Conference on Advanced Topics in Photonics

CATP 2024 Sofia

BOOK OF ABSTRACTS

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Conference on Advanced Topics in Photonics
CATP 2024 Sofia

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ABSTRACTS OF PLENARY, KEYNOTE, INVITED LECTURES, AND POSTER PRESENTATIONS

accepted to be presented on the

Conference on Advanced Topics in Photonics - CATP'24

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Sofia, Bulgaria

Editors: *Maya Zhekova, Alexander Dreischuh, Lyubomir Stoyanov*

Dear colleagues, friends of CATP’24,

We are excited and honored by your participation and contribution to the very first edition of the Conference on Advanced Topics in Photonics or simply CATP‘24.

It is our privilege and pleasure to welcome you for three days of engaging discussions and presentations, covering various fields of photonics like laser physics, nonlinear optics, spectroscopy, quantum optics, metamaterials and materials processing, singular optics, and many more.

We hope that the conference will provide a nice and friendly atmosphere and serve not only as platform for presenting scientific results but also as an opportunity to extend your network and connect with leading experts and explore the latest advancements in photonics.

From personal experience we know that sharing results and building lasting professional relationships are easier in informal settings. For this reason, we tried to make a rich social program with coffee-breaks, lunches, an official conference dinner, and welcome cocktail combined with the poster session.

There will be six tutorials and eleven keynote lectures orientated towards the students and early-stage researchers. The most recent results in various research fields of photonics will be presented through nineteen invited lectures. Poster session with more than 20 poster presentations in a cozy atmosphere is envisaged for the early-stage researchers. The three best posters will be awarded by the Scientific committee.

On behalf of the Organizing committee, I would like to wish you a nice time in the lively city of Sofia.

Sofia, Bulgaria 2024,

Editors

PLENARY TALKS (60 mins)

KEY TALKS (45 mins)

INVITED TALKS (25 mins)

POSTER PRESENTATIONS

One Talk, Two Stories: Imaging in the Extreme UV and Detecting Vacuum Birefringence

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As the title suggests, I will present two central topics of my research. First, I will give an introduction to coherence tomography in the extreme ultraviolet (XUV) spectral region. Coherence tomography is an established technique in the optical and near-infrared regime. Its most well-known application is in ophthalmology, where it delivers cross-sectional imaging of the retina with a resolution of a few micrometers and thus became an extremely valuable medical diagnostic.

We realized coherence tomography in the XUV (XCT), which enables non-invasive cross-sectional imaging with nanoscale resolution. XCT is also distinguished by its remarkable sensitivity. We succeeded to demonstrate a number of applications, most recently in the material sciences. Details will be presented in other presentations during this meeting.

The second topic is the detection of the birefringence of vacuum polarized by intense laser radiation. It is well established that vacuum is more than just nothing. Rather, there is a perpetual creation and annihilation of particles and their anti-particles, electrons and positrons for example. In a strong electric field, they align themselves to a certain degree, depending on field strength – and vacuum becomes birefringent. This can be probed by a crossed-polarizer setup, analogous to the lecture hall experiment to demonstrate stress-induced birefringence. However, in order to achieve the required sensitivity, X-rays and thus X-ray polarizers must be used. We have made continuous progress in the development of X-ray polarizers in the past 15 years. Today, the extinction ratio has reached the level of 1×10^{-11}, which is by far the best value for polarization purity across the entire electromagnetic spectrum! This has brought proof of vacuum birefringence within reach.

Acknowledgements:
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Recent Advances and Near Future Upgrades of the FERMI facility and laser systems

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FERMI, the first worldwide free-electron laser (FEL) facility has now been operating for more than a decade. Its two FEL lines, FEL-1 and FEL-2 [1,2] cover the photon energy range from about 10 eV to 300 eV, making it a versatile and powerful tool for a wide range of scientific applications. The initially implemented seeding scheme is based on the so called high-gain harmonic generation (HGHG), in both single- and double cascade version. Compared to the more standard self-amplified (SASE) scheme, it has a number of advantages, like extreme wavelength and intensity stability, combined with intrinsically low timing jitter [3]. In addition, it offers high flexibility and deterministic control of the output pulse properties by acting on the deep-UV seed and on the undulator chain parameters [4,5]. The continuous stimulation from the user community drives the development of new advanced options (e.g. [6,7]), as well as the search of new solutions for addressing the known challenges in seeded FEL operation, i.e. extending the range to shorter wavelengths and generating shorter pulses. In the last years both have been pursued and steps towards improvement of both aspects were made by the FERMI team.

The pulse duration of a seeded FEL is proportional to the seed pulse duration and shortens with increasing the harmonic order [8]. Seed pulse duration in the 100 fs FWHM range has initially been chosen at FERMI, offering a good compromise for optimizing the FEL performance in the large wavelength range mentioned above. Seed- pulse duration in the 60 fs is now also available, and in some modalities 40 fs long seed can be provided, giving access to sub-15 fs FEL pulses at high photon energies. There are, however, some limitations in using even shorter seed pulses from both laser and FEL hardware side that will be discussed in more details. We will present the latest results and ongoing developments to overcome these limitations.

The strategy for extension of the wavelength range of FERMI aims to extend the shorter wavelength side in order to cover the Oxygen K-edge and reach the L-edges of important transition metals, which is expected to largely enrich the range of scientific applications. The chosen path includes a number of parallel actions on different aspects of the machine, including a gradual increase of the electron beam energy to about 2 GeV and implementation of the Echo-Enabled Harmonic Generation scheme (EEHG) [9]. The talk will concentrate on the seed laser related aspects and challenges of the upgrades.

* On behalf of the FERMI team

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Diffraction of Laguerre-Gaussian and Cosine-Laguerre-Gaussian Beams by Fork-Shaped Gratings

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The generation and propagation of the optical beams with phase singularities, the vortex beams, has become one of the mostly investigated topics in modern optics during the last three decades, due to their unique properties and many applications. Here we study the transformation of Laguerre-Gaussian (LG) laser beam, with or without phase singularities, in the process of its diffraction by the fork-shaped grating (FG) with encoded phase singularity of order p.

