Yb-laser radiation. The production of the amorphous TiO_x on Thin Ti films was shown, as well as mixed TiO_2 anatase-rutile phase on the bulk Ti, with the possibility to shift the composition to predominately rutile or anatase phases by tuning laser processing parameters (average power and pulse repetition rate). Additionally, the LIPSS formation was shown in main processing regimes, and the results shown are promising for the solution to the problems of photocatalysis.

Research was supported by RSF grant # 21-79-10241.

FT-S06-2 Controlled formation of regular lattices based on thermochemical laser-induced periodic surface structures on titanium thin films

A.R. Suvorov, M.D. Vasilev, D.A. Sinev
ITMO University, St. Petersburg, Russia
suvcom@bk.ru

Laser-induced periodic surface structures (LIPSS) are a universal phenomenon that occurs in a strictly confined processing regimes on solid materials when irradiated by linearly polarized laser radiation. LIPSS usually form as a linear, one-dimensional reliefs, although the two-dimensional microgratings are in a high demand in the area of modern photonics, where they can serve as frequency selective surfaces, diffractive gratings, photonic crystals, metamaterials, etc. However, 2D-grating formation as sresult of superposition of one-dimensional LIPPS of mutually perpendicular orientation was previously shown only in narrow modes of ultra-short laser exposure within a laser spot. This work demonstrates the possibility of stable formation of two-dimensional thermochemical LIPPS using the radiation of a commercially available laser complex "MiniMarker 2". Patterns formation with period of about 0.7 μm with linear, square, and hexagonal symmetries is shown, depending on the polarization of recording light and processing parameters. It is shown that the optical properties of the obtained two-dimensional and one-dimensional structures differ in the visible range, which in the future will allow to apply the obtained results for the creation of new elements of diffractive optics and modern photonics.

This work was supported by the grant #21-79-10241 from the Russian Scientific Foundation.

S06-9 Resonant laser printing of photonic metasurfaces - structural colors, metalenses and holograms

Xiaolong Zhu
State Key Laboratory of Precision Spectroscopy, School of Physics and Electronic Science, East China Normal University, Shanghai, China
xlzhu@lps.ecnu.edu.cn

Optical metasurfaces are a new class of ultrathin optical elements comprising arrays of nanoscale artificial atoms which collectively control the amplitude, phase, polarization, and spectral properties of light. Dielectric metasurfaces possess low intrinsic losses, which are desired in many optical applications. Arrays of optically resonant dielectric nanostructures have offered the control of light with nanoscale precision, which are typically realized by the state-of-the-art nanofabrication technologies. However, the absorption in metallic or dielectric elements provides a new route for photo-to-thermal conversions and processing. Here, we introduce a resonant laser processing (RLP) technique as a flexible photo-thermal post-writing technology for mass-customization of dielectric metasurfaces. [1]

In RLP of dielectric metasurfaces, photothermal effects are taking place in the center of the dielectric nanostrucrues, which helps to gradually control structural and shape modifications of dielectric nanostructures. Depending on the laser pulse energy density, different surface morphologies that support different optical resonances can be created. We applied the laser-induced reshaping in color printing. This technology can create laser printed dielectric color metasurfaces with a printing resolution up to 127 000 DPI. [2]

Here, we propose an optical system that is driven by a pulsed laser emitting at a resonance frequency of the system, leading to self-organized surface structures with self-adaptive morphology through a phase modulation feedback. [3] An optical cavity, comprising an ultrathin film on lossy dielectric, which is designed to support attenuated Fabry−Perot-type interference. Controlled by the laser power, the surface undergoes a structural transition from random, semiperiodic, and periodic to amorphous patterns with nanoscale precision. The reliability, upscaling, and subwavelength resolution of this approach are demonstrated by realizing metasurfaces for structural colors, optical holograms, and diffractive optical elements.

1. Zhu, X.; Hedayati, M. K.; Raza, S.; Levy, U.; Mortensen, N. A.; Kristensen, A. Digital resonant laser printing: Bridging nanophotonic science and consumer products. Nano Today 2018, 18.
2. Zhu, X.; Yan, W.; Levy, U.; Mortensen, N. A.; Kristensen, A. Resonant-laser-printing of structural colors on high-index dielectric metasurfaces. Sci. Adv. 2017, 3, e1602487.
3. Zhu, X.; et.al, Resonant Laser Printing of Optical Metasurfaces. Nano Lett. 2022, DOI: 10.1021/acs.nanolett.1c04874.

S06-10 Laser functionalization of metal surfaces for different task: from industry to medicine and art

G.V. Odintsova, V.P.Veiko
ITMO University, St. Petersburg, Russia
gvodintsova@itmo.ru

Generally, the interaction between objects in living and unliving nature as well as in artificial technosphere happens through their surfaces. The nature of the interaction depends on the used materials and specific properties of surfaces. Following nature, people functionalize the surface of products to achieve various goals.

The objects of optimization are often the tribological properties of the surface, mechanical and chemical stability, electrical protection and emission properties, and many others. As science and technology develop, new areas of application are revealed and new materials and methods of their processing appear, which states a new problem as how to the control of surface properties (at micro- and nano-level).

An important and interesting example of such problems is the widespread development of implantology and the emergence of requirements for biocompatibility properties of surfaces of various materials with living tissue. With the advent of laser technologies, it has become possible to locally control the surface geometry and partly its chemical composition (during processing in various media) in order to impart certain properties to it.

In this work, metals are chosen as materials for functionalization, because they are widely used in industry, medicine, and even in art. Based on the requirements of the real sector of the economy, the following functional properties were selected: colorimetric, wettability, biocompatibility, antibacterial, biofouling, and corrosion resistance.

Thus, the following technologies have been researched and developed in the work: control of the colorimetric characteristics of metals by laser oxidation; formation of rainbow hologram on the surface of stainless steel due to light diffraction by LIPSS; creating color wear-resistance images on the surface of precious metals due to the formation of plasmonic nanoparticles under direct pulsed laser exposure in air. All three of the above technologies can be used to apply a unique identification mark to metal products to protect it from falsification. It should be noted that these identification marks are non-toxic, which allows them to be used for medical purposes. Also, these technologies can be used to encode information. The ability to record and erase a color image in conjunction with a manual device, a laser brush, will allow the use of these technologies in arts and crafts.

The technology of laser formation of a biomimetic osteon relief on the surface of titanium improves cell proliferation, differentiation, and migration was also developed. And the crystalline morphotypes of laser-induced titanium dioxide exhibit high photoactivity when irradiated with UV light, which leads to the formation of hydroxyl radicals, which gradually destroy bacterial membranes, which leads to their death. This technology can be used for local functionalization of the surface of metal implants.

It is also worth noting the development of the technology of formation of local hydrophilic, hydrophobic structures due to laser structuring and subsequent change in surface energy by storage in air, low-temperature annealing, and coating with silanized silicon NPs.

Thus, in the report we will demonstrate the approach and results of laser functionalization of metal surface for different task in industry, medicine, and art.

Authors acknowledge the support of the Ministry of Science and Higher Education of the Russian Federation research agreement No. 075-11-2021-045 of 24.06.2021, project title "Development of high-tech production of equipment and technologies for laser functionalization

of the surface of medical products" (within the framework of decree of the Government of the Russian FederationNo. 218 of 09.04.2010).

S06-11 Effect of treatment with nanosecond laser pulses on the fatigue properties and structure of ultrafine-grained titanium

Yu.R. Kolobov [1], S.S. Manokhin [1], A.Yu. Tokmacheva-Kolobova [1], G.V. Odintsova [2]
[1] Institute for Problems of Chemical Physics RAS, Chernogolovka, Moscow region, Russia
[2] ITMO University, St. Petersburg, Russia
kolobov@icp.ac.ru

On the example of lamellar (~1 mm thick) samples of polycrystalline (grain size ~3 μm) commercially pure titanium (VT1-0 grade), it is shown that nanostructuring of thin (1-3 μm) near-surface layers by processing nanosecond laser pulses according to an optimized one, including Based on computer simulation data, the processing mode leads to a significant (up to two times) increase in the conditional endurance limit for high-cycle (up to 10^6 cycles) fatigue in the uniaxial loading mode (figure).

Molecular dynamics modeling of the evolution of the structural phase state of hcp titanium under the action of laser-induced shock waves has been carried out. It has been established that the physical mechanism for the formation of a nanocrystalline structure in titanium under these conditions is the process of phase recrystallization, which is implemented as a chain of phase transformations from the initial hcp α-phase to the high-pressure ω-phase, and again to the initial α-phase. Limiting temperature (700K) is calculated; above which α --> ω the phase transition is not observed under the studied conditions.

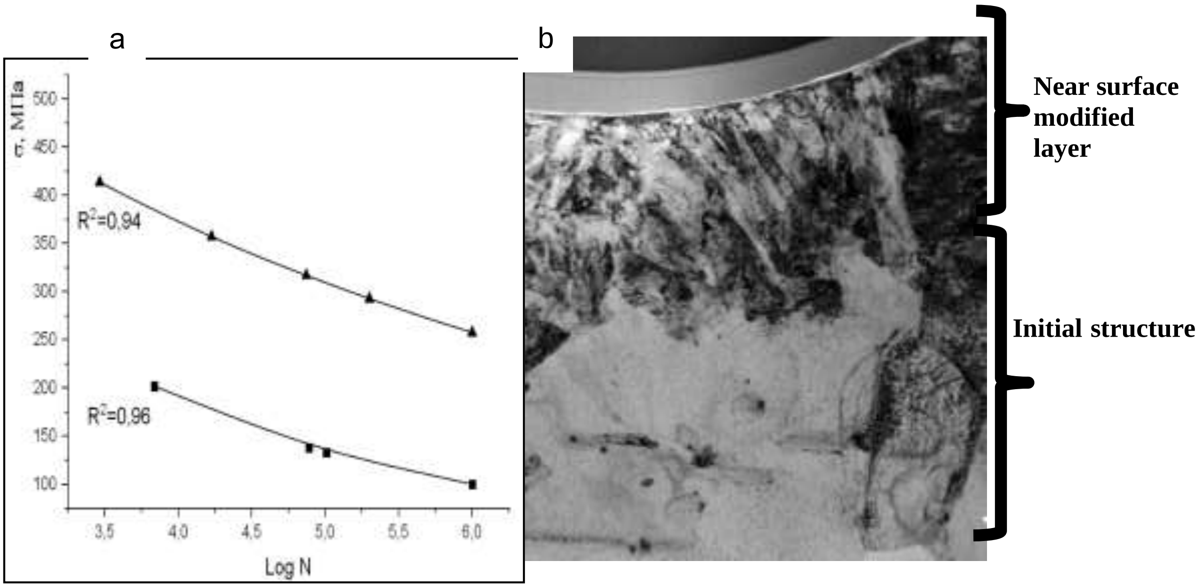


Fig. a - fatigue curves for VT1-0 alloy samples in the initial recrystallized state with a grain size of about 2-3 μm (marked in graph ■) and after preliminary treatment with nanosecond laser pulses under a layer of water (marked in graph ▲);
b - microstructure of a sample of recrystallized commercially pure titanium (VT1-0) after treatment with nanosecond laser pulses under water (at an energy density of 1 GW/cm^2) and

fatigue tests (10^6 cycles, cycle stress 100 MPa). Bright field image, transmission electron microscopy.

This work, in the main part related to the study of the structure of the VT1-0 alloy after nanosecond laser ex-posure, was carried out with the financial support of the State Assignment, state registration number AAAA-A19-119022690098-3, and in the additional part, related to the determination of the parameters of mechanical proper-ties, was carried out with financial support of the State task, state registration number AAAA-A19-119111390022-2. Structural studies were carried out using the scientific equipment of the Center for Collective Use of the Federal Research Center "Crystallography and Photonics" of the Russian Academy of Sciences (Moscow).

S06-12 Modelling of writing, erasing and rewriting of colors on titanium surface under the action of pulsed-periodic nanosecond laser

D.S. Polyakov
ITMO University, St. Petersburg, Russia
polyakovdmitry1988@gmail.com

Laser treatment of metals in oxygen environment is the promising way to produce the oxide coatings, that lead to the controllable color formation on it surface. The field of applications of such technology is rather wide: from jewelry and decoration to medicine. At present time there are a lot of works (see, for example, [1, 2]) dedicated to the development of color laser marking technology. Recently, in work [2], an interesting possibility of direct color erasing and rewriting by the action of the same laser, which was used for writing, without necessity of using the special atmosphere was demonstrated (i.e. all operations may be done in air at normal conditions). The explanation of the observed phenomena was given by the authors for the most part in a qualitative way. In this report the quantitative model of oxide grows on titanium surface under the action pulses-periodic nanosecond laser suitable for the modes of writing, erasing and rewriting of colors was proposed. The model based on the assumption that the one of the important limiting factors of oxidation kinetics is the oxygen depletion of the air layer adjacent to the surface [3]. The model consists from the 3D heat transfer equation for titanium, 3D diffusion equation for oxygen concentration in the air and the oxidation law, which is sensitive to the oxygen concentration in the air near the surface. The results of calculation show a good agreement between calculated oxide thickness and oxide thickness obtained in experiment for writing/erasing/rewriting cases.

The study was supported by the Russian Science Foundation (project 20-62-46045).