The theoretical study about Fraunhofer diffraction of LG beam with radial mode number n=0 and azimuthal mode number l by the fork-shaped grating with phase singularity p is presented. The zeroth-diffraction-order beam is found as LG beam of mode (l,n=0) with topological charge (TC) l. The analytical solution for the wave field amplitudes of the higher-diffraction-order beams shows they are mathematically described by the product of Gauss-doughnut function of order $|l \pm mp|$ and a hypergeometric Kummer function. Their TC in the mth diffraction order is equal to the algebraic sum of the incident beam TC (l) and the product of the diffraction order and the TC of the FG (p). Experimental results which confirm the theory are presented. Transformation of LG beam with nonzero radial mode number n and azimuthal mode number l in the process of its diffraction by the FG, is theoretically studied as well. The zeroth-diffraction-order beam is obtained as (l,n)th-mode LG beam. The higher mth diffraction-order beam is described in radial direction through a product of the Gauss-doughnut function of order $|l \pm mp|$ by the finite sum of hypergeometric Kummer functions. It can be a vortex beam with increased or reduced TC compared to that of the incident beam, or it can be a non-vortex beam. The nonzero value of n results in smaller vortex radius of the vortex beam and smaller central bright spot radius for the non-vortex beam.

Another interesting class of LG beams are those whose amplitude variation in azimuthal direction is described by cosine function, named as cosine-Laguerre-Gaussian beams. We study the transformation of cosine-LG beam of mode (l,n=0), which does not possess phase singularity, in the process of its diffraction by the FG with TC p. While the zeroth diffraction-order beam is non-vortex, similar to the incident beam, in the higher diffraction orders multiple-vortex compositions are obtained. For incident cosine-LG beam of mode (l=2,n=0), also experimental results are obtained and compared to the theoretical results. The presented research can find interest and applications in optical trapping experiments, STED microscopy or quantum information processing.

Laser Beam Sculpting Using Optical Vortices

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Optical vortices (OVs) are singularities in a laser beam where the phase of the light wave spirals around a central point, creating a doughnut-shaped intensity profile with a dark core [1]. These vortices can be generated using devices such as spatial light modulators, q-plates, and spiral phase plates, which imprint the required phase structure onto the beam. The topological charge of an optical vortex, an integer value representing the number of 2π phase windings around the vortex core, determines the amount of orbital angular momentum carried by the beam. [1] Their unique properties make them valuable in applications such as optical tweezers, quantum information processing, and high-resolution microscopy.
In this plenary talk we will discuss the possible ways of ordering hundreds of OVs into ordered arrays of OVs. We will show two characteristic shapes of these OV lattices – namely square-shaped and hexagonal OV lattices. Moreover, we demonstrate the beauties of the Fourier optics by analyzing the reshaping of these lattices in the focal plane of a focusing lens. Results showing the rich possibilities for the controllable generation of ordered focal structures of bright peaks and the possible additional structuring of each peak with other singular beams will be shown [2].
In the second part of this talk we will describe a method based on singular optics for the generation of high-quality quasi non-diffracting long-range Bessel-Gaussian beams (BGBs) [3]. We will extend this approach and go even further where we will show the generation of BGBs in a few-cycle laser field (~7 fs) [4]. These results paved the way for the successful generation of such long-range BGBs by using transmissive vortex phase plates at wavelengths substantially different (more than 300 nm offset) from their design wavelength. This allows us to specify the discussed method as wavelength-tolerant or insensitive to topological-dispersion.

Acknowledgements:
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Infrared Vision Through Nonlinear Up-Conversion in Metasurfaces

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Light carries a vast amount of information about the world around us, but most of it remains invisible to our eyes. This information is contained in the light's polarisation, phase, momentum, and frequency range beyond the visible spectrum. Metasurfaces, arrays of subwavelength resonant nanostructures, offer unique opportunities to visualise this hidden information by enabling smart and precise measurements of these properties. Prominent examples include polarisation imaging, which can remove specular reflections or edge-detection that can improve object recognition for autonomous vehicles. This presentation will explain the underlying principles for the detection of such hidden properties of light and demonstrate new applications in satellite hyperspectral and polarisation imaging, as well as in aberration correction for large telescope adaptive optics. We will further show how metasurfaces can enhance the conversion of infrared light to visible, enabling compact and low-noise infrared imaging. Finally, we'll demonstrate how such nonlinear up-conversion can offer unique opportunities for all-optical convolution operations and advanced image processing for object recognition applications.

Taming Molecules – Production and Applications of Cold and Ultracold Molecules

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Cold and ultracold molecules represent a fascinating research frontier in physics and chemistry, providing an indispensable and exquisite tool for studying collision dynamics and reaction pathways in the cold regime, and open new avenues for research in diverse fields – from controlled chemistry, through quantum many-body systems, quantum information processing and quantum sensing, to the exploration of fundamental physics, *e.g.*, measurement of the electric dipole moment of the electron through precision spectroscopy. Preparing, however, samples of cold and ultracold molecules is very challenging. A myriad of experimental techniques for production and characterization of cold and ultracold molecules have been implemented and advanced theoretical models for prediction and description of their properties and behaviour have been developed alongside.

The talk will present an overview of the state-of-the-art techniques for production and studying of cold and ultracold molecules [1], including the very recent break-through achievement with a far-reaching impact in science and technologies – the realization of the first molecular Bose-Einstein condensate [2]. Special emphasis will be put on the so-called cryofuge decelerator, which allowed for the first time the deceleration of continuous molecular beams [3] and enabled the experimental investigation of cold molecular collisions [4,5]. Some fascinating applications of cold and ultracold molecules will be highlighted. The outlook and perspectives for this thriving research field will be outlined.

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Spectroscopic Coherence Tomography with Extreme Ultraviolet Light

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We present the use of XUV coherence tomography (XCT) [1] for the spectroscopic imaging of encapsulated nanolayers. XCT, a derivative of optical coherence tomography (OCT), employs broadband high harmonic generation (HHG) sources to achieve nanoscale resolution in axial imaging. The depth profile of a sample can be determined by analyzing interferences in the reflected XUV spectrum in a common-path interferometric configuration. By applying a one-dimensional phase retrieval algorithm [2], the amplitude and phase of the reflected field can be reconstructed. These can then be further processed to derive the spectrally resolved field reflectivities of individual sample interfaces. Characteristic, element-specific features in these reflectivities allow to distinguish different elements and reveal additional quantitative information such as the interface roughness or the thickness of native oxide layers [3].

We show that the method can be applied to the investigation of encapsulated 2D materials, e.g. to characterize graphene monolayers beneath 200nm of silicon encapsulation [4]. However, the use of XCT for the analysis of 2D materials is not limited to graphene encapsulated in Si. A broad selection of functional layers and encapsulants can be characterized. We anticipate that XCT can be established for the characterization of nanoelectronic devices and will provide insights into the physics of interface and interlayer effects in modern heterostructures.