1. Odintsova G., Andreeva Y., Salminen A., Roozbahani H., Van Cuong L., Yatsuk R., Golubeva V., Romanov V., Veiko V. Investigation of production related impact on the optical properties of color laser marking//Journal of Materials Processing Technology, 2019, Vol. 274, pp. 116263
2. Veiko V.P., Andreeva Y.M., Cuong L., Lutoshina D., Polyakov D.S., Sinev D., Mikhailovskii V.Y., Kolobov Y.R., Odintsova G.V. Laser paintbrush as a tool for modern art//Optica, 2021, Vol. 8, No. 5, pp. 577-585
3. Libenson M.N., Minaev S.M., Laser stimulation of heterogeneous reactions// SPIE, 1989 Vol. 1352, pp. 149-168

S06-13 Laser-assisted surface activation for the fabrication of flexible non-enzymatic Cu-based sensors

I.I. Tumkin[1], E.M. Khairullina[1], K. Ratautas[2], M.S. Panov[1], V.S. Andriianov[1], S. Mickus[2], A.A. Manshina[1], G. Račiukaitis[2]

[1] Institute of Chemistry, Saint Petersburg University, SPbU, St. Petersburg, Russia
[2] Center for Physical Sciences and Technology, Vilnius, Lithuania
i.i.tumkin@spbu.ru

In this work, a promising laser-assisted technique for fabrication of sensor-active materials based on copper and other metals by the Selective Surface Induced by Laser (SSAIL) method was proposed. In comparison with many existing analogical methods, the proposed approach does not require a template. It can be used to create metallic patterns on the surface of polymers of any desired geometry, even for small-scale production and prototyping. Typically, laser fabrication on polymer surfaces is quite difficult due to utilization of too high laser power, at which the destruction of the substrate material may occur. Moreover, it is necessary to note that the scanning speed of the laser beam along the polymer surface may reach values of several meters per second, and the subsequent stage of chemical copper plating allows extensively increasing the amount of material fabricated per unit of time without using expensive equipment.

We performed laser activation and selective copper plating of flexible polymer substrates such as PEN, PET and PI. We also produced bimetallic composites based on Cu-Au and Cu-CuO systems by modifying the previously fabricated copper structures. The electrocatalytic performance of the obtained materials toward non-enzymatic detection of such biologically important analytes as glucose, hydrogen peroxide and ascorbic acid. It was demonstrated that the modification of copper electrodes with gold-based nanostructures significantly improves their electrochemical characteristics, including sensitivity and detection limit. In turn, deposition of CuO on the surface of copper electrodes provides conditions for the dopamine acid sensing in a neutral medium. Finally, it is possible to conclude that the discussed technique can be used for synthesis and modification of electrode materials on flexible surfaces with high electrocatalytic activity toward a wide range of analytes based on a single source system.

I.I.T., E.M.K. and M.S.P. acknowledge Russian Science Foundation (grant 20-79-10075).
The authors would like to thank the SPbSU Nanotechnology Interdisciplinary Centre, Centre for Physical Methods of Surface Investigation, Centre for Optical and Laser Materials Research and Centre for X-ray Diffraction Studies.

S06-14 Laser controlled wetting of metal surfaces for various applications

N.N. Shchedrina, M. Karsakova, A. Karamyants, D. Zuev, G.V. Odintsova
ITMO University, St. Petersburg, Russia
schedrina.nadezda@itmo.ru

Laser micro- and nanostructuring of metal surfaces and subsequent wettability control allows surfaces to acquire desirable functional properties such as resistance to corrosion, biofouling and bacteria, increased adhesion of objects and coatings, and even control of the distribution of NPs. The precision control of the wetting angle of different surfaces, especially metals, is a principal characteristic when surfaces with wetting gradients are created, which can provide directional fluid flow. By applying microvolume droplets of nanoparticles solutions over structures with wetting angles, it is possible to control their distribution, which is promising to use for problems of green printing and for the creation of photonic nanostructures. Laser formation of structures for the directional flow of microvolume solutions of nanoparticles on the surface of stainless steel by creating a wettability gradient using a fiber laser with a nanosecond pulse duration is suggested.

Using laser irradiation parameters with 60% laser spot overlapping and a power density from 19 MW/cm^2 to 181 MW/cm^2, samples with wetting gradient with angles ranging from hydrophilic to superhydrophilic were created, on which directional flow of microvolume droplets is possible at an average speed of 20 mm/s due to a decrease in the surface energy. The laser irradiation was carried out above the thresholds of melting and boiling, which led to an increase in surface roughness. The obtained surfaces are fully consistent with the Wenzel model. The creation of patterns with complex shapes such as branching, merging, turning, and bending around obstacles are also demonstrated. An experiment was carried out with the distribution of silicon nanoparticles over the surface with a wetting gradient. A 0.1 μL drop of a solution of silicon nanoparticles with an average size of 140 nm was applied to the gradient structure. SEM images showed that the distribution of nanoparticles varied depending on the gradient area. The concentration of deposited NPs increases with a decrease in the contact angle. The self-assembling process of Si NPs starts on areas with concentration over 0.4 particles/μm^2.

The study is funded by RPMA grant of School of Physics and Engineering of ITMO University.

S06-15 Fabrication and investigation of nanopipettes with controlled geometry for scanning ion-conductance microscopy

S.Yu. Lukashenko, M.V. Zhukov, I.D. Sapozhnikov, M.L. Felshtyn, O.M. Gorbenko, A.O. Golubok
Institute for Analytical Instrumentation RAS, St. Petersburg, Russia
stas.lukashenko@mail.ru

Scanning microscopy of ionic conductivity (SICM) is one of the actively developing areas of scanning probe microscopy (SPM). Quartz or glass nanocapillaries are used as nanoprobes in SICM. Typically, high quality nanocapillaries are obtained by using CO_2 laser by melting and breaking off [1,2]. At the same time, electric heaters can be used to fabricate glass nanocapillaries. This paper presents borosilicate and aluminosilicate glass nanocapillaries for SICM, made using MDI PMP107 Multipipette puller. Technological regimes for obtaining high quality glass nanocapillaries with different geometric dimensions are presented. The scanning electron microscope images of obtained nanocapillaries are presented, the current-voltage characteristics of the nanopipettes in physiological saline are measured, the effective aperture diameters are estimated. The rectification effect (diode-effect) of the current-voltage characteristics depending on the nanopipettes aperture diameter is studied. Features that arise during the interaction of nanopipette with various samples are discussed. The ion current increasing when nanopipette interacts with the sample surface and the appearance of a characteristic peak on the approach curve are discussed. The «peak effect» depending on the geometry of the nanopipette, the polarity of the silver chloride electrode located in the pipette and chemical composition of glass are studied. SICM images of the test structure in three SICM modes: direct ion current mode (DC mode), alternating current mode (AC mode), and hopping mode are presented. Also, CHO (chinese hamster ovary) cells in DC and hopping mode are measured. Advantages and disadvantages of these SICM modes are discussed.

1. Veiko V.P., Golubok A.O., Levichev V.V., Zuong Z., Yakovlev E.B. MULTIFUNCTIONAL UNIVERSAL SPM NANOPROBE FABRICATION WITH LASER TECHNOLOGY // Laser Physics. 2009. T. 19. № 5. C. 1142-1151.
2. Dung D.C., Nghia H.L., Veiko V.P., Golubok A.O., Yakovlev E.B. GLASS NANOPIPETTE: FABRICATION AND APPLICATION FOR STUDYING LIVING CELLS // IFMBE Proceedings. "The Third International Conference on the Development of Biomedical Engineering in Vietnam". Ho Chi Minh City, 2010. C. 127-129.

FT-S06-3 Formation by IR laser ablation of amphiphobic teflon surfaces for oil/water separation

D. Kuznetsov, K. Volchetskaya, M. Kosobokov, V.Ya. Shur
Institute of Natural Sciences and Mathematics, Ural Federal University, Ekaterinburg, Russia
dimak@urfu.ru

The surface microstructures were formed on polytetrafluoroethylene (teflon) substrates by IR laser treatment. The treated surfaces possessed strong superhydrophobicity (low water adhesion) and ultrahigh superoleophobicity simultaneously. The device for efficient oil/water separation has been fabricated by laser drilling of the treated teflon plate.

Separating the mixture of water and oil by the superhydrophobic/superoleophilic materials has attracted increasing interests.

The surfaces of 2-mm-thick teflon substrates were treated by scanning CO_2 gas laser based on VLS3.50 Universal Laser System (λ = 10.6 μm, 40 W). The imaging of obtained surface structures was made by scanning electron microscope Merlin (Carl Zeiss). The treated surface structures contain at least two spatial scales: microfibered layer consisting of fibers and nanoparticles up to 100 nm and treated layer with relief features up to 10 μm. The structured surface showed strong superhydrophobicity (low water adhesion) and, at the same time, ultrahigh superoleophobicity. Contact angle for water droplet on the untreated surface was about 100 degrees and directly after treatment it increased up to 140 degrees.

The device with many micro-holes arrays with diameter ranged from 200 μm to 1 mm were made on the treated teflon substrate by a subsequent laser drilling. It was shown that the fabricated separation system was very efficient for oil/water separation due to combination of its superhydrophobicity and superoleophilicity, thus exhibiting the strong potential for practical application.

Additional “lotus” and “rose petal” effects were obtained on structured teflon surfaces after special conditions of treatment. Mechanical removing of fibered layer allowed to obtain surfaces with self-cleaning properties (“lotus effect”). It was shown that graphite powder totally removed from treated surface after water immersion.

Formation of two-dimensional surface structure with alternation of the treated and untreated areas leads to high-adhesive superhydrophobic properties (“rose petal effect”) which allow to keep droplets up to 18 μL.

The equipment of the Ural Center for Shared Use “Modern nanotechnology” Ural Federal University (Reg.№ 2968) was used with the financial support of the Ministry of Science and Higher Education of the Russian Federation (Project № 075-15-2021-677 and state task FEUZ-2020-0054).

FT-S06-4 Protection of metal surfaces from biofouling using nanosecond laser structuring

E.A. Davydova, N.N. Shchedrina, A. Peltek, I.A. Filatov, G.V. Odintsova
ITMO University, St. Petersburg, Russia
zhenyadavydova1@gmail.com

This paper demonstrates the change in the wetting parameter on the surface of steel and aluminum during various processing methods, including preliminary pulsed nanosecond laser exposure, to impart properties to the surface that are significant in industrial production. Wetting angle values were obtained, and the degree of biofouling was assessed for various processing methods to create hydrophobic structures.

A fiber ytterbium laser source with a wavelength of 1064 nm was chosen as a processing tool since metals absorb well at this wavelength. The following methods for the formation of hydrophobic structures were considered in the work: laser structuring followed by long-term storage in air and laser structuring followed by low-temperature annealing. To assess the degree of biofouling, the film obtained on the samples was measured using the method of confocal microscopy. Distilled water was used as the test liquid, and a water sample from the coastal zone of the Gulf of Finland was taken as the sample medium.

Technological parameters of laser structuring were determined by creating specific biomimetic structures on the surfaces of various alloys. Samples with different treatments were placed in a water sample from the Gulf of Finland for a month, the angles were measured every week. According to the results of measuring the wetting angles for samples studied immediately after laser treatment, there is a slight increase in the angle over time for all modes. In the course of studying the dependence, conclusions were drawn about the transition of structures in an aqueous medium from a hydrophobic state to a hydrophilic state upon processing by low-temperature annealing and when the samples were exposed to laser structuring in air. The results of confocal microscopy showed the lowest degree of biofouling during laser structuring and subsequent prolonged exposure to air. With other treatments, a decrease in biofouling is observed while the samples are in water. This may be due to the fact that the geometric parameters of the structures were successfully selected, that the microorganisms fail to attach their adhesive substance to the surface for colonization.

FT-S06-5 Laser nanostructuring of the surface of precious metals

D.S. Lutoshina, A.A. Morozova, T.A. Nguen, G.V. Odintsova, M.M. Sergeev
ITMO University, St. Petersburg, Russia
ld3282@itmo.ru

In this paper, we consider the result of laser action of a nanosecond pulsed ytterbium fiber laser on the surface of precious metals such as silver, gold, and platinum.

It was found that laser exposure leads to a change in the micro- and nanorelief of the surface as a result of the processes of heating and reverse deposition of the material. Moreover, the process is fast, local and does not require the use of consumables.

The formed nanorelief changes the optical characteristics in the visible range of the electromagnetic spectrum, which leads to the observation of different colors on the surface of processed precious metals.

A theory about plasmon effects arising on clustered nanoparticles has been put forward. It is known that the composition, size, concentration, and shape of nanoparticles contribute to plasmon effects. The relationship between the parameters of the nanostructured region and the spectral characteristics was determined.

The composition of the modified surface was also studied to explain the mechanism of surface coloration in different colors, to confirm the theory.

The resulting nano-coatings add aesthetic appeal due to the fact that color images can be created on the surface of precious metal products. However, nanocoatings showed low resistance to mechanical and chemical influences. For application in the jewelry industry, a method was proposed to protect the synthesized coatings from the influence of external environmental factors, leading to the fading or complete disappearance of color from the painted area.

This research was funded by the grant of the Russian Science Foundation (project No. 19-79-10208).

FT-S06-6 Features of additive laser processing of the surface layer of titanium samples

X.A. Egorova[1], K.A. Rozanov[1], A.I. Kiian[2], D.A. Sinev[1]
[1] ITMO University, St.Petersburg, Russia
[2] INSCIENCE, St.Petersburg, Russia
x_egorova@itmo.ru

At the moment, additive laser processing methods are in the lead at the development of materials science, because of the achievement of a high level of mechanical and functional properties of the final product thanks to high spatial and temporary temperature gradients. The greatest interest is in obtaining new properties of materials by modifying the surface using laser exposure under a layer of additional substances. The methods presented to date do not allow the formation of a uniform distribution of mechanical properties over the surface, and do not provide high reproducibility of the results.

In this work, the possibility of forming continuous coatings and controlling the parameters of surface laser-induced microstructures by additive laser treatment under layers of additional substances was studied, using a commercially available laser system based on a pulsed ytterbium fiber laser.

For a comparative analysis of the effect of the graphite layer on the result of laser processing, a series of experiments were made out in which the processing was carried out by forming modified zones under the graphite layer on pre-formed laser-induced oxide films or immediately on the titanium surface. As a main result of the project, the method was developed to increase the hardness of the surface layer of titanium samples by additive laser treatment under a layer of graphite powder under compression in contact with an additional transparent dielectric coating. The study of the efficiency of the suggested method for receiving a surface layer of a titanium alloy with increased characteristics of the surface layer was made for testing for microhardness by applying a print on the test surface of the sample under static load.