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The Role of Low-Energy Electron Recollisions in the Dissociative Multiphoton Ionization of D_2

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The dissociative ionization of molecular hydrogen in an intense laser field is a prototypical example for the correlated motion of electrons and nuclei. To access the femtosecond dynamics of molecular bond breaking (*i.e.* dissociation) directly, one needs to employ ultrashort pulses of radiation [1]. Exposing molecules to intense femtosecond laser pulses leads to rapid ionization. Subsequently, the molecular cation may be electronically excited via single- or multi-photon absorption from the laser which leads to dissociation at low kinetic energy release KER (*i.e.* up to few eV) ion emission. Laser-driven inelastic electron recollisions, on the other hand, are known to contribute to dissociation with high KER (*i.e.* several eV) ion emission from D_2 [2], with a strong anti-correlation of the energies of photoelectron and nuclear fragments [3]. In contrast, direct vibrational excitation induced by the laser is forbidden in homonucelar diatomics such as D_2. However, we see evidence of molecular bond breaking at moderate dissociation energies down to 0 eV via vibrational excitation induced by the recolliding electron.

Superimposing a perturbative fundamental (1030 nm, ≈ 0.01 TW/cm2) on a second harmonic field (515 nm, 40 fs, 90 TW/cm2), we introduce sidebands in the ATI spectrum, the latter generated by the 515 nm light. Both, main ATI peaks and sidebands depend on the relative two-color phase, allowing us to use phase-of-the-phase (PP) spectroscopy [4]: The experimental data is Fourier-transformed with respect to the relative phase, and the oscillation amplitude and the oscillation phase (PP) are plotted as a function of the electron momentum, as shown in Fig. 1. The PP map shows various color patterns corresponding to direct electron emission, forward and backward scattering.

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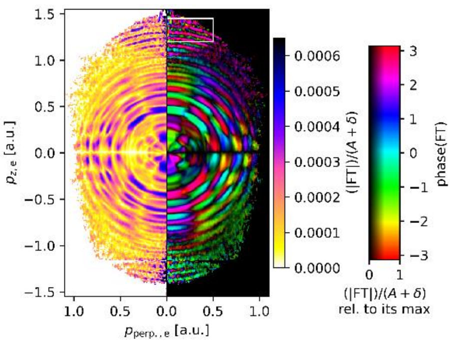

Figure 1: Phase-dependent ATI momentum distribution of electrons detected in coincidence with D_2^+. Each plots shows Fourier amplitude (left) and phase (PP, right) at the frequency $\omega_{FT} = \omega_{515nm}$.

Laser Acceleration of Alpha Particles to Relativistic Velocities. Application to Laser Nuclear Fusion.

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Recently, new physical mechanism for trapping of neutral atoms, molecules and particles into the envelopes of femtosecond laser pulses was suggested [1-3]. This mechanism allow light atoms, such as hydrogen and helium, to be accelerated up to the group velocity of the pulse. The accelerated neutral atoms admit energies in the range of 200 MeV to 1-2 GeV. In this presentation we will show how the nuclei of the accelerated light atoms can be trapped by an external electric field on the cathode of a cylindrical condenser. Since the kinetic energy of the impact of the nuclei on the cathode (~1 GeV) is two orders of magnitude greater than the binding energy of the nucleons in the alpha particle (28 MeV), this leads to two decay channels of the alpha particle: to nuclei isotope He^3 with neutron emission or to two deuterium nuclei with intense gamma radiation. On the other hand, the Coulomb repulsion of the helium nuclei isotopes or deuterium nuclei, trapped on the cathode, is greatly reduced, and secondary fusion reactions are possible along several fusion channels [4].

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Broad-Band Optical Solitons

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The evolution of broad-band optical pulses, propagating in single-mode and hollow microstructured optical fibers (photonic crystal fibers) is investigated in the present work. The nonlinear amplitude equation (NAE) is used to describe the behavior of these light pulses in two regimes – in nonlinear dispersive media such as single-mode optical fibers and in dispersionless media such as hollow photonic crystal fibers.

In the first case new analytical solutions of NAE in the form of Jacobi elliptic functions are found for waveguides with anomalous and normal dispersion. These solutions represent periodic cnoidal waves, which strongly depend on the value of the modulus of ellipticity κ. At specific values of this parameter ($\kappa \rightarrow 1$), the obtained solutions are reduced respectively to fundamental bright and dark solitons. They are different from the standard soliton solutions of the nonlinear Schrodinger equation for broad-band optical pulses only. The expressions lead to a new kinds of nonlinear dispersion ratios, in which the dimensionless parameter (α) is involved. It is connected with the nonparaxiality of the theoretical model and significantly affects the modulus of ellipticity κ.

In the second case the nonlinear regime of propagation of laser pulses in isotropic dispersionless ($\beta \approx 0$) media, such as hollow microstructured optical fibers is studied. The obtained analytical solution of the NAE describes a dark soliton. It is formed as a result of the balance between the effects of diffraction and the nonlinearity of the medium.

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Unveiling the Potential of Quantum Imaging in the Infrared through "Two-color" Schemes

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Quantum imaging protocols have been emerging in the last decades as powerful tools to move beyond the limitations imposed by classical optics on existing imaging systems, and unlock quantum-enhanced capabilities, in terms of resolution [1], enhanced signal-to-noise ratio [2], low-light illumination-enabled reduced phototoxicity [3], and the possibility to exploit quantum frequency correlations to perform imaging in wavelength ranges where detection technology is underdeveloped using standard CMOS silicon camera technology [4]. Focusing on the last of the above-mentioned four directions to pursue a "quantum advantage" in imaging systems, we present our latest progress in "two-color" quantum imaging schemes, based on frequency correlations of photon-pairs generated through Spontaneous Parametric Down-conversion (SPDC), to access the mid-infrared spectral region with enhanced detection efficiency for bio-medical applications. We further discuss technical implementation bottlenecks through two distinct quantum imaging techniques, namely Quantum Imaging with Undetected Light (QIUL) and Quantum Ghost Imaging (QGI) and discuss feasibility and scalability towards market uptake.

Acknowledgements:
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Diatomic molecules. Beyond the Born-Oppenheimer approximation.

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Physics describes the observations in nature with models. Depending on the complexity of the problem, the models can be relatively accurate, but it happens that they are just qualitative.
In this lecture I will briefly present the basic model, used to describe a diatomic molecule – the Born-Oppenheimer approximation (BOA) [1,2]. Its accuracy depends on the particular state of the molecule, but also on the uncertainty of the experimental observations. Modern laser spectroscopy can readily achieve $\Delta\nu/\nu$ of the order of 10^{-8}, and it is surprising that BOA is often adequate. However, there are cases where a breakdown of the BAO is observed, called perturbations. It will be shown that a relatively modest extension of the BOA allows to achieve again 10^{-8} and better [3,4].