In this work, the developed technological maps of laser exposure showed the dependence of the microhardness of the surface layer of titanium samples on various pre-formed oxide layers. In comparison with the original surface of the titanium plate, an increase in the value of hardness by 10 times at least was showed when structuring under a layer of graphite powder.

The reported study was financially supported by the Ministry of Science and Higher Education of the Russian Federation research agreement No. 075-11-2021-045 of 24.06.2021, project title "Development of high-tech production of equipment and technologies for laser functionalization of medical devices" (within the framework of decree of the Government of the Russian Federation No. 218 of 09/04/2010)

S06-16 Laser-induced formation of microbumps on nickel

Yuriy Pestov[1], Vladimir Makin [2]
[1] Scientific Research Institute for Optoelectronic Instrument Engineering, Sosnovy Bor, Russia
[2] "Kometa" corporation – NPC OEKN, Saint-Petersburg, Russia
ypestov@yandex.ru

The mechanisms of the laser-induced formation of micro- and nanostructures of residual relief on surfaces of materials are of fundamental interest. The significant role of the degree of wetting by melt of its solid phase in the mechanism of the laser-induced formation of the cone-shaped peaks (microcones) on superrefractory metals and germanium and dependence of wetting from gas atmosphere was discussed in [1, 2]. Formation of the microbumps (microcones with smooth apexes) on the surface of nickel in air at the atmospheric pressure as a result of local laser irradiation with the energy density Q lower than the ablation threshold was studied in this work. The height of the microbumps was growing with Q. The microbump and adjacent melted area in air were covered by a NiO oxide. To study dynamics of the relief a rapid-speed video filming has been carried out. The temporary dependence of value of effective wetting angle θ between the meniscus and tangent to the solid state – gas boundary was evaluated from video frames. Formation of smooth peaks and temporary dependence of θ can be explained by formation of solid phase thin film of NiO oxide on the surface of melt. Although melting point of NiO (1682°C) is slightly lower than melting point of Ni (1726°C), formation of solid phase thin film of NiO on the surface of melt may occur because the crystallization of metal occurs under supercooling conditions.

The growth mechanisms for microbumps caused by the melt redistribution under the action of surface tension force in conditions of partial wetting dynamics and density changing at the phase transition and mathematical models for microbumps formation were proposed.

[1] Yu. I. Pestov, V. S. Makin. Journal of Optical Technology, 75(6), 371-377 (2008)
[2] Yu. I. Pestov. Journal of Optical Technology, 87(3), 155-160 (2020)

S06-17 Pulsed laser deposition of large-area thin films of second-generation high-temperature superconductors

I. Rodionov, A. Bortnyansky, D. Getman, V. Kubasov, A. Mosesov, D. Nikiforov, F. Podtykan, N. Sigitova, A. Yudin
JSC 'NIIEFA', Saint-Petersburg, Metallostroy, Russia
rodionov@sintez.niiefa.spb.su

The aim of the work was to develop an experimental technology capable of producing long-length wide second-generation high-temperature superconductor (2G HTS) tapes and large magnetically impenetrable screens with high current density and critical field. Rare-earth compounds were selected as superconducting material.

A distinguishing feature of rare-earth HTS compounds is a small coherence length, which reduces the size of defects that can locally disrupt the superconductivity: accordingly, even nanosized defects arising during deposition have influence on the characteristics of produced superconducting tapes. Therefore, the deposition process must be optimized to meet high quality requirements.

Experimental studies were carried out on a unique PLD facility developed at JSC 'NIIEFA', which makes it possible to form thin-film structures of second-generation high-temperature superconductors on long-length textured substrate tapes up to 150 mm wide and on large-area substrates for magnetic screens.

Laser deposition was carried out in a vacuum chamber in various conditions. A repetitively pulsed XeCl excimer laser was used as a beam source. Substrate tapes were rolled on large steel drum inside the chamber. In order to maintain correct film growth and ensure uniform wear of the target surface, a 3D target positioning system synchronized with the laser was developed along with optical scheme for beam preparation. Thickness and other parameters of deposited layer were varied during the study.

Quality control of involved materials and products was performed both by original methods and various techniques based on modern measuring devices.

The results of studies on the development of technology and optimization of the regimes of laser deposition of superconducting and buffer layers are presented along with original methods of input, interoperational and output control.

Values of the critical current density up to $2.5 \cdot 10^6$ A/cm^2 at 77.3 K were obtained in samples of produced long-length wide undoped YBCO-123 superconducting tapes, which satisfies the manufacturing requirements.

FT-S06-7 Laser-induced deposition of copper and nickel from deep eutectic solvents

A.S. Levshakova, E.M. Khairullina, A.Yu. Shishov, I.I. Tumkin
Institute of Chemistry, Saint Petersburg University, SPbU, St. Petersburg 199034, Russia
i.i.tumkin@spbu.ru

The fabrication of conductive metal structures on the surface of various dielectric materials is necessary for creating flexible electronics, sensors, and other modern devices [1]. There are many chemical and physical methods and approaches that can be used for this purpose. We propose to significantly improve the LCLD method [2] through the use of deep eutectic solvents (DES), which made it possible to significantly increase the rate of the process. Here we investigated the influence of various physicochemical parameters on the process of laser-induced deposition of metals from DESs. The proposed approach can successfully compete with existing laser microstructuring technologies, such as laser sintering and laser-induced substance transfer (LIFT), since it significantly benefits in ease of implementation, including laser deposition from DES does not require the use of vacuum systems, preliminary synthesis of special precursors or the use of expensive high-precision developments, as well as the speed of the process compared to classical water systems, increases by more than two orders of magnitude.

In this work, the conditions for laser synthesis in the DES medium were optimized. At the same time, both physical and chemical parameters affecting the ongoing processes were studied. As physical parameters, the scanning speed of the laser beam, the radiation power, and its type (pulsed/continuous) were studied; it was shown that the above parameters have a significant effect on the physicochemical and morphological characteristics of the resulting structures. Qualitative and quantitative composition of DES were considered as chemical factors. Mixtures based on choline chloride were used as eutectic solvents, as one of the most common hydrogen bond acceptors; donors were organic acids, alcohols, urea, etc. It was shown that DES based on choline chloride as an acceptor and organic acids and/or sugars as donors are shown to be the most promising systems for laser-induced synthesis.

Acknowledgements

A.S.L. and A.Yu.S. acknowledge the RFBR (20-33-70277) support for the design of chemical compositions. I.I.T. and E.M.K. acknowledge the Russian Science Foundation's (grant 21-79-10241) support for direct laser selective metallization and laser fabrication of patterns studies.

The authors also express their gratitude to the SPbSU Nano-technology Centre, the Centre for Optical and Laser Materials Research and the Centre for X-ray Diffraction Studies.

1. J. Zhang, J. Feng, L. Jia, H. Zhang, G. Zhang, S. Sun, T. Zhou, Laser-Induced Selective Metallization on Polymer Substrates Using Organocopper for Portable Electronics, ACS Appl. Mater. Interfaces. 11 (2019) 13714–13723.
2. M. Panov, I. Tumkin, A. Smikhovskaia, E. Khairullina, D. Gordeychuk, V. Kochemirovsky, High rate in situ laser-induced synthesis of copper nanostructures performed from solutions containing potassium bromate and ethanol, Microelectron. Eng. 157 (2016) 13–18.

FT-S06-8 Near-IR pulsed laser-induced copper deposition from deep eutectic solvents for controlled fabrication of microstructures

E.A. Avilova[1], D.A. Sinev[1], V.P. Veiko[1], E.A. Eltysheva[1], M.A. Zaikina[1], E.M. Khairullina[1,2], I.I. Tumkin[2], A.Yu. Shishov[2]
[1] ITMO University, Saint Petersburg, Russia
[2] Institute of Chemistry, Saint Petersburg State University, St. Petersburg, Russia
eaavilova@itmo.ru

The method of laser-induced deposition of metals from solutions allows to create the prototypes of the arbitrary configured structures with electrically conductive characteristics on substrates of various composition. This method is promising for the flexible electronics objectives, as it require only a limited amount of consumables, and is economical in terms of the components used. The current approaches though are characterized by low production rates (about 0.01 mm/s), and the accuracy of recording is usually insufficient, which makes it difficult to use this method in optical instrumentation. Another major setback is that the technological processes are currently presented in laboratory rather than industrial laser equipment.

In this work the geometric characteristics, component composition and conductive properties of the structures were studied experimentally, using the system based on a pulsed ytterbium fiber laser (λ = 1070 nm). The optimal processing parameters were selected by varying the adjustable parameters of laser exposure, and by preliminary structuring of the acceptor substrate using the laser-induced microplasma method. It is also proposed to use an auxiliary glass to stabilize the recording process due to the surface tension of the solvent. The processes of formation of laser-induced surface periodic structures on the surface of the formed tracks and the possibility of their functionalization are studied. The resulting structures have high adhesion to the surface and are characterized by a high copper content (from 70% to 98%). The shape and size of the structures available for deposition are limited only by the processing area, and the processing productivity is increased to 2–3 mm/s, which raises the applicability of the method for creating microelectronic elements.

Authors thank the School of Physics and Technology, ITMO University for the grant support of students' scientific and research projects.

FT-S06-9 Laser ablation of porous silicon: effect of target porosity

M.S. Grigoryeva[1], I.N. Zavestovskaya[1], A.P. Kanavin[1], A.Yu. Kharin[2]
[1] P.N. Lebedev Physical Institute, RAS, Moscow, Russia
[2] National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Moscow, Russia
grigorevams@lebedev.ru

In the present work, the ablation of a porous silicon target under irradiation with ultrashort laser pulse is simulated using the molecular dynamics approach. The number of ablated atoms and ablation threshold are calculated for targets with different porosity and pores size. It is found that an increase of the porosity to 80% leads to a 1.5-3 times decrease of the ablation threshold compared to the bulk silicon, while a decrease of pores size from 5 to 1 nm leads to the ablation threshold drop almost 40%.

Despite the reduction of the ablation threshold, the ablation rate of porous silicon substrates is significantly lower than that of crystalline targets. Reducing the ablation threshold can be important in the laser ablation synthesis of nanoparticles due to lowering the laser requirements for the ablation. However, a decrease in the ablation rate with an increase in porosity leads to the need to optimize the treatment regimes and the initial porous target for each specific synthesis process.

Acknowledgments: The reported study was funded by RFBR, project number 20-02-00861.

FT-S06-10 Transformation of crystalline copper oxide nanoparticles in colloid produced by laser ablation in water

V. Pryakhina[1], B. Lisjikh[1], V. Lebedev[2], T. Syed[2], V.Ya. Shur[1]
[1] Institute of Natural Sciences and Mathematics, Ural Federal University, Yekaterinburg, Russia
[2] Bernal Institute, University of Limerick, Ireland
viktoria.pryahina@urfu.ru

Laser ablation of Cu metallic target in water resulted in creation of colloidal round nanoparticles. The aging of the colloid at the controlled temperature leads to growth of crystalline copper oxide nanoparticles.

Nanoparticle colloids had been synthesized by laser ablation of Cu target (99.995 %) in deionized water. The Cu target, placed into glass dish and covered by water layer, was scanned by Yb-pulsed fiber laser using the laser marking system MiniMarker2-M20 (wavelength 1064 nm, pulse duration 100 ns, frequency 21 kHz, averaged power up to 20 W).

The nanoparticles shape and size were studied by scanning electron microscope Auriga CrossBeam WorkStation (Carl Zeiss). The structure of the nanoparticles was characterized by HR-TEM. The composition of nanoparticles was investigated by X-ray photoelectron spectrometer K-Alpha+ (Thermo Fisher Scientific) and confocal Raman microscope Alpha 300AR (Witec). The optical absorbance of nanoparticle colloids was measured by double-beam spectrophotometer Cary 5000 (Agilent).

The as-synthesized colloid contains spherical $Cu@Cu_2O$ core-shell nanoparticles with 14±7 nm diameter. The long-time aging (up to hundreds of hours) of the prepared colloid at various temperatures ranging from 25 to 85 °C leads to appearance and growth of CuO polycrystalline nanoparticles. The nanoparticles appeared at 25-35 °C had a near-spherical shape with complex surface and diameter up to 220±50 nm. Whereas the aging at the temperature in the range from 45 to 85 °C resulted in formation of spindle-like nanoparticles with length to width ratio 5±1. The kinetic of the colloid transformation and growth of nanoparticles was characterized by changes in absorbance spectrum. The transformation process was considered in terms of Kolmogorov-Avrami approach.

The work was supported by Russian Science Foundation (project 21-72-00116). The equipment of the Ural Center for Share Used «Modern Nanotechnologies» Ural Federal University (Reg. 2968) was used.

S06-18 Nanoscale 3D printing of functional structures using blended resin mixtures with micro/nanojoining of metallic nanowires

Yong Feng Lu[1], Ying Liu[1], Wei Xiong[1], Peixun Fan[1], Aofei Mao[1], Jean-François Silvain[2]
[1] Department of Electrical and Computer Engineering, University of Nebraska-Lincoln, Lincoln, USA
[2] Institut de Chimie de la Matière Condensée de Bordeaux, Avenue du Docteur Albert Schweitzer, Pessac Cedex, France
ylu2@unl.edu

Three-dimensional (3D) electrically conductive micro/nanostructures are now a key component in a broad range of research and industry fields. Direct laser writing by two-photon polymerization (TPP) has been established as one of the most promising methods for achieving 3D fabrication in micro/nanoscales, due to its ability to produce arbitrary and complex 3D structures with sub wavelength resolution. However, the lack of TPP-compatible and functional materials represents a significant barrier to realizing the functionality of the fabricated devices, such as high electrical conductivity, high environmental sensitivity, and high mechanical strength, etc.

In this work, a novel method was developed to realize metallic 3D micro/nanostructures with silver-thiol-acrylate composites via TPP followed by femtosecond laser nanojoining. Complex 3D micro/nanoscale conductive structures have been successfully fabricated with ~200 nm resolution. The loading of silver nanowires (AgNWs) and joining of junctions successfully enhanced the electrical conductivity of the composites from insulating to 92.9 S m^{-1} at room temperature. Moreover, for the first time, a reversible switching to a higher conductivity was observed, up to ~10^3-10^5 S m^{-1} at 523 K. The temperature-dependent conductivity of the composite was analyzed using the variable range hopping and thermal activation models. The as-developed nanomaterial assembly and joining method in this study paves a way toward a wide range of device applications, including 3D electronics, sensors, memristors, micro/nanoelectromechanical systems (MEMS/NEMS), and biomedical devices, etc.

S06-19 $CsPbBr_3$ deposited by laser ablation as indirect detector of ionizing radiation

Anna Paola Caricato
Department of Mathematics and Physics “Ennio De Giorgi”- University of Salento and INFN (National Institute of Nuclear Physics), Lecce, Italy
annapaola.caricato@unisalento.it

All-inorganic perovskites are characterized by outstanding optoelectronic properties, encompassing long carrier diffusion length, extended optical absorption, high photoluminescence and low non-radiative recombination making them particularly attractive for disparate applications, from solar cells and light-emitting diodes to photo-detectors.

The application of perovskite for ionizing radiation detection is relatively recent, but among the most promising [1]. Their success as radiation detectors rests partly on the same material properties that have led to their success in other optoelectronics applications, plus additional specific properties like high stopping power, high mobility-lifetime product, large carrier-lifetime product, large bulk resistance, fast response. Among radiation detectors, perovskite-based scintillators could offer, in principle, unique advantages compared to both direct detectors and conventional scintillators.

In all the applications, the performances of the perovskite-based devices critically depend on the deposition technique.

In this paper we report on the deposition of all-inorganic perovskites films, with particular attention to $CsPbBr_3$, by laser ablation.

The laser ablation mechanism will be discussed together with the influence of some deposition parameters (ambient gas, target-substrate distance, post-deposition annealing, laser frequency) on the film properties (morphological, compositional, structural and optical properties) with particular attention to the scintillation capability under ionizing radiation excitation.

1. Q.Chen, et.al; All-inorganic perovskite nanocrystal scintillators, Nature 561, 88–93 (2018).

S06-20 Laser synthesis of long linear carbon chains

A. Kucherik[1], S. Kutrovskaya[1,2], A. Osipov[1], V. Samyshkin[1], A. Abramov[1], A. Povolotskiy[3]

[1] Department of Physics and Applied Mathematics, Stoletov Vladimir State University, Vladimir, Russia

[2] Skolkovo Institute of Science and Technology, Moscow, Russia

[3] Institute of Chemistry, St. Petersburg State University, St. Petersburg, Russia

kucherik@vlsu.ru

Here we study stable elongated carbon chains synthesized by the laser ablation technique in a colloidal solution [1]. The mechanical stabilisation of carbyne is achieved due to the electron bonding of carbon chains to gold nanoparticles (NPs) [2]. When deposited on a substrate, the stabilized chains demonstrate straight parts whose lengths significantly exceed the theoretical limit for a free stable monoatomic carbon chain. The high-resolution transmission electron microscopy (HR TEM) of our samples shows straight linear carbon chains of the lengths that sometimes exceed 5 nm. The time-resolved photoluminescence (TRPL) spectra show that the radiative life-time of the observed transitions is of the order of 1 ns, that is similar to the data reported for excitons in CNTs. The exciton radiative lifetime decreases with the decrease of the length of the chain. We refer to the Su-Schrieder-Heeger model [3] to argue that the transition that dominates low temperature PL spectra is based on the edge electronic states that form the HOMO-LUMO pair in carbon chains stabilized by gold NPs.

This observation demonstrates a high potentiality of synthesized carbon chains for optoelectronic applications. Moreover, the observation of radiatively active excitons in ultimate one-dimensional crystals is of a great fundamental interest.

The study was carried out using the equipment of the interregional multispecialty and interdisciplinary center for the collective usage of promising and competitive technologies in the areas of development and application in industry/mechanical engineering of domestic achievements in the field of nanotechnology (Agreement No. 075-15-2021-692 of August 5, 2021). This work was also partially supported by the framework of the state task of VlSU № 0635-2020-0013

1. Kucherik, S.M Arakelian et al Two-stage laser-induced synthesis of linear carbon chains, Quantum Electronics 46, 627 (2016).
2. S. Kutrovskaya, I. Chestnov et al Electric field assisted alignment of monoatomic carbon chain, Scientific Reports 10(1) (2020)
3. W. P. Su, J. R. Schrieffer, and A. J. Heeger, Solitons in polyacetylene, Phys. Rev.Lett. 42, 1698 (1979).

S06-21 Mass customization of flow chemistry reactors and microfluidic chips using femtosecond laser micromachining

Ya Cheng
East China Normal University, Shanghai, China
ya.cheng@siom.ac.cn

We discuss mass fabrication of customized microfluidic reactors for flow chemistry application using femtosecond laser assisted chemical etching (FLACE). We overcome the inherently low fabrication efficiency in femtosecond laser modification of glass by creating a relatively large focal volume in glass with balanced transverse and longitudinal resolution. The fabricated microreactors can have reaction volumes up to tens of milliliters, allowing for high-throughput continuous manufacturing of chemical products in a safe, clean, and highly efficient manner. Besides, the versatility of femtosecond laser micromachining enables integration of optical fibers into the microreactors for real-time monitoring of the chemical reaction process.

S06-22 Laser irradiation influence on the semiconductor films for its multi-functional application

M.M. Sergeev, V.R. Gresko, A.A. Olkhova, A.D. Dolgopolov, Y.M. Andreeva
ITMO University, St. Petersburg, Russia
maxim.m.sergeev@gmail.com

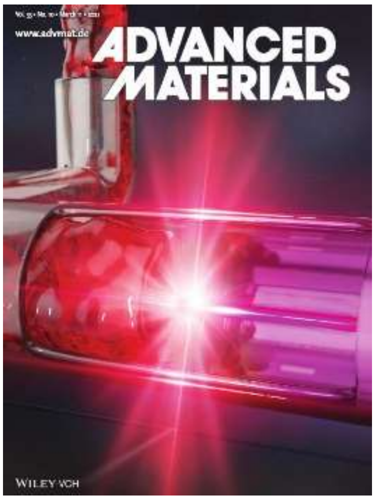
Semiconductor films now are widely used as functional elements for detecting signals and various substances. A feature of such materials is sensitivity to visible UV and IR radiation, photoelectric properties, such as resistance and mobility of charge carriers, as well as the possibility of correcting these characteristics in various ways. Changing the optical and electrical properties of films by laser action is one of the promising methods of processing for the manufacture of photodetectors and elements as part of integrated optical systems. An urgent problem is the description of the mechanisms of laser modification of the properties of such films, as well as the development of methods for laser action on them, in which the result of a change in properties will be predictable.

The paper presents the results of laser modification of the structure, leading to a change in the electrical and optical properties of films: AlZnO:Ag, TiO_2:Ag, PbSe. Based on the accumulated experimental data, an approach was formulated for describing the optical and electrical properties of semiconductor multicomponent films with/without nanoparticles. Models for describing the optical properties of a film in the form of an effective medium were supplemented by thermophysical models of heat sources that appear in the region of a laser spot, as well as a model for the growth and destruction of nanoparticles in a solid matrix.

This research was funded by the grant of the Russian Science Foundation (project No. 19-79-10208).

S06-23 Laser-based functionalisation of microsystems

J. V. Wochnowski
Technische Hochschule, Lübeck, Germany
Joern.Wochnowski@fh-luebeck.de



The production of tailor-made three-dimensional structures in the micro- and nanometer range[1] using micromachining technology using preferred femtosecond lasers has only been possible for about ten years.
An essential aspect for applications of this technology in microoptics, micromechanics, microelectronics and microchemistry is the possibility - the structures obtained via this micromachining technology - to modify their surfaces retroactively.[2-3] Such modifications often require the introduction of metals or metal components into such micro- or nano-systems for numerous applications.
The chemical vapor deposition of organometallic compounds (OMCVD) allows metal deposition from the vapour phase without damaging these often very temperature-sensitive micro- or nanostructured substrates. In a subsequent step, these are to be functionalised with interesting metals using OMCVD, so that novel applications in the areas of micro(nano)optics, micro(nano)mechanics, micro(nano)electronics and micro(nano)chemistry can become possible.[4]
This functionalisation by OMCVD will be presented and discussed intensively in this talk.

1. J. R. Varghese, C. Wendt, F. B. Dix, D. Aulakh, U. Sazama, A. A. Yakovenko, M. Fröba, J. Wochnowski, D. V. Goia, and M. Wriedt*, Design and Characterization of Metal Nanoparticle Infiltrated Mesoporous Metal–Organic Frameworks, Inorg. Chem. 2021, 60, 17, 13000–13010.
2. J. Wochnowski et al., Modified multichannel structures and their production and use Patents: WO 2008135542 (DE 102007020800 (A1), EP2152928 (A1).
3. J. Wochnowski et al., Hollow waveguide used in medicine and in structural analysis comprises a channel structure having an inner coating with a specified thickness Patents: DE 102007049929 (B4)
4. J. Wochnowski et al., Surface-modified structures, useful e.g. in optical or catalytic applications, comprise substrate, e.g. of glass, silicate primary coating and secondary coating, e.g. of metal Patents: DE 102007049930 (B4).

FT-S06-11 Laser-induced modification of ZnO thin films properties for optoelectronic application

V.R. Gresko, M.M. Sergeev, V.V. Smirnova, A.D. Dolgopolov
ITMO University, Saint Petersburg, Russia
gresko.97@mail.ru

ZnO thin films due to their physical properties are often used as photosensitive elements and layers of various optoelectronic devices for example in solar cells [1], UV photodetectors [2], and photocatalysis devices [3]. Nanoparticles increase the efficiency of such devices, for example, due to the Schottky effect [4]. As a rule, to change the properties of such films in a wide range it is necessary to make changes in the material manufacturing technology. In most cases, this is problematic for production with an already debugged technological process. Laser radiation is a very convenient tool for a fast, highly efficient and, at the same time, easy-to-implement method for local modification of film properties with the possibility of their correction in real time. By choosing the radiation wavelength and the irradiation mode, it is possible to influence both the ZnO matrix itself and the nanoparticles located in it.

In this work, we studied the possibility of ZnO UV photosensitivity increasing under the action of continuous wave radiation with a wavelength of 405 nm. Areas 4x4 mm^2 in size were recorded on the surface of the films at different scanning speeds and various radiation powers. The results of optical microscopy showed a change in the morphology of the films, their structure was compacted and recrystallized. Also, the nanoparticle size changed and the plasmon resonance peak shifted to shorter wavelengths. A study of the electrical characteristics showed that it was possible to significantly reduce the electrical resistance of the material. Measurement of the photocurrent showed that the signal-to-noise ratio increased from 4.6 to 7.6.

This research was funded by the grant of the Russian Science Foundation (project No. 19-79-10208)

1. Nasser H. et al. Fabrication of Ag nanoparticles embedded in Al: ZnO as potential light-trapping plasmonic interface for thin film solar cells //Plasmonics. – 2013. – Т. 8. – №. 3. – С. 1485-1492.
2. Klochko N. P. et al. Solution-processed flexible broadband ZnO photodetector modified by Ag nanoparticles //Solar Energy. – 2022. – Т. 232. – С. 1-11.
3. Karimi-Maleh H. et al. Tuning of metal oxides photocatalytic performance using Ag nanoparticles integration //Journal of Molecular Liquids. – 2020. – Т. 314. – С. 113588.
4. Zheng Y. et al. Photocatalytic activity of Ag/ZnO heterostructure nanocatalyst: correlation between structure and property //The Journal of Physical Chemistry C. – 2008. – Т. 112. – №. 29. – С. 10773-10777.

FT-S06-12 Investigation of conditions for laser-plasma recording of micro-optical elements arrays in glass

A.A. Boloshko, V.S. Rymkevich, M.I. Egorova, M.M. Sergeev
ITMO University, St. Petersburg, Russia
boloshko_nastya@mail.ru

The methods of a glass surface processing using laser-induced plasma are relevant due to their practical significance and ease of integration into the technical process [1]. They can be used for fabrication of microoptical elements and also to increase the resolution and to improve the processing quality [2-4]. The production of big arrays of similar microoptical elements is possible by photolithography or the direct laser writing, but they are expensive and need a lot of time. In this work the considered method of laser induced processing by microplasma (LIMP) differs from those often considered in the scientific literature LIPAA and LIBDE by a gap absence between the target and the sample, as well as the target in the form of a graphite plate.

In this work was studied the influence of changes in energy density and the pulse repetition rate on geometric dimensions such as diameter and depth of microcraters formed in fused silica glass. In this experiment, writing of several microcraters arrays with dimentions10x10 elements was performed with the microscope objective 10^x NA = 0.3. Laser exposure parameters was varying among arrays. The fused silica surface was studied by the optical microscope Zeiss Axio Imager and optical profilometer Zemetrics ZeScope. Obtained values were compared with the measuring results of the microlenses arrays made with using F-theta lens.

Experimentally, it was found that with power density increase there is an increase in both the diameter and the depth of the microcraters in the sample. The difference between using the microscope objective and F-theta lens is significant less microcraters diameters, in the first case. Also, writing the microlens array in random order allows to achieve greater uniformity in depth. The obtained results can be used in the manufacture of microlens arrays.

1. Kostyuk G., Zakoldaev R., Sergeev M., Veiko V. Laser-induced glass surface structuring by LIBBH technology // Optical and Quantum Electronics. – 2016. – Т. 48, № 4. – С. 249.

2. Shkuratova V., Kostyuk G., Sergeev M., Zakoldaev R., Yakovlev E., Medvedev O. Rapid fabrication of spiral phase plate on fused silica by laser-induced microplasma // Applied Physics B. – 2020. – Т. 126, № 4. – С. 1-6.
3. Shkuratova V., Rymkevich V., Kostyuk G., Sergeev M. Laser-induced microplasma as effective tool for phase elements fabrication on amorphous and crystalline materials // Journal of Laser Micro Nanoengineering. – 2018. – Т. 13, № 3. – С. 211-215.
4. Zakoldaev R., Kostyuk G., Koval V., Sergeev M., Rymkevich V., Yakovlev E. Microlens array fabrication on fused silica by LIBBH technology with CO2 laser smoothing // Известия высших учебных заведений. Приборостроение. – 2016. – Т. 59, № 5.