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Annihilation Upconversion in Lamellar Micelles

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Cell cultures go through several stimuli, such as drugs, pollution and/or nutrition shortage which reflects on the local temperature distribution and local oxygen concentration. However, determining the temporal variation of local temperature and/or local oxygen concentration in biological objects remains a significant technological challenge. The process of triplet-triplet annihilation upconversion, performed in a nano-confined environment with a continuous aquatic phase, appears as a possible solution to these severe sensing problems. This process generates two optical signals - delayed emitter fluorescence and residual sensitizer phosphorescence, in response to a single external stimulus – local temperature. Agarose / silk fibroin translucent hydrogels embedding non-ionic micellar systems containing energetically optimized annihilation couples simultaneously fulfil two crucial functions: firstly, to serve as a mechanical support (for further application as a cell-culture scaffold) and secondly, to allow tuning of the response window to achieve a maximum temperature sensitivity of better than 100 mK for the physiologically important region around 36 °C.

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Amplitude Vortex Structures in Nonlinear Dispersive Media

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A theoretical model for the formation and evolution of vortex structures during the propagation of ultra-short laser pulses in isotropic nonlinear medium is presented. The evolution of laser vortices is described by the nonlinear amplitude equation (NAE), which includes terms related to the peculiarities of their dynamics in different types of optical media. These optical vortices exist in the profiles of the components of the vector amplitude function characterizing the pulse envelope. The amplitude vortices are completely new type of vector vortex structures, significantly different from the scalar ones which have phase singularities.

A suitable mathematical method has been developed to find exact analytical solutions of the corresponding system of nonlinear partial differential equations for the components of the vector amplitude function. These new solutions characterize the processes of generation and propagation of optical vortices. They describe vortex structures with amplitude type singularity and show the influence of the initial parameters of the light pulses and medium on the formation and evolution of optical vortices.

The numerical experiments for a laser pulse with a carrier wavelength of *1400 nm* propagating in the anomalous dispersion region in optical fiber are performed.

The obtained results give a possibility for physical explanation and precise control of the parameters of the vortex structures.

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Fluorescence Correlation Spectroscopy Studies of Nanocarrier-based Drug Delivery Systems

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Using nanoparticle-based carriers is an extremely promising way for the administration of therapeutic agents, such as drug molecules, proteins and polynucleotides. However, in order to get full advantage of this approach and develop efficient nanocarrier systems, a careful characterization at all stages of the drug delivery process is needed. In particular, one needs to monitor and quantify: the encapsulation of the therapeutic agents during preparation; the possible interactions of the nanocarriers with e.g. plasma proteins and their stability in the blood stream; the kinetic of drug release in the cytoplasm of the target cells.

In this presentation I will show that due to its very high sensitivity, selectivity and sub-femtoliter probing volume the fluorescence correlation spectroscopy (FCS) technique is a very powerful and versatile tool for such studies. FCS measures the diffusion coefficient, hydrodynamic radius, local concentration and fluorescence brightness of fluorescent molecules and nanoparticles, thus allowing monitoring of the formation of nanocarriers, drug loading efficiency, stability or kinetics of drug release [1]. First, I will discuss examples of such FCS studies performed in aqueous environments. Next, I will present results on FCS characterization of nanocarriers in human serum and whole blood [2,3].

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Laser-matter Interactions: Applications in Micro- And Nanostructuring

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In this presentation, some general aspects and applications of laser ablation process will be given. As examples, main characteristics of the laser ablation process of nitride ceramics (AlN, Si_3N_4) and glasses of the type $ZnO:B_2O_3:WO_3:Nb_2O_5$ doped by Eu will be presented. The characterization of the ablation phenomena is based on analyses of the ablation depth, surface morphology and chemical changes induced by the laser radiation. These are given for laser systems with pulse duration that varies from femto- to nanosecond regime. The dependences of the characteristics on the processing parameters are studied. These include the pulse duration, laser wavelength, fluence and applied pulse number, the ambient pressure. The ablation efficiency as ablation depth per incident fluence and per pulse are presented. The results for drilling and cutting geometries are given and thus they cover the main laser processing technologies used nowadays. Results on ceramic and glass surface structuring will also be presented, as variety of micro- and nanostructures on the surface of the material will be described. New results on formation of different types of ripple structure with respect to the period and orientation will be given. It is demonstrated that laser treatment may lead to significant change of the ceramic composition as electrically conductive areas on the surface can be produced. It also found that laser surface structuring of luminescent glasses can influence the emission intensity, as in some cases, significant enhancement could be achieved. On the basis of the obtained materials characteristics a discussion on potential new applications of these materials in different fields will be presented.

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Advances in Yb CPA Lasers towards Extremely Short Output Pulses. Prospectives and New Applications in Ultrafast Spectroscopy

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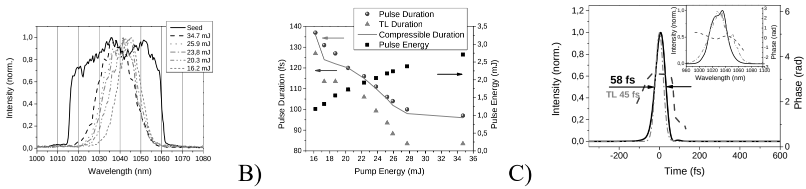
Since Yb-laser media were established in the late 1990s as an effective alternative to Ti-sapphire for ultrafast laser development, a lot of progress has been made in getting ultrashort pulses with record-high energies or average powers. However, for the past three decades, the pulse duration of Yb doped CPA systems has been limited to the 180–300 fs range, despite the availability of broadband (>50 nm) Yb doped materials.
We report a comprehensive study of the physics involved in Yb based regenerative amplification. We thoroughly studied the Yb:CALYO's gain bandwidth, output pulse duration, and spectrum as a function of pump pulse energy, or pump pulse fluency, for a fixed pump beam waist (Figs. 1.a and 1.b). The pulse durations were measured by the FROG technique, the retrieved intensity of the shortest pulse with the highest pulse energy is shown in Fig. 1c. Reference [1] contains details about the CPA setup.



A) B) C)

Fig. 1 a) Spectrum of the seed (solid) and the amplified pulses (dashed) for different pump energy; b) The output pulse duration and energy versus pump pulse energy; c) The reconstructed pulse intensity (black), TL (dash dot) and phase (dash) for the shortest achieved pulses are shown. Inset is the pulse reconstructed (solid) and measured (dash dot) spectrum and reconstructed phase (dash).

We presented an approach for sub-100 fs Yb-based 1 kHz CPA, reporting an experimentally verified pulse duration of 97 fs at 2.7 mJ after compression. We developed an innovative transient absorption spectrometer using these lasers, which increased the scanning time interval by 10exp6 times compared to standard ones.

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High Harmonic Generation in Zinc Oxide

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Numerical results are reported from a theoretical study of the photo-ionization and high harmonic generation in the bulk of zinc oxide irradiated with intense femtosecond laser pulses with mid-infrared wavelengths, in a wide range of intensities. The laser polarization direction is parallel or perpendicular to the optical axis of the ZnO crystal. The time dependent Schrödinger equation in velocity gauge is solved and the ground state electronic structure of zinc oxide is described by the empirical pseudo-potential method. For laser irradiation linearly polarized along the optical axis of the crystal when the dielectric screening response of electrons and holes is dominant, their sub-cycle dynamics is exhibited in the transient profile of the intra-band current. After the end of the pulse, interference in time of transitions from all half-cycles manifests in creation of a quasi-DC polarization and internal electric field, which produces post-pulse ionization of the pumped solid. For the highest field strength dynamical Bloch oscillations are observed in the temporal profile of the intra-band current near and after the pulse peak. In the regime of weakly ionized plasma, the power spectrum of the photocurrent exhibits distinct odd-order harmonic peaks below the band edge. For increased field strength with $F \geq 0.6$ V/Å, the probability for non-adiabatic transition increases and the HHG spectrum of the total photocurrent lacks harmonic structure. For laser polarized perpendicularly to the optical axis, the non-adiabatic response of conduction electrons and valence band holes manifests in HHG. We reproduce the conditions in the ZnO experiment[2], and find that the inter-band mechanism due to collective response of multiple valence and conduction bands is dominant for HHG in the entire range of laser intensities. Clean odd-order harmonic peaks extending beyond the band edge are obtained, in very good quantitative agreement with the experiment and without including ultra-fast de-phasing process.

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Correlative Fluorescence and Soft X-Ray Microscopy in the Water Window Region in an Integrated Lab-based Setup

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We present a correlative fluorescence and water window (WW) microscope in an integrated lab-based setup [1]. The WW spectral region between the absorption edges of carbon and oxygen (280-530 eV) is particulary interesting for biological samples as the high absorption in carbon and the high transmission in oxygen provide a natural structural contrast. The combination with the functional contrast of fluorescence microscopy provides a holistic picture of the sample.

The presented wide-field zoneplate microscope is based on a laser plasma source. The fluorescence microscope is built in a wide-field epi configuration. By placing the zoneplate and the fluorescence objective on a common stage, it is possible to switch between the imaging modalities without alternation or moving of the sample.

With the WW microscope we can achieve a resolution of 50nm half pitch which was measured using a Siemens star test target. Correlative imaging of different samples will be presented. These range from simple test samples, such as fluorescent nanobeads, to biological samples such as cyanobacteria, critical-point dried NIH-3t3 and COS7 cells.

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Multi-Instrument Study of a Wintertime Atmospheric Desert-Dust Load Event over Sofia, Bulgaria

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In recent years, the intensity and frequency of wintertime Saharan dust outbreaks have increased, making them an important component of the global dust cycle and a challenging issue to comprehend in light of the ongoing climate change. Systematic multi-instrument observations and multi-aspect analyses of the distribution and properties of desert aerosols are necessary for their proper monitoring and characterization. In this work, we report on a combined multi-sensor study of Saharan dust load event observed in the atmosphere above Sofia, Bulgaria, in February 2021 [1]. The event was part of a strong dust episode affecting the whole of Europe, caused by a blocking synoptic pattern that persisted over the Mediterranean basin, providing clear skies and stable measurement conditions. Various (lidar, satellite, and radiometric) remote sensing techniques, in situ particle analysis, and modeling/forecasting resources were used to complete this study, implementing actual measurements and data (re)analysis. Combining the applied approaches and instruments in terms of complementarity, calibration, and normalization, a number of columnar and range/time-resolved parameters (optical, microphysical, physical, topological, and dynamical) of the detected aerosols dominated by desert dust are obtained and profiled with high accuracy and reliability. Utilizing the LIRIC-2 inversion code to link up lidar and sun-photometer data, vertical profiles of the aerosol/dust total and mode (fine and coarse) volume concentrations are retrieved and examined. The findings demonstrate the potential for significant synergy and improvement in the verification and enhancement of theoretical models aiming at comprehensive aerosol/dust characterization through the interactive combination and use of multiple pertinent approaches, instruments, and data.

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The Monomethine Group as a Strategic Fragment for the Synthesis of Dyes with Sensory Properties

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Organic molecular sensors are compounds undergoing a dramatic change in their photophysical properties depending on even small variations in the surrounding environment due to phenomena such as fluorochromism, solvatochromism, halochromism, photoinduced electron transfer, Förster energy transfer and triplet-triplet energy transfer. Such organic compounds are used in every branch of so-called high technologies. In the presentation, the specific methods for the synthesis of new molecular sensors and biosensors based on monomethine functional groups will be discussed concerning the needs of sensors with definite photophysical properties.

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Interferometric Determination of the Gouy Phase of Zeroth-order Gauss-Bessel Beams

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The Gouy phase is a phase shift along the axis of propagation of a beam relative to a plane wave. It has significant consequences, for example, in nonlinear optics, since the nonlinear processes require high peak intensity and phase matching of the focused beams. Here, we present an analytical model for the Gouy phase of long-range Bessel-Gaussian beams obtained by annihilating highly charged optical vortices [1]. The model accounts for the various experimental parameters (topological charge, radius-to-width ratio of the initial ring-shaped beam, and focal length of the Fourier-transforming lens). We also present some interferometric methods to directly measure the Gouy phase and compare analytical and experimental results [2].

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Machine Learning with Insufficient Data for Applications in Biophotonics

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In recent years, the algorithms of artificial intelligence (AI) are being developed extensively and they attract increasing attention of scientists since they open doors to efficient solutions of many problems that otherwise require a lot of time, effort, expenses and often inspiration. A main challenge to their wider application in biophotonics is the lack of ample amount of diverse and representative data for training. Therefore, we present here the application of Neural Network (NN) algorithms trained with insufficient data for solving two biophotonics tasks. The first one is classification of Laser-Induced Fluorescence (LIF) and reflection spectra of human skin (i.e. optical biopsy) for the purpose of early and non-invasive diagnosis of skin diseases. The second one is related to verification of food quality, and more specifically the identification of mixtures of sunflower and extra virgin olive oils with different concentrations, which can be treated both as a classification and as a fitting task. We present and compare the output of different approaches for treating the insufficient data problem.