FT-S06-13 Influence of factors controlling surface microgeometry of fused silica during fabrication of multisector binary phase plates by laser-induced microplasma on functioning quality

G.K. Kostyuk[1], D.S. Stepanyuk[1], A.A. Petrov[1], V.A. Shkuratova[1], O.S. Vasilev[2]
[1] ITMO University, St. Petersburg, Russia
[2] Laser center LLC , St. Petersburg, Russia
gkkostiuk@itmo.ru

At the present time, considerable attention is paid to the application of multisector binary phase plates (MBPPs) both for generating superposition of scalar vortex beams (SVBs) [1] and for transforming cylindrical first-order vector beams (radially or azimuthally polarized) beams into hybrid beams of higher orders [2].

MBPPs fabrication technologies are based on local control of the microgeometry of fused silica plates using laser radiation with a short pulse duration. One of the technologies used for fabrication of MBPPs is laser-induced microplasma (LIMP) [3]. The microrelief formation by LIMP includes two stage energy transformation: from laser radiation to plasma and from plasma to the energy of material decomposition and destruction [4]. Therefore, the results of microrelief formation do not depend directly on laser radiation characteristics. Due to the absence of direct analytical relationships between etching depth and laser radiation regimes, the selection of impact parameters was experimentally performed based on the results of preliminary writing of the so-called depth map. The area of a unit square in it was 0.25 x 0.25 mm^2. The variable parameters during its writing were the average power P [W], the scanning speed V [m/s] and the number of scans N.

The quality of MBPPs functioning is determined by: (i) compliance of the sectors etching depth with the calculated value; (ii) deviation of the etching depth in different MBPP sectors from the calculated one; (iii) the surface roughness in the etched sectors.

In this research, MBPPs were made by LIMP according to the writing parameters chosen from the depth map. A part of MBPPs was processed by wet laser cleaning. Another part of MBPPs was annealed in a furnace. Studies of the MBPPs writing results were performed on the Hommel Tester T8000 profilometer with the resolution of ± 0.01 μm.

The results of the etching depths compliance in MBPPs sectors showed that to ensure the quality of the MBPPs functioning, the following should be done: (i) fabrication of the unit square of the depth map with an area close to the MBPPs sectors area; (ii) exclusion of additional wet cleaning operation.

This work was supported by the Russian Science Foundation [project number 20-71-10103].

1. L. Zhou, Y. Jiang, P. Zhang, W. Fan, X, Li, Directly writing binary multi-sector phase plates on fused silica using femtosecond laser, High Power Laser Sci. 6 (2018) e6, https://doi.org/10.1017/hpl.2018.1.
2. S. N. Khonina, A. V. Ustinov, S. A. Fomchenkov, A. P. Porfirev, Formation of hybrid higher-order cylindrical vector beams using binary multi-sector phase plates, Sci. Rep. 8 (1) (2018) 1-11, https://doi.org/10.1038/s41598-018-32469-0.

3. G.K. Kostyuk, V.A. Shkuratova, A.A. Petrov, M. M. Sergeev, Phase masks from birefringent plates for creation of given laser beam shape with ultrafast duration for materials processing at imagine plane, Journal of Instrument Engineering 65 (2) (2022) 101-111 (in Russian), https://doi.org/10.17586/0021-3454-2022-65-2-87-166.
4. V.P. Veiko, S.A. Volkov, R.A. Zakoldaev, M.M. Sergeev, A.A. Samokhvalov, G.K. Kostyuk, K.A. Milyaev, Laser-induced microplasma as a tool for microstructuring transparent media, Quantum Electron. 47 (9) (2017) 842, https://doi.org/10.1070/QEL16377.
5. L. Zhou, Y. Jiang, P. Zhang, W. Fan, X. Li, Directly writing binary multi-sector phase plates on fused silica using femtosecond laser, High Power Laser Sci. 6 (2018) e6, https://doi.org/10.1017/hpl.2018.1.

FT-S06-14 Multisector binary phase plates on fused silica for generation of scalar vortex beams

G.K. Kostyuk, V.A. Shkuratova, A.A. Petrov, D.S. Stepanyuk
ITMO University, St. Petersburg, Russia
gkkostiuk@itmo.ru

Almost all the main phase optical elements (POEs) (q-plates, s-plates, vortex half-wave plates, spatial light modulators, and their combinations) for laser beam transformation convert only single laser beams. Reports on the creation of laser beams superposition from a single laser beam are single cases [1-3]. These reports include information about design, manufacturing and testing of POEs known as multisector binary phase plates (MBPPs). In recent years, significant attention is paid both to the application of MBPP for generation of optical vortex beams (OVBs) superposition [1, 2] and the transformation of cylindrical vector beams of the first order (radially or azimuthally polarized beams) into hybrid high order beams [3]. The application of MBPPs in these areas is firstly stimulated by the simplicity of their design, manufacturing, and application reliability in comparison with other POE used for the solution of the same tasks where MBPPs are used. The main of these tasks are sharp focusing and beam shaping for laser micro- and nanoprocessing [1], optical manipulation [4], communications [5].

It is known that MBPPs can be regarded as spiral phase plates (SPPs) quantized in two phase levels of 0 and π [6]. In this case in the paraxial approximation, when $\cos(\varphi) = 1$ and $\sin(\varphi) = 0$, intensity distribution generated by MBPPs in the far field will be OVBs superposition with opposite topological charges [6]. The MBPPs executed with two phase levels of 0 and $\pi/2$ can also be regarded as SPPs quantized in two phase levels of 0 and $\pi/2$. In the paraxial approximation, intensity distribution peculiarity in the far field generated by such MBPP will be OVBs superposition with topological charges of the same sign.

The technology of structuring transparent dielectrics by laser-induced microplasma (LIMP) was used for fabrication of a wide class of POEs on fused silica [7], including SPP [8]. In this research, we offer to use this technology for fabrication of MBPPs, which are simpler phase elements compared to SPPs.

MBPPs testing was performed based on registration of intensity distributions generated in the vicinity of the far field by CCD camera and in a scheme with a nanosecond fiber laser (wavelength $\lambda = 1.06$ μm) for simultaneous processing of steel plates.

Key words: phase optical element, vortex beams, laser-induced microplasma, laser processing.

This work was supported by the Russian Science Foundation [project number 20-71-10103].

1. A. Kuchmizhak, A. P. Porfirev, S. A. Syubaev, P. A. Danilov, A. A. Ionin, O. B. Vitrik, Yu. N. Kulchin, S. N. Khonina, S. I. Kudryashov, Multi-beam pulsed-laser patterning of plasmonic films using broadband diffractive optical elements, Opt. Lett. 42 (14) (2017) 2838-2841, https://doi.org/10.1364/OL.42.002838.
2. L. Zhou, Y. Jiang, P. Zhang, W. Fan, X, Li, Directly writing binary multi-sector phase plates on fused silica using femtosecond laser, High Power Laser Sci. 6 (2018) e6, https://doi.org/10.1017/hpl.2018.1.

3. S. N. Khonina, A. V. Ustinov, S. A. Fomchenkov, A. P. Porfirev, Formation of hybrid higher-order cylindrical vector beams using binary multi-sector phase plates, Sci. Rep. 8 (1) (2018) 1-11, https://doi.org/10.1038/s41598-018-32469-0.
4. M. Chen, M. Mazilu, Y. Arita, E. M. Wright, K. Dholakia, Dynamics of microparticles trapped in a perfect vortex beam, Opt. Lett. 38 (22) (2013) 4919-4922, https://doi.org/10.1364/OL.38.004919.
5. J. Wang, J.-Y. Yang, I. M. Fazal, N. Ahmed, Y. Yan, H. Huang, Y. Ren, Y. Yue, S. Dolinar, M. Tur, A. E. Willner, Terabit free-space data transmission employing orbital angular momentum multiplexing, Nat. Photonics. 6 (7) (2012) 488-496, https://doi.org/10.1038/nphoton.2012.138.
6. S. N. Khonina, Simple phase optical elements for narrowing of a focal spot in high-numerical-aperture conditions, Opt. Eng. 52 (9) (2013) 091711, https://doi.org/10.1117/1.OE.52.9.091711.
7. V.P. Veiko, S.A. Volkov, R.A. Zakoldaev, M.M. Sergeev, A.A. Samokhvalov, G.K. Kostyuk, K.A. Milyaev, Laser-induced microplasma as a tool for microstructuring transparent media, Quantum Electron. 47 (9) (2017) 842, https://doi.org/10.1070/QEL16377.
8. V. Shkuratova, G. Kostyuk, M. Sergeev, R. Zakoldaev, E. Yakovlev, O. Medvedev, Rapid fabrication of spiral phase plate on fused silica by laser-induced microplasma, Appl. Phys. B. 126 (4) (2020) 1-6, https://doi.org/10.1007/s00340-020-7410-x.

FT-S06-15 Laser colour patterning of glass material: comparison between laser induced film transfer in air and in vacuum

A. Ramos-Velazquez, A.A. Lebedko, R.A. Zakoldaev, V.P.Veiko
ITMO University, St.Petersburg, Russia
alejandroramosv@itmo.ru

Recently, the marking of transparent materials has attracted significant research attention due to its practical applicability to include key information during the manufacturing process of glass products. Indirect laser-induced methods such as LIPAA, PLD and LIFT have been demonstrated as viable techniques for precise colour marking of glass [1]. Monochromatic high contrast indirect marking of glass has been demonstrated using one component materials [2]. However, the current industry requires a wider colour palette for a higher storage density, protection against counterfeiting, and design of attractive labels. Towards this end, we have demonstrated the possibility of generating polychrome marks on glass using a single multicomponent material [3].

Beyond practical applications, understanding the nature of colour formation is critical for optimising the use of indirect polychrome laser marking. On the one hand, it has been demonstrated that components of the donor material play a crucial role in the indirect colour marking process [1]. On the other hand, physicochemical alterations caused by the light-matter interaction, high temperatures and atmospheric conditions may be the origin of such colours [4]. Due to the large number of conditions that may be involved in colour generation, it is necessary to exclude factors such as oxidation (or nitridization) of the material. To this end, the present report investigates the influence of the environment on the colorimetric characteristics of the applied marks.

Herein, we investigate the behaviour of indirect laser-induced marking process when it is performed under different ambient environments (vacuum and air). The influence of processing parameters on the applied patterns was investigated, as well as the influence of atmospheric conditions on the colour formation. Different diagnostic techniques such as scanning electron microscopy, optical microscopy and spectroscopy were employed in order to compare the influence of the atmospheric conditions on the characteristics of the marks i.e. colour, morphology, spectrum.

The reported study was financially supported by the Ministry of Science and Higher Education of the Russian Federation Research Agreement No. 075-11-2019-066 of 22.11.2019.

1. Hong, Minghui, Koji Sugioka, Ding Jiang Wu, L. L. Wong, Yongfeng Lu, Katsumi Midorikawa, and Tow Chong Chong. "Laser-induced-plasma-assisted ablation for glass microfabrication." In Photonic Systems and Applications, vol. 4595, pp. 138-146, 2001
2. Liu, Huagang, Wenxiong Lin, and Minghui Hong. "Hybrid laser precision engineering of transparent hard materials: challenges, solutions and applications." Light: Science & Applications 10 no. 1, 1-23 (2021)
3. Velazquez, A. Ramos, et al. "Investigation of Laser-Induced Formation of Polychrome Marks on Glass." Сборник трудов конференции «International Conference on Advanced Laser Technologies (ALT)». No. 21. Федеральное государственное бюджетное учреждение науки Федеральный исследовательский центр «Институт общей физики им. АМ Прохорова Российской академии наук», 2021.
4. Bronnikov, Kirill, et al. "Regulating Morphology and Composition of Laser-Induced Periodic Structures on Titanium Films with Femtosecond Laser Wavelength and Ambient Environment." Nanomaterials 12.3 (2022): 306.

FT-S06-16 Laser-inducted modification of the PbSe chalcogenide film photosensitivity

A.A. Olkhova, A.A. Patrikeeva, M.M. Sergeev
ITMO University, St. Petersburg, Russia
lazareva.a.a@mail.ru

The continuous wave (CW) laser influence on the optical properties and PbSe films structure modification was investigated.

In recent years, the issue of preserving the environment from harmful emissions into the atmosphere from the production of the oil and gas, coal and chemical industries has been increasingly raised. For effective space sensing and environmental protection, various gas analyzers and sensors capable of capturing the content of harmful substances in the air are in demand. Chalcogenide films are excellent gas detectors because they have high absorption in the IR range, where gas molecules have absorption peaks. There are many ways to increase the photosensitivity of such films: heat treatment, alloying, etc. However, one of the affordable and low-cost methods is laser modification of their structure.

The result of laser influence on PbSe films at a moving spot of CW radiation with a 405 nm wavelength was studied. The laser processing of these films in the scanning regime led to the formation of a track in the case of structure photodarkening and photobleaching. The spectral reflection in these regimes differ insignificantly from each other and tend to black body, however, they have a strong difference from the original PbSe film and are close in position to the film after heat treatment.