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Industrial Laser Soldering System Based on CW Diode Laser

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Laser soldering is a process known for more than 25 years [1], with numerous industrial systems available on the market nowadays [2]. CW diode lasers have been neglected in the past, because of their low peak power and poor beam quality. However, the interest in industrial and scientific applications of these lasers is constantly growing, because of their low cost, compactness and easy to control. Although they can operate in pulse mode, by controlling the pump current, the peak power can't exceed the average power of the laser, which commonly leads to the assumption that they cannot be used efficiently for laser material processing. However, the pulse mode in CW diode lasers offers a possibility for precise control over process parameters by controlling the temporal shape of the light pulse.

In this report, we demonstrate a laser soldering system based on commercial CW 5 W, 450 nm, diode laser, with advanced control over the temporal shape of the light pulse. A theoretical model that allows calculation of a temporal shape of the light pulse required to heat the sample with specific temperature profile, has been developed and this model was tested experimentally. The reflection as a function of the temperature for 40/60 solder was measured in a wide temperature range including the melting point, for 450 nm and 808 nm diode lasers, as well as its surface tension [3].

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Tunable Device for Arbitrary Polarization Control

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The possibility to manipulate light polarization is essential in precise measurements like ellipsometry, signal transmission, and etc. This leads to an exploration for structurally new polarization devices. In this work, we propose a tunable device which can operate as retarder or rotator or adjustable combination of both. It is composed of two half-wave plates and two quarter-wave plates, where the retardance and the rotation can be modified by rotating the half-wave plates. The results from simulations and from analyzed experimental data indicate a possibility to transform an arbitrary input polarization to achieve an arbitrary output one by rotating two of the elements. The simulation of the device properties accounts for the real retardation of the wave plates so it can be constructed even with multi-order wave plates.

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From Farfield to Nearfield and Back: Interplay of the Valley- Pseudospin in 2D Semiconductors with a Resonant Plasmonic Nanoantenna

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Among many fascinating optical properties of two-dimensional transition metal dichalcogenides (2D-TMDs), the valley-pseudospin has attracted particular interest. The direct bandgap character of 2D-TMDs as well as valley-contrasting circular optical selection rules allow for an efficient optical manipulation of the valley-pseudospin in these materials. Resonant optical nanostructures provide a versatile toolbox to further enhance and control the light-valley interaction at the nanoscale. This study aims to experimentally investigate a hybrid model system where the valley-specific emission from monolayer molybdenum disulfide is interacting with a resonant plasmonic nanosphere. Despite the cylindrical symmetry of the hybrid system, we reveal an almost complete depolarization of the emission as shown by cryogenic photoluminescence microscopy. This counterintuitive observation is analyzed by numerically modelling the TMD-nanoparticle interaction at excitation and emission level. We show that the depolarization is mostly caused by contributions from emitters displaced away from the system's symmetry point. By additionally considering the polarization of the scattered excitation field, we are able to accurately model the observed depolarization effect. Our study provides a quantitative model for the addressing and read-out of the valley-pseudospin by resonant optical nanostructures which poses a crucial prerequisite for the further development of nanoscopic valleytronic devices. [1]

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Silicon Optical Metasurfaces for Lasers and Optical Communications

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It has been shown that optical 2-D metasurfaces made of a single layer of dielectric or semiconductor nanostructures can be used in many ways to change the spatial and temporal properties of light, which are similar to lenses, all optical switches, and mirrors. However, the application of a metasurface as a mirror with pronounced dichroic properties in power-scalable lasers has not been studied so far. Here, we demonstrate the design and implementation of a metasurface mirror with a steep spectral change in its reflection. The single-mode stable diode pumped Yb-laser operation has been achieved using this dichroic metasurface mirror as a pump cavity mirror. We have achieved up to 1 W output CW power. In addition, we have studied the dynamics of the relaxation processes of electrons injected upon optical excitation in such 2-D structures. Based on the specific topology of the nanostructures, we obtained temporal responses of 25 ps and 100 ps, respectively. The metasurfaces time-responses are characterized via pump-probe spectroscopy (Fig.1a) where a ~150 fs pump beam at 520 nm excites the sample and generates free carriers in the silicon.

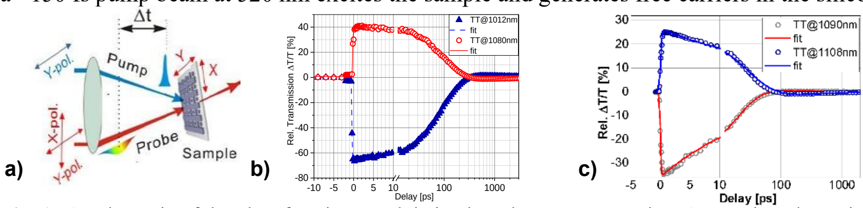

Fig. 1. a) Schematic of the ultra-fast time-modulation based on a pump-probe. **b)** Transient dynamics at wavelengths of 1012 nm (triangles) and 1080 nm (circles),sample 1. The time responses for relaxation of the carrier injection obtained from exponential fit (dash lines) are 102 ps (at 1012 nm) and 120 ps at 1080 nm. **c)** Transient dynamics at wavelengths of 1090 nm (red) and 1108 nm (blue). The time response for relaxation of the carrier injection is 25 ps.

In summary, we demonstrate lasing using Si-metasurfaces as a cavity mirror and a record-higher ultra-fast transmission modulation in the dichroic metasurface mirrors.