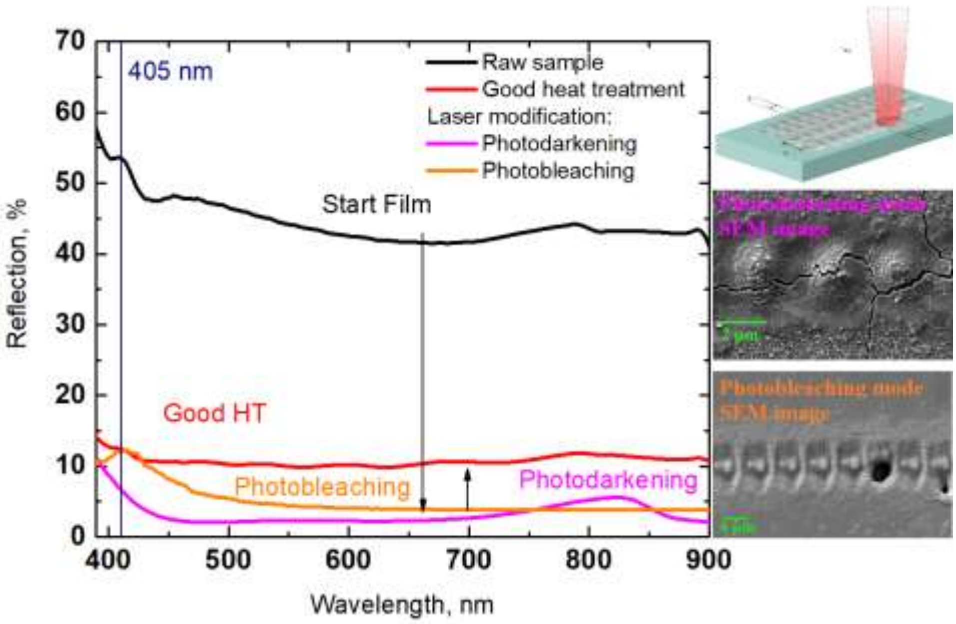


Figure 1 – Reflectance spectra and SEM images obtained from samples subjected to various treatments

Thus, the possibility of controlling the optical and structural characteristics of lead selenide films by means of CW laser radiation was demonstrated. Laser processing of this material can be used in the application of gas analysis, since chalcogenide films have a high absorption capacity in the mid-IR range (1–4 μm), as well as in the creation of substrates for microanalytical studies of various liquids.

FT-S06-17 The fabrication processes and simple micro-cavity size adjustment of fiber Mach-Zehnder interferometer by laser-induced micro-plasma

Cai Shuhao[1,2]*, M.Sergeev*[1]*, A.Petrov*[1]*, S.Varzhel*[1]*, Li Li*[2]
[1]ITMO University, St. Petersburg, Russia
[2]School of Electronic and Optical Engineering, Nanjing University of Science and Technology, Nanjing, China
caishuhao@mail.ru

The detailed fabrication processes of fiber Mach-Zehnder interferometers (FMZIs) by nanosecond pulsed laser-induced micro-plasma and its simple micro-cavity size adjustment are proposed and demonstrated. The fabrication can be divided into 4 processes: (1) heat transfer, (2) micro-plasma formation, (3) micro-plasma expansion and ablation, (4) cooling down and micro-structure formation. The simple micro-cavity length adjustment is proposed based on the above understanding, instead of the “point fabrication method” of femtosecond laser, here only the focus position is required to be moved. The fabricated FMZI exhibits a high sensitivity of -15811 nm/RIU (refractive index unit) for the index sensing application.

FT-S06-18 Fused silica processing by laser induced microplasma: pulse duration influence

V.S. Rymkevich, A.A. Boloshko, M.M. Sergeev
ITMO University, Saint Petersburg, Russia
v.rymkevich94@gmail.com

Glass processing based on laser-induced technologies such as dry laser-induced back surface etching (LIBDE) [1], laser-induced plasma etching (LIPAA) [2] and microplasma are relevant due to the ease of implementation and a wide choice of laser sources.

According to numerical simulations in the work [3], in LIPAA method with an increase in the pulse duration in the millisecond range, an increase in the channels size on the glass surface formed by the plasma plume occurs due to more energy pumping into the plume and as result an increase its lifetime. In this paper, we considered the glass treatment method of laser-induced micro plasma (LIMP) [4]. In the LIMP method, the graphite target and the sample do not have a gap between each other, which distinguishes it from the LIPAA method often considered in the scientific literature. Historically, LIMP has implemented on a 50 ns pulse duration, but there is no scientific justification for this decision in the known literature. Thus, the study of the pulse duration influence on the microplasma treatment process is scientific and practical interest.

In this work, the goal was to determine the laser pulse duration influence in the femto- to nanoseconds range on the plasma plume lifetime and the structures geometry formed by the microplasma plume on the fused silica surface. In the LIMP with femtosecond pulses, the maximum energy density was chosen in such a way as to exclude direct laser recording. In the nanosecond range, the energy density was constant at 0.89 J/cm^2, while in the femtosecond range it varied from 1.96 J/cm^2 to 3.33 J/cm^2. In the experiment, the tracks were recorded at 40 kHz pulse repetition rate and a workplane linear velocity of 20 mm/s. The plasma plume radiation in the treatment zone was guided through the fiber, directed as much as possible perpendicular to the medii interface, into the photoelectron multiplier. The signal from the photomultiplier, representing the plasma plume relative radiation intensity, was transmitted to the oscilloscope. The plasma plume intensity was recorded for each laser pulse and then averaged. At the same time, a laser radiation signal was recorded. The geometry of the formed tracks was studied using optical profilometry.

A linear dependence of the plasma formation limiting energy density according to the pulse duration was experimentally revealed in the range from 220 fs to 3 ps. In the femtosecond range (from 220 fs to 3000 fs), the track depth varied linearly. At the same time, at the range from 220 fs to 1500 fs, the track width increased linearly from 5 to 7 µm, and then decreased to 3 µm at the range from 1500 fs to 3000 fs. The plasma lifetime in the femtosecond range had a quadratic dependence: it decreased to 1000 fs and increased to 3000 fs. In the nanosecond region (from 4 ns to 200 ns), the width and depth of the track had a square root dependence. In the nanosecond range, the plasma lifetime had two different behaviors (before and after 30 ns). The data located on the segment up to 30 ns are well approximated by the square root dependence, and after that they have an exponential form. This behavior may serve as evidence that the plasma plume is fed by the remaining part of the laser pulse.

1. Ehrhardt M., Lorenz P., Bayer L., Han B., Zimmer K. Studies of the confinement at laser-induced backside dry etching using infrared nanosecond laser pulses // Applied Surface Science. – 2018. – T. 427. – C. 686-692.
2. Hanada Y., Sugioka K., Midorikawa K. Laser-induced plasma-assisted ablation (LIPAA): fundamental and industrial applications // High-Power Laser Ablation VI. – T. 6261 –International Society for Optics and Photonics, 2006. – C. 626111.
3. Sarma U., Joshi S. N. Numerical modelling and simulation of microchannel fabrication on polycarbonate using Laser-Induced Plasma Assisted Ablation (LIPAA) // Optik. – 2020. – T. 223. – C. 165379
4. Rymkevich V. S., Sergeev M. M., Zakoldaev R. A. Laser microplasma as a spot tool for glass processing: Focusing conditions // Journal of Materials Processing Technology. – 2021. – T. 292. – C. 117061

FT-S06-19 Spiral phase plates for generation of scalar vortex beams made on fused silica by laser-induced microplasma

G.K. Kostyuk, V.A. Shkuratova, A.A. Petrov, D.S. Stepanyuk
ITMO University, St. Petersburg, Russia
gkkostiuk@itmo.ru

Spiral phase plates (SPPs) are a common method, which provides direct efficient generation of beams carried orbital angular momentum from Gaussian beams [1-3]. The field of such beams is characterized by a helical (vortex) wavefront and an annular intensity distribution with intensity decrease in the beam central part, which appears due to destructive interference in the far field [4, 5]. Vortex beams are in great demand for such applications as an optical tweezer, micro- and nanoprocessing of materials, high-resolution microscopy, telecommunications [4].

SPP is the optical element with spiral-like relief. The thickness of SPP h varies proportionally to the azimuthal angle φ and is determined as $h = h_0 + s\varphi / 2\pi$ [1], where h_0 is the minimal SPP thickness, s is the step height. The plane wave transforms into the helical wave through SPP, and the phase circulates around the point of zero amplitude.

SPPs can be fabricated both on glasses and on polymers by numerous of techniques involving the electron-beam lithography, electron-beam deposition, gray-scale laser lithography, molding method and direct femtosecond polymerization [1-3, 6, 7].

We propose to use the technology of structuring transparent dielectrics by laser-induced microplasma (LIMP) for SPP fabrication on fused silica. This technology already was applied for fabrication of a wide class of optical elements [8].

SPP testing was performed based on registration of generated intensity distribution in the far field by CCD camera and in a scheme of two-beam interferometer containing a single mode CW laser with the wavelength of 1.064 μm. Registered interferograms demonstrated spiral structure of beam depending on the topological charge sign. The SPP conversion efficiency were determined by measuring the power of the initial beam before SPP and the transmitted beam through SPP, and it appeared to be more than 80%.

This work was supported by the Russian Science Foundation [project number 19-79-10208].

1. Massari M. et al. Fabrication and characterization of high-quality spiral phase plates for optical applications // Applied Optics. – 2015. – V. 54. – №. 13. – P. 4077-4083.
2. Oemrawsingh S. S. R. et al. Production and characterization of spiral phase plates for optical wavelengths // Applied Optics. – 2004. – V. 43. – №. 3. – P. 688-694.
3. Cheong W. C. et al. Direct electron-beam writing of continuous spiral phase plates in negative resist with high power efficiency for optical manipulation // Applied Physics Letters. – 2004. – V. 85. – №. 23. – P. 5784-5786.
4. Wang X. et al. Recent advances on optical vortex generation // Nanophotonics. – 2018. – V. 7. – №. 9. – P. 1533-1556.
5. Yao A. M., Padgett M. J. Orbital angular momentum: origins, behavior and applications // Advances in Optics and Photonics. – 2011. – V. 3. – №. 2. – P. 161-204.
6. Jun C. et al. Generation of optical vortex using a spiral phase plate fabricated in quartz by direct laser writing and inductively coupled plasma etching // Chinese Physics Letters. – 2009. – V. 26. – №. 1. – P. 014202.
7. Brasselet E. et al. Photopolymerized microscopic vortex beam generators: Precise delivery of optical orbital angular momentum // Applied Physics Letters. – 2010. – V. 97. – №. 21. – P. 211108.
8. Veiko V. P. et al. Laser-induced microplasma as a tool for microstructuring transparent media // Quantum Electronics. – 2017. – V. 47. – №. 9. – P. 842-848.

FT-S06-20 Fabrication of microfluidic channels in quartz glass by laser-induced plasma

M.A. Dubkova, M.M. Sergeev
ITMO University, St. Petersburg, Russia
maria.dubkova@mail.ru

The fabrication of microfluidic channels is part of the creation of microfluidic devices, which includes a factory to produce microfluidics.

Today, the demand for microfluidic devices is constantly growing, as their use allows to increase the efficiency, mobility of analysis, reduce the consumption of liquids and reagents, the size of the installations, and the costs of production and implement the mass production of these systems.

Now, the production of microfluidic channels using laser observation is the most efficient, environmentally friendly, and waste-free method.

There are many ways to manufacture microfluidic channels: photolithography, micro-mechanical cutting, embossing and imprinting etc., however, the creation of microfluidic channels using laser radiation is the most efficient, environmentally friendly and waste-free method.

The technology for creating microfluidic channels using laser microplasma (LIMP) has been studied. This method makes it possible to obtain microfluidic channels up to 2 cm in length, with a diameter of 40 µm to 60 µm, and a depth of 5 µm to 10 µm. The formation of channels on the surface of quartz glass using LIMP technology does not require the use of special optics for sharp focusing and is carried out using a relatively cheap laser device (MiniMarker based on a Yb laser and a flat field objective), to obtain microfluidic channels in the volume of glass, the sample was sintered in a furnace or welded with femtosecond pulses.

Thus, the possibility of creating microfluidic channels using the LIMP technology has been demonstrated. The formation of channels using this method can be used to create a microfluidic system for both studying the behavior of oil in porous soil, and for conducting an express blood test.

FT-S06-21 CO_2-laser glass structuring: development of microfluidic elements

A.G. Bondarenko, R.A. Zakoldaev
ITMO University, St. Petersburg, Russia
ag_bondarenko@itmo.ru

CO_2-laser glass structuring of silica materials is a promising way for functionalization of glass surfaces for needs of microoptics [1] and microfluidics [2]. Among other methods such as photolithography, wet and dry etching, ion-reactive processing, etc. laser direct writing is a cost-effective method of creating microchannels of various geometries. In recent years, in some scientific papers, CO_2-lasers were used to create microchannels on the glass surface [3,4]. A significant result of glass surface treatment by CO_2-laser radiation is wettability control. The change in roughness, the formation of a microrelief and surface periodic structures [5] are an important advantage of the developed technique. All this can form the basis for the creation of new microfluidic elements.

The paper proposes a method for direct laser writing of microstructures on the surface of quartz glass using a laser setup "C-Marker" based on an 80-watt CO_2-laser (wavelength 10.6 µm). To study the results obtained and measure the depth, width and roughness of the surfaces, an optical microscope (LOMO) and an optical profilometer (ZeScope) were used. A microscope (LOMO), a camera (ToupCam) and a syringe (500 µl) were used to study the wettability of surfaces.

The dependence of the depth, width and roughness of microstructures on the parameters (scanning speed and output power) of laser radiation was derived. As a result, microchannels and micro-basins of various geometries were obtained (Figure 1).

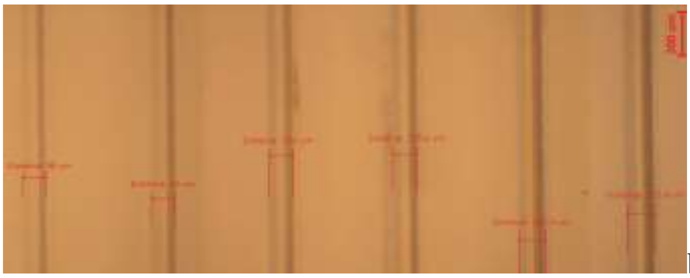
a)  b) 

Figure 1. Microchannels (a) of various geometries and micro-basin (b) on the glass surface obtained by a CO_2-laser

The wettability of the obtained microstructures was also investigated to determine the laser treatment modes in order to obtain hydrophilic and hydrophobic regions. Studies using a microscope with crossed polarizers have proved the possibility of recording channels without defects.

The researchers express their gratitude to the "Laser Center". The study is funded by RPMA grant of School of Physics and Engineering of ITMO University.

1. Zhao, L., Cheng, J., Yin, Z., Yang, H., Liu, Q., Tan, C., Yuan, X. (2020). Rapid CO2 laser processing technique for fabrication of micro-optics and micro-structures on fused silica materials. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 095440542093753.
2. Perrone, E., Cesaria, M., Zizzari, A., Bianco, M., Ferrara, F., Raia, L., Guarino V., Cuscunà, M., Mazzeo M., Gigli, G., Moroni, L., Arima, V. (2021). Potential of CO2-laser processing of quartz for fast prototyping of microfluidic reactors and templates for 3D cell assembly over large scale. Materials Today Bio, 12, 100163.
3. Azouz, A. B., Vázquez, M., Paull, B., & Brabazon, D. (2012). Laser Processing of Quartz for Microfluidic Device

Fabrication. Advanced Materials Research, 445, 436–441.
4. Aono, Y., Hirata, A., & Tokura, H. (2016). Non-textured laser modification of silica glass surface: Wettability control and flow channel formation. Applied Surface Science, 371, 530–537.
5. Tan, C., Zhao, L., Chen, M., Cheng, J., Yang, H., Liu, Q., Liao, W. (2021). Formation mechanism of surface morphology in the process of CO2 pulsed laser processing of fused silica optics. Optics & Laser Technology, 138, 106838.

FT-S06-22 Effect of molybdenum doping on photo-induced changes in glassy As_2S_3

E.V. Kapustina[1], V.R. Gresko[1], M.M. Sergeev[1], V.P. Veiko[1], M. Krbal[2], S.I. Nesterov[3], P.S. Provotorov[4], A.V. Kolobov[4]
[1] International Laboratory of Laser Micro- and Nanotechnologies, ITMO University, St. Petersburg, Russia
[2] Center of Materials and Nanotechnologies, Faculty of Chemical Technology, University of Pardubice, Pardubice, Czech Republic
[3] A.F. Ioffe Physico-Technical institute, St. Petersburg, Russia
[4] Department of Physical Electronics, Institute of Physics, Herzen State Pedagogical University of Russia, St. Petersburg, Russia
maxim.m.sergeev@gmail.com; akolobov@herzen.spb.ru

Chalcogenide glasses, of which As_2S_3 is a typical representative, exhibit a number of photo-induced phenomena, such as reversible photostructural change, photo-induced anisotropy, photo-induced volume expansion, etc. Reversible photostructural change, experimentally detected by structure-sensitive techniques such as Raman scattering, x-ray scattering and extended x-ray absorption fine structure ((EXAFS) manifests itself as photodarkening, when the optical band gap decreases upon illumination. The initial properties can be restored by subsequent annealing at temperatures close to the glass-transition temperature. The band gap decrease depends on the material composition and can reach a value as large as 0.3 eV. For reviews see refs [1-4].

The ability of chalcogenide glasses to undergo structural transformations, which opens up interesting perspectives for their application in various photonic devices [5], is associated with the presence of lone-pair electrons, i.e. paired elections that occupy the top of the valence band but do not participate in the formation of covalent bonds. When the materials is optically excited, these electrons may form additional (dynamic) bonds, which can lead to bond reconfuguration, resulting in a structural change. One can thus expect that the extent to which the structure changes depends on the concentration of lone-pair electrons. The latter can be controlled by doping with transition metals.

In this talk we report on the photodarkening and photo-induced change in the dissolution rate is inorganic solvents of As_2S_3 doped with Mo in concentrations from 2 to 18 at.%. Our results demonstrate that both the photo-induced shift of the optical absorption edge and the solubility contrast decrease with an increase in the Mo concentration, in full agreement with the proposed hypothesis.

This work has been supported by a joint Russian-Czech project funded by the Russian Foundation for Basic Research (grant 19-53-26017) and the Czech Science Foundation (grant 20-23392J).

1. A.V. Kolobov (ed.) Photo-inducd phenomena in amorphous semiconductors, Wiley-VCH, 2003
2. A.V. Kolobov, J. Tominaga, Chalcogenides: metstability and phase-change phenomena, Springer 2012
3. K. Tanaka, K. Shimakawa, Amorphous chalcogenide semiconductors and related materials, Springer, 2nd edition, 2021

4. A.V. Kolobov and K. Shimakawa (eds), The World Scientific Reference of Amorphous Materials, v. 1, World Scientific 2021
5. B. Eggleton, B. Luther-Davies, and K. Richardson, Nature Photonics, **5,** (2011) 141–148

Industrial Application of Lasers (S07)

S07-1 Development of Laser Additive Technologies

A.G. Grigoryants, D.S. Kolchanov, A.A. Drenin
N.E. Bauman Moscow State Technical University, Moscow, Russia
dkolchanov@bmstu.ru

The need to accelerate the release of new products, reduce the number of labour–intensive assembly and intermediate operations, increase the reliability and reduce waste - all these requirements characterize the current situation of modern production. Computer simulation simplifies the tasks of optimizing the geometry and structure of components and parts. As a result of the simulation, the mass of the product and the number of parts in the assemblies are reduced due to the combination of elements, the geometry becomes much more complex. Traditional production and processing methods often face difficulties in producing optimized products, increasing the labour intensity and time of operations. Some design options, with internal channels and cavities or complex internal structure, cannot be manufactured indecomposable. Additive technologies make it possible to solve these problems by turning the difficulties into advantages. The successful implementation of additive processes reduces the cost, labor intensity, mass and simplify the components that construction is developed or processed for additive processes.

Additive technologies are widely used in various industries. 3D printing is increasingly moving from prototype production to full functional products, including those made of metal alloys and composites. This paper presents the experience of Bauman Moscow State Technical University (BMSTU) in the development of equipment and technologies of selective laser melting.

In BMSTU, the traditional approach of combining theoretical research with various experimental work has been successfully used in the study of the selective laser melting (SLM) process. The developed equipment with the use of modern mathematical calculation programs made it possible to study processes occurring in a small volume in short periods of time with heating to melting points and almost instant cooling to the initial state. Metallurgical and rheological processes cannot be traced without the use of computer technology. In-depth study of the SLM process of various materials, technological features and successfully conducted research and development and design and development works were realized in the creation of an additive section based on the complex for selective laser melting SLM-250 at the enterprise of defense industrial complex and laboratory in BMSTU. Additional equipment allows to carry out the input control of materials and their preparation, as well as monitor the parameters of the grown products. Integration of additive technology into production is provided also by training of personnel (structural engineers, technologists, operators) according to the training program developed in BMSTU «Laser additive technology». The personnel issue in this matter plays one of the key roles. Thus, BMSTU covers all the fundamental issues for the successful introduction of additive technologies into production.

S07-2 Development of technological regimes and equipment for pilot tests for mechanical, thermal and chemical stability of laser-induced identification codes on the surface of structural and functional materials

Yu.R. Kolobov [1], S.S. Manokhin [1], V.P. Veiko [2], I.V. Nelasov [1], A.Yu. Tokmacheva-Kolobova [1], G.V. Odintsova [2]
[1]Institute for Problems of Chemical Physics, RAS, Chernogolovka, Moscow region, Russia

[2] ITMO University, St. Petersburg, Russia
kolobov@icp.ac.ru

A unique two-module test stand has been developed, manufactured and certified for conducting research and full-scale industrial tests for frictional wear of laser-induced identification codes on the surface of structural and functional materials for various purposes. The stand was put into operation in real production conditions at Laser Center LLC (St. Petersburg). The requirements for the storage and operation of products containing laser coding are formulated for the maximum permissible levels of external impact on structural and functional materials (the work was carried out in the format of Government Decree No. 218 of April 9, 2010).

Figure 1 – Two-module computerized test bench for determining the mechanical and chemical stability of laser-induced identification barcodes in a wide temperature range, including solutions with different pH values

Using the developed test bench, research and development technological work was carried out to study the microstructure, elemental and phase composition of the surface and thin near-surface layers of inorganic (metals, alloys, semiconductor compounds, ceramics, glass, polymers, etc.) and other materials (leather, fabric, paper, cardboard, etc.) aimed at characterizing the surface and near-surface layers of these materials before and after laser processing, as well as after testing the resistance of the generated laser-induced barcodes to mechanical, thermal and chemical damage to these materials. In order to increase the stability of laser-induced identification codes and the reliability of their reading for the studied materials, recommendations were developed for preliminary surface preparation, modes of application and reading of identification codes. Requirements for the storage and operation of products with surface laser coding have been developed for the maximum permissible levels of external impact on the surfaces of structural and functional materials.

This work in the main part, related to the study of the structure of the VT1-0 alloy after nanosecond laser exposure, was carried out with the financial support of the State Assignment, state registration number AAAA-A19-119022690098-3, and in the additional part, related to the determination of the parameters of mechanical properties, carried out with the financial support of the State task, state registration number AAAA-A19-119111390022-2. Structural studies were carried out using the scientific equipment of the Center for Collective Use of the Federal Research Center "Crystallography and Photonics" of the Russian Academy of Sciences (Moscow).

Authors acknowledge the support of the Ministry of Science and Higher Education of the Russian Federation research agreement No. 075-11-2021-045 of 24.06.2021, project title "Development of high-tech production of equipment and technologies for laser functionalization of the surface of medical products" (within the framework of decree of the Government of the Russian FederationNo. 218 of 09.04.2010).

S07-3 Investigation of the physical mechanisms of laser cleaning of the surface of hot-rolled metal from mill scale under the influence of continuous laser radiation with a wavelength of 1.06 microns

D.V. Zhurba, A.A Petrov
ITMO University, St-Petersburg, Russia
zhurba.danila306@yandex.ru

A searching study of the possibility of non-evaporative laser cleaning of the steel surface from rolling scale by radiation of a continuous ytterbium fiber laser was carried out. Previously unexplored mechanisms of destruction and removal of rolling scale have been discovered, which are more energy efficient compared to evaporative mechanisms of laser cleaning. Preliminary results of the study show the high prospects of the investigated approach to the problem under consideration. Pulsed laser cleaning of mill scale from the surface of hot-rolled steel is characterized by extremely low productivity. At the moment, the task of effective laser cleaning of mill scale layers is not solved. In this work, the search and study of more effective mechanisms of destruction and removal of mill scale based on the action of laser heating is carried out. Mill scale mainly consists of iron oxides and iron oxide decomposition products: mixtures of magnetite and metallic iron. The thickness of the mill scale is ~ 30 microns. The use of a continuous ytterbium fiber laser source with a scanning system providing a range of exposure durations of 1 – 1000 μs is proposed. The combination of physico-chemical and thermomechanical mechanisms during continuous laser treatment makes it possible to destroy and remove the source layer of mill scale. Further investigation of more effective physical mechanisms of mill scale cleaning by continuous laser radiation contributes to the development of a new in-demand industrial technology for removing mill scale and to create scientific and technical groundwork in the field of laser cleaning of thick oxide layers of metals.

Authors acknowledge the support of the Ministry of Science and Higher Education of the Russian Federation research agreement No. 075-11-2021-045 of 24.06.2021, project title "Development of high-tech production of equipment and technologies for laser functionalization of the surface of medical products" (within the framework of decree of the Government of the Russian FederationNo. 218 of 09.04.2010).

FT-S07-1 Digital rainbow hologram synthesis on the surface of stainless steel

E.V. Prokofiev, M.K. Moskvin, N.A. Afanasev, Bi Jinming, D.A. Sinev, G.V. Odintsova
ITMO University, St. Petersburg, Russia
zhenya.prokofev.1998@mail.ru

Surface modification using pulsed laser radiation allows to perform the structural colouring of surfaces in a wide range of materials. The formation of colour on the surface is possible due to creating various structures on the material surface. Approaches to colour forming can be divided into two main groups according to physical effects they are based on: interference and diffractive.

This work considers the creation of diffractive digital rainbow holograms on stainless steel surface based on laser-induced periodic surface structures (LIPPS). A pulsed fiber laser with a wavelength of 1.06 μm and a pulse duration of 100 ns was used for synthesis of digital rainbow holograms. The creation of different image dynamics was obtained by adjusting the direction of the structures depending on changes in the polarization of the laser radiation and the scanning trajectory. The module for controlling the polarization of laser radiation for laser equipment “Mini-Marker 2” was developed, consisting of a Glan-Taylor prism and a half-wave plate. The basis of the rainbow hologram is surface periodic structures with a period of ~1 μm with different recording geometry and a controlled direction of the visually observed surface color gradient.

The following types of images were obtained: figures with a homogeneous holographic colour, concentric circles, and figures with convergent and divergent holographic stripes, both with effect of smooth and fast colour change. Complex overlapping vector images were also created, appearing separately depending on the viewing angle.

The study was supported by the Russian Science Foundation (project No 21-79-10241).

FT-S07-2 Enhancing of mechanical properties of convex reliefs fabricated on metal surfaces by laser irradiation

J.V. Amiaga, A. Ramos-Velazquez, A.F. Igolkin
ITMO University, St. Petersburg, Russia
joooneg@gmail.com

Laser melting of metal surfaces is widely used in industrial applications such as welding, polishing and texturing [1]. Recently, there has been a great demand for sculpted metal surfaces for various applications in tribology [2], surface sculpting for diffractive sequence marks [3], and structuring of large surface area [4].

Several studies have reported the formation of surface features by moving the melt during laser heating below the ablation threshold of the material. For instance, the creation of diffraction structures by creating micro craters[3], as well as the generation of metallic macrostructures [5]. Moreover, the remelting of metallic surfaces to create a net, mass-neutral, lateral displacement of material by pulse power modulation (“Pulsed laser micro structuring”) [6] and continuous wave laser power (“WaveShape”) has been demonstrated.