Acknowledgements:

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Nanomechanical Properties of Epitaxially Grown $GaAs_{1-x}P_x$ Layers for Nonlinear Optical Applications

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The crystalline structure, quality and homogeneity of ternary $GaAs_{1-x}P_x$ layers grown epitaxially from the vapor phase have been widely studied by various techniques [1]. The transmission behavior which is essential to evaluate the residual losses, the band-gap and mid-IR edge dependences on composition determines the clear transparency range and the potential applications in nonlinear optical frequency conversion of such orientation-patterned structures with engineered properties [2,3]. Practical implementation depends also on the mechanical performance, which can be evaluated in terms of Hardness (H) and Young's modulus (E). Both are related to some fundamental material aspects and the character of the chemical bonding, Microhardness studies with large scatter of the results can be found in the literature only for the two binary compounds GaAs (x=0) and GaP (x=1). In the present work, the dependence of H and E on the phosphorous (P) content has been investigated by nanoindentation using thin (< 0.35 mm), unpatterned ternary layers after careful removal of the GaAs substrate employed in the growth process and appropriate surface polishing. TThe measurements indicated H(GaAs) = 9.0 ± 0.2 GPa and H(GaP) = 11.0 ± 0.3 GPa for the two binary parent compounds and a nonlinear dependence on the composition, with a maximum at about P = 0.8, $H(GaAs_{0.2}P_{0.8}) \approx 13.1$ GPa. Young's modulus displays a linear dependence on the composition, similar to the trend observed in other ternary systems, with E(GaAs) = 127 ± 2 GPa and E(GaP) = 154 ± 2 GPa.

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Yb:CALYO 1 kHz - 1 MHz Amplifier. A Breakthrough in Obtaining the Shortest Pulse Duration from 1 micron CPA lasers

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We demonstrate an Yb - regenerative amplifier (RegA) based on Yb:CALYO single crystal at peak performance with output pulses of 2.7 mJ and 97 fs at 1 kHz and 133 fs at 6.3 W, at 1 MHz. We seed the amplifier with pulses with an energy of 0.5 nJ at 52 MHz and a spectral bandwidth FWHM of 40 nm. The CPA setup details are described in reference [1]. The Yb:CALYO crystals have a length of 8 mm with 1.8 at.% doping of the Yb^{3+} ions. The electronic modules for control and synchronization as well as the power supplies of the system have been developed by IBPhotonics, Bulgaria. The regenerative amplifier achieves 3.5 mJ output pulse energy which is compressed afterwards with 80% efficiency yielding a sub-100 fs pulse duration. It was measured by the FROG technique, the retrieved intensity of the shortest pulse with the highest pulse energy is shown in fig.1 a).

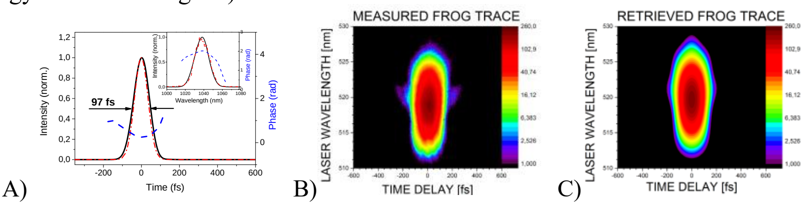

Fig. 1 A) The reconstructed pulse intensity (black), TL (dash dot) and phase (dash) for the shortest achieved pulses are shown. Inset is the pulse reconstructed (solid) and measured (dash dot) spectrum and reconstructed phase (dash). B) The measured FROG trace. C) The retrieved FROG trace. The FROG error was < 0.2%.

In conclusion, we presented aYb:CALYO regenerative amplifier providing the as-yet-unattained Yb-based RegA pulse duration of 97 fs at 2.7 mJ, after simple Tracy-type compression at a repetition rate of1 kHz.

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Generation of Signal Waves with GHz Spectral Shift and coherent GHz Wave. Influence of the Initial Polarization of Laser Pulse

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The propagation of femtosecond laser pulses in air with source intensity of the order of 10^{11}–10^{12} W/cm^2 is characterized by the generation of coherent GHz radiation [1]. In our previous work we present a new parametric conversion mechanism in the frames of third order nonlinearity to explain the origin of this coherent GHz generation [2]. In 3D+1 space-time appear additional degenerate four photon parametric processes as well as new vector type wave synchronisms which influence significantly on the efficiency of the GHz generation. We present a new theoretical model including all these nonlinear mechanisms and obtain a 3D+1 vector set of differential equations describing the evolution of the main, signal, idler and GHz waves. The efficiency of the GHz generation is investigated numerically in the three main cases of polarization of the initial laser pulse: linear, circular and elliptical.

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Electron-Beam Processing of Metals and Alloys – Techniques and Trends

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The electron-beam technologies have been widely used for the processing of metals and alloys. These methods are known as accurate and efficient and are characterized by many advantages in comparison with the conventional ones, such as uniform distribution of the energy of the electron beam, very short process time, precise control of the beam parameters, etc. [1]. Currently, modern trends in the processing of metals and alloys are based on the combination of electron-beam technologies with other methods, such as thin film deposition, etc. These techniques result in a significant improvement in the functional properties of the materials which can be involved in new fields of modern industry. This talk aims to summarize the topics related to surface treatment and modification of metals and alloys by electron-beam technologies. The benefits of these technologies, as well as their combination with other methods, are extensively discussed.

Acknowledgements: This research was funded by the Bulgarian National Science Fund, grant number KP-06-N 67/7.

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Laser Based Texturing for Enhancing "High Traffic" Surfaces Antimicrobial activity

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Due to rising numbers of antibiotic-resistant bacteria cases, new approaches for fighting biofilm formations emerged. Diverse pathogens, are forming biofilms by adhesion to a surface, creation of conglomerates, which evolve in development of extracellular polymeric matrix. In order to alter this matrix formation, creating a dual roughness by means structures with diverse sizes, it is possible to mechanically affect the distribution of the biofilm, leading to bacteria rupture and death.

An alternative method to chemical treatments is the laser surface modification processing, due to the abilities to create micro/nanofeatures with modulated properties.

In this research we perform a systematic parametric study on femtosecond laser-induced surface processing on mirror polished stainless steel surface and their effect on both wettability and bacterial-adhesion properties. We developed diverse structures in the form of laser-induced periodic surface structures (LIPSSs), and conical structures decorated with LIPSSs. We define the optimal conditions for the creation of the hybrid structures and demonstrate that the scanning velocity is the main controlling parameter which influences the morphology of the created structures.

Moreover, it was demonstrated the synergetic antimicrobial effect, of the as created features and the post modification via magnetron sputtered layer of silver (Ag) and copper (Cu) known as powerful antimicrobial agents.

Thus, by using different approaches of surface treatment it is expected to create a bacteria resistant surface which reduces the transfer of pathogens, in different devices, medical equipment, personal electronics, public tranpostration and etc.

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Quasi-Phase Matching & Crystal Segmentation for Robust Optical Parametric Amplification

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We propose a novel optical parametric amplification scheme that combines quasi-phase-matching with a composite pulse approach that involves crystal segments of specific lengths. The presented scheme highly increases the robustness of the frequency conversion against variations of the nonlinear coupling and of the pump, idler, or signal wavelengths, and has therefore the potential to enhance high amplification and broadband operation. Simulation examples applied to LiNbO are given.