To date, ensuring the quality of textured parts is fundamental in the industry. To this end, the mechanical properties of the laser induced surface features must be optimized to prevent defects and guarantee production quality. In this study, a system with a 100 W pulsed fiber laser is used to obtain the relief on steel surface described in [7]. During the laser treatment, the melt moves and cools in the air, therefore formation of mill scale is inevitable, which are then mixed with the rest of the melt.

To reduce the amount of mill scale, the effect of an additional treatment to evaporate part of the substrate and oxides deposited around the treatment region was investigated. The results show that alternating laser modes of cleaning and shaping leads to microhardness decreasing in the treated zone and consequently increasing the wear resistance of the resulting relief.

1. Kusiński, J., et al. "Laser modification of the materials surface layer-a review paper." Bulletin of the polish academy of sciences. Technical sciences 60.4 (2012): 711-728.
2. Dunn, Andrew, et al. "Laser surface texturing for high friction contacts." *Applied Surface Science* 357 (2015): 2313-2319.
3. Wlodarczyk, Krystian L., et al. "Laser microsculpting for the generation of robust diffractive security markings on the surface of metals." *Journal of Materials Processing Technology* 222 (2015): 206-218.
4. Patel, Divyansh, V. K. Jain, and J. Ramkumar. "Micro texturing on metallic surfaces: State of the art." *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture* 232.6 (2018): 941-964.

5. Blackburn, Jonathan, and Paul Hilton. "Producing surface features with a 200 W Yb-fibre laser and the surfi-sculpt® process." *Physics Procedia* 12 (2011): 529-536.
6. Pfefferkorn, Frank E., and Justin D. Morrow. "Controlling surface topography using pulsed laser micro structuring." *CIRP Annals* 66.1 (2017): 241-244.
7. Amiaga, John V., et al. "Groove Formation on Metal Substrates by Nanosecond Laser Removal of Melted Material." *Metals* 11.12 (2021):2026.

FT-S07-3 Laser modification of the cranial implants surface to reduce their roughness after 3D printing

K. Mikhailova, E. Lovushkina, V. Romanov, Yu. Karlagina, G.V. Odintsova
ITMO University, St. Petersburg, Russia
kseniyamikhailowa@yandex.ru

At present, one of the main methods of manufacturing individual cranial implants is selective laser melting (SLM). Most often, VT6 powder is used in the SLM method. After the implant is manufactured, its surface has an increased roughness - Ra in the range of 10-12 microns, which negatively affects its physical properties. To reduce roughness, post-treatment methods of the surface are used: sandblasting, mechanical grinding and polishing. However, these methods have a number of disadvantages - a multi-stage labor-intensive process, low processing accuracy, as well as the presence of hard-to-remove residual contaminants on the surface. We suggest using a one-stage, non-consumable and ecofriendly polishing process using laser radiation.

For experiments, we used mesh products made of VT6 titanium alloy, manufactured using the SLM method. The treatment was carried out using a MiniMarker-2 laser complex based on a pulsed fiber ytterbium laser (λ = 1,064 microns; P = 20 W; τ = 200 ns) by line-by-line scanning of the sample surface with a laser beam. A number of experiments were carried out on irradiating the surface of a titanium product in order to determine the best laser treatment mode to reduce the initial surface roughness. After that we compared the results obtained with the raw products using the methods of SPM, SEM and EDX. It was found not only a decrease in surface roughness, but also the formation of a nanorelief, which presumably contributes to better cell adhesion.

In the course of our research, a method of laser polishing of cranial implants manufactured by the SLM method was proposed. This method makes it possible to reduce the initial surface roughness and simultaneously form a biocompatible nanorelief.

Authors acknowledge the support of the Ministry of Science and Higher Education of the Russian Federation research agreement No. 075-11-2021-045 of 24.06.2021, project title "Development of high-tech production of equipment and technologies for laser functionalization of the surface of medical products" (within the framework of decree of the Government of the Russian FederationNo. 218 of 09.04.2010).

FT-S07-4 Application of color laser marking technology in barcoding

V.V. Romanov, G.V. Odintsova, I.A. Konyakhin, Xiangyu Sun
ITMO University, St. Petersburg, Russia
vvromanov@itmo.ru

The report presents the results of work on the development of a device layout for the study of colorimetric characteristics of oxide structures formed on the surface of metals using laser radiation. The layout of the device allows you to determine the color of the surface at different angles of observation, illumination, as well as the direction of the scan lines. The results of the studies carried out on the model of the device, representing a colorimetric map of the reflection of the color of the surface depending on different viewing angles and lighting, are presented. The possibility of using the technology of color laser marking of metals for the formation of color barcodes is demonstrated, where color is used as an additional information axis, which allows increasing the amount of encoded information, and using the constructed colorimetric reflection map, uniquely determine the color of cells and decipher the information encoded in the barcode.

Authors acknowledge the support of the Ministry of Science and Higher Education of the Russian Federation research agreement No. 075-11-2019-066 of 22.11.2019, project title "Development of high-tech production of equipment and technologies for laser coding of transported goods and their optical identification for the implementation in modern material flow management systems" (within the framework of decree of the Government of the Russian FederationNo. 218 of 09.04.2010).

FT-S07-5 Laser marking of polymer composites based on PVC with a biodegradable additive

U. Gabysheva, G. Odintsova, M. Sergeev, M. Uspenskaya, E. Samuylova
ITMO University, St. Petersburg, Russia
gabysheva.u.e@mail.ru

The amount of non-recyclable plastic in the environment is increasing every year. The process of preparing waste for recycling is complicated by the presence of labels and paints on products that must be separated during the recycling process. As a solution to the environmental problem, a method is presented that combines the use of lasers for marking polyvinyl chloride (PVC) products and the use of a biodegradable component as an additive.

PVC plastic has found its application in various fields, and therefore its production, and hence the amount of waste, is growing. The main disadvantage of polymer packaging at the moment is its non-environmental friendliness, which consists in a long decomposition period and the complexity of processing due to the presence of a label.

This report describes the use of biodegradable polyhydroxybutyrate (PHB) as an additive and the imaging of a product using 1064 nm laser light. The obtained samples were evaluated for the contrast of the marking and its wear resistance. As a result of the impact of laser radiation on the material in the near-surface layer of the sample, a change in the structure occurs, which is accompanied by a change in color. Optical microscopy of the samples showed that under the influence of laser radiation, carbonization occurs, which originates in the areas of inhomogeneity of the polymer matrix. In the course of the experiments, the color coordinates of the contrast areas were obtained, according to which the contrast values were calculated, and tests were carried out for the wear resistance of the samples.

The addition of PHB makes polymer packaging more environmentally friendly, and the use of laser light for marking will simplify disposal. Laser marking allows you to get a sufficiently contrasting, for visual perception and wear-resistant, when used, image mark. With the introduction of laser marking in combination with the addition of a biodegradable polymer, the amount of waste will decrease and the amount of products made from recycled plastic will increase.

FT-S07-6 Angular and spectral selectivity of temperature noncritical pockels cell based on single KTP crystal

J.R. Istamgulova [1], S.V. Gagarskiy [1], S.G. Grechin [2], P.Y. Druzhinin [3], A.N. Sergeev [1]
[1] ITMO University, St-Petersburg, Russia
[2] Prokhorov General Physics Institute of the RAS, Moscow, Russia
[3] Photon energy GmbH, Ottensoos, Germany
IJR2000@mail.ru

Pockels cells based on KTP crystal are widely used for a variety of nonlinear applications including electro-optic modulators. KTP crystals used for electrooptics has high laser-induced damage threshold, relatively low voltage necessary for electroptical switching, low piezoelectric response. However, KTP crystal used for electrooptics have high temperature sensitivity. For compensation of temperature effect in Q-switch modulators a pair of similar KTP crystals can be used, but such scheme require preliminary selection of matching crystals and can compensate only uniform heating of crystals. Even small temperature gradient can lead to a dramatic decrease of Q-switch contrast, which is particularly important problem for high power and industrial lasers. We suggest using of temperature-noncritical (TNC) cut of KTP crystal for electrooptic modulators at wavelength of 1064 nm. As we showed before [1], temperature width for the TNC-cut crystal was 10 °C at the 10% contrast drop level, but TNC-cut crystals require higher voltage (3200 V quarter-wave voltage for 3x3x8 mm TNC-cut crystal) and has higher angular and spectral sensitivity. This work is focused on investigation of angular and spectral sensitivity of TNC-cut KTP crystal for electrooptic modulators.

1. S. Gagarskiy, S. Grechin, P. Druzhinin, A. Sergeev, Y. Fomicheva, V. Rusov, N. Maklakova, and A. Yurkin, "Temperature noncritical Pockels cell based on a single KTP crystal," in 2021 Conference on Lasers and Electro-Optics Europe and European Quantum Electronics Conference, OSA Technical Digest (Optica Publishing Group, 2021)

FT-S07-7 Influence of laser structuring on the corrosion resistance of AISI 304 stainless steel

V.M. Prokopiev [1], N.N. Shchedrina [1], I.A. Filatov [1], G.V. Odintsova [1], V.A. Vorkel [2], R.I. Bogdanov [2]
[1] ITMO University, St. Petersburg, Russia
[2] National Research Nuclear University MEPhI
vladprokopev@yandex.ru

This work presents an assessment of the corrosion resistance of samples of high-strength alloys in the initial state and after laser surface modification based on the results of electrochemical studies.

Nowadays the development of high-strength alloys of the Ni-Cr-Fe system with a wide range of applications is being actively studied.

During the exploitation in aqueous media containing chlorides of structural elements and products made of Ni-Cr-Fe alloys, local corrosion (like pits), which may cause the crack initiation. The initiation and propagation of early stages of corrosion centers depends on the structure and chemical composition of the near-surface layer of the alloy, which can be changed by laser action. In this regard, the influence of laser structuring of the high-strength alloys surface on their corrosion resistance is an urgent problem.

A technology of laser structuring of high-strength alloys surface by nanosecond pulses for protection against corrosion damage is proposed. A fiber ytterbium laser source with a wavelength of 1064 nm was chosen as a processing tool. The advantages of this corrosion resistance method are accuracy, lack of consumables and non-contact processing, which allows working with finished products.

The following methods of metal surface treatment were considered in the work laser: structuring without post-processing, laser structuring followed by storage in air for 1 month to adsorb hydrophobic organic compounds, laser structuring followed by low-temperature annealing.

Electrochemical studies were carried out by taking potentiodynamic curves (0.2 mV/s) on alloy samples in an aerated aqueous solution of 3.5 wt.% NaCl in a three-electrode cell, a silver chloride electrode served as a reference electrode, and a platinum electrode served as an auxiliary one. Based on the results of electrochemical studies, the areas of potentials of active dissolution and passivation of alloys, the potentials of free corrosion and pitting formation are determined. An assessment of the corrosion resistance of samples in the initial state and after laser surface modification is presented, based on the obtained data.

The sessile drop method, a high-resolution P3S camera, ToupCam, and software for measuring the contact angle were used to evaluate the contact angles on the samples. The morphology was studied by optical microscopy.

The analysis of the dependence of the results of corrosion tests on the composition and topography of the near-surface layer, as well as on the values of wetting angles, has been carried out. The surface morphology was studied immediately after laser exposure, as well as after passing corrosion tests.

FT-S07-8 Application of laser films for marking machine-building parts

E.Yu. Troshina, E.I. Pryakhin
Saint Petersburg Mining University, St Petersburg, Russia
ivan.grey.90@mail.ru

This work touches upon the modern problems of labeling using film labels. The article substantiates the relevance of the development of films for laser marking machine-building parts with operational temperature resistance from 300 °C.

Marking and tracking of goods and products in the modern world is gaining more importance over time. Marking of parts and machines, including, is no exception.

In mechanical engineering, the ways of fixing information behind a product are: direct marking of parts (DPM), fixing nameplates, and gluing labels. Each method has its advantages and disadvantages.

Production structures use not just labels for marking, but a self-adhesive polymer laser-sensitive film. Enterprises looking for temperature-resistant labeling methods need to apply information through laser-sensitive stickers and labels. But the existing films do not have the properties of high temperature resistance.

As part of the research the Department of Materials Science conducted tests on the temperature resistance of laser films. But the test results confirmed that the existing self-adhesive films do not withstand high temperatures (more than 250 °C).

Modern industrial companies and productions still need temperature-resistant labeling with films and labels. Practice shows that materials and products for solving this need do not yet exist. To use laser films for labeling, the authors of the article have developed a film with higher temperature resistance. The new film retains its functions when operating at temperatures from

300 ° C to 600 ° C. The results of the heat resistance tests are shown in Figure 1. The QR code applied by the laser is perfectly readable even after exposure to high temperatures.

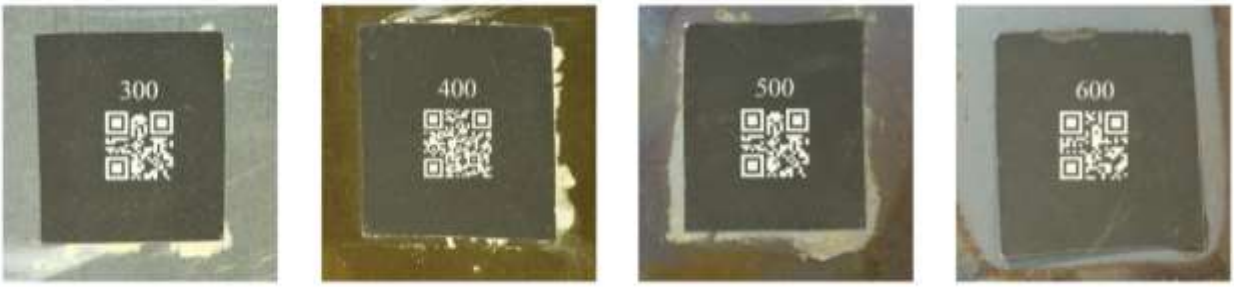


Figure 1 - Designed film with laser marking after temperature exposure (300-600 °C) for 1 hour

AUTHOR INDEX

AUTHOR INDEX

AUTHOR INDEX

AUTHOR INDEX

AUTHOR INDEX

IT's MOre than a
UNIVERSITY