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Towards Adequate Modeling of the Interaction of Attosecond Pulses with Correlated Electrons

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Nowadays the most common sources of VUV and X-ray attosecond pulses are the high-harmonic generation and the free electron lasers. The routine generation of isolated attosecond pulses by high-harmonic generation would allow to study important phenomena such as electron–electron interactions in atoms and molecules, coherent electron dynamics in molecules and nanostructures, molecular dynamics, and elementary chemical reactions, among others, where correlation effects occur at the attosecond time scale. Most of the existing theoretical methods are not suitable for treating time-dependent processes where correlation and entanglement are important. A new method named time-dependent quantum Monte-Carlo (TDQMC) has been devised to circumvent most of the limitations of the existing methods and apply it to problems of principle importance. These include the motion electrons subjected to strong high-frequency optical fields where the effects of quantum non-local causality can be considered a minor correction to that of the Coulomb interaction between the electrons. The significance of this finding for light-matter interaction is that the exponential scaling of the many-body problem can be avoided by correctly considering the correlations that are due to the Coulomb interaction alone and forgetting about the non-local causality. Furthermore, we introduce a method for describing quantum entanglement locally as a function of the distance between two hydrogen atoms that form a simple molecule. Our findings indicate that it is possible to dynamically track the processes of information transfer in molecules and in solid-state with attosecond time resolution.

Coherent Anti-Stokes Raman Spectroscopy (CARS) for Characterization of Transparent Polymers

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Multiplex coherent anti-Stokes Raman scattering (CARS) was applied to characterize optically-transparent bulk polymers poly-(methyl methacrylate) (PMMA) and polystyrene (PS). These synthetic solid-state clear glassy polymers are widely used in conventional and laser optics, optical limiting films, as well as for a broad spectrum of nonlinear optical (NLO) and photonic devices. CARS spectroscopy was performed with nanosecond-pulsed laser sources irradiating in the visible spectral range. In this kind of nonlinear laser spectroscopy, the optical intensity of timely-synchronized and spatially-overlapped pulses of the two laser beams focussed within the PMMA and PS samples was up to 90 MW/cm^2 (laser peak fluence ≅ 2.25 J/cm^2). The activation of two-photon enhanced NLO processes led to a significant NLO response of the polymer media. Thus, the laser-induced coherent Raman scattering serves as both an optical excitation and probing mechanism in the exact location of interaction of focused lasers with the medium – in the focal center where the CARS signal is generated. In this case, the laser-induced two-photon Raman-resonant NLO effects and relevant CARS spectroscopy can be used to monitor the molecular-structure status of the laser-irradiated polymeric material, exploiting the change in the spectral characteristics related to CARS. The coherent optical signal resulting from optical four-wave mixing (FWM) as a NLO parametric process at two-photon Raman resonance obtained for the probed polymer samples exhibited both electronic and Raman-resonant contributions. The analysis of the complex CARS signal allows to determine the single-shot laser pulse intensity threshold for photodegradation of the studied PMMA and PS [1].

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Second Harmonic Generation by Bessel-Gaussian Beams

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Ever since the first observation of the second harmonic generation (SHG) of the emission of a ruby laser [1], nonlinear optics attracts continuous research interest and is a subject of intensive further development. Part of it is the singular nonlinear optics [2,3], a field in photonics in which the objects of interest are beams/pulses with phase and/or polarization dislocations. Classical examples of such beams are the one-dimensional dark beams and the optical vortices (OVs). The phase profile of a one-dimensional dark beam is characterized by a π-phase jump [3], whereas the phases of OVs change azimuthally from (conditionally) zero to an integer multiple of 2π, i.e. they carry true two-dimensional point phase dislocations [2]. Not that obvious, but Bessel-Gaussian beams can also be classified as singular beams.

In this work we demonstrate both experimentally and by numerical simulations a strong reshaping of the second harmonics of zeroth- and first-order Bessel-Gaussian beams (BGBs). Even though the efficiency of second harmonic generation (SHG) with Bessel-Gaussian beams was studied previously, the question of their spatial profile still raises many questions. Here we show that the characteristic for BGBs radial π-phase jumps doubled in the process of SHG. In fact, this leads to their erasure. The result is a drastic change in the spatial profile of the BGBs. The narrow central peak at the fundamental wavelength is vastly broadened in the SH, covering the area occupied by the first two or even three bright rings in the fundamental beam. Detailed interferometric measurements showing flat phase profiles of the broadened central part of the SH beam, and between it and the neighboring rings, will be presented, discussed, and compared with numerical simulations.

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Experimental Determination of the Gouy Phase of Even Hermite-Gaussian Laser Modes

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It is known that any focused light beam experiences an axial phase shift with respect to a reference plane wave when passing through its focus. This phase anomaly was first studied by Gouy and is named after him. The chronology of early studies can be found in [1]. Later, most of the research was related to the development of microwave optics, lasers, nonlinear optics, terahertz radiation, and singular optics, just to mention a few.

The Gouy phase is related to the axial phase shift experienced by any focused light beam with respect to a reference plane wave when passing through its focus. Let us denote by L_D and z the Rayleigh diffraction length of a Gaussian beam and the longitudinal coordinate, respectively. Then, the Gouy phase for a Gaussian beam is given by $\Phi_G = atan(z/L_D)$. Generally, the Gouy phase ΦG for a higher-order Hermite-Gaussian (HG) beam is this for the fundamental Gaussian beam multiplied by a factor, which is the sum of the mode indices of the HG beam plus unity ($1+l+m$, where l and m are the mode indices) [2].

Although this result is a paradigm in optics, we are not aware of its experimental verification. In this paper, we present experimental results obtained with a single-lens interferometer for higher-order HG modes generated using spatial light modulator. The retrieved Gouy phase ΦG is found in a very good quantitative agreement with the mentioned theoretical result.

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Top-hat Beam Generation and Refocusing Using SLM Modulator

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Top-hat beam profiles have been widely used for decades in practical applications having their intensity distributed uniformly through the beam's cross section. Its main advantage is the on-off cutoff on the edge of the beam, making it perfect for ablation processes without destruction of adjacent material. The main issue with such types of beams is the lack of this uniformity along the propagation axis.
With the development of dynamic beam shaping elements, such as deformable mirrors (better for high intensity beams) and spatial light modulators (better for high precision beam modulation), we are able to change the intensity distribution of any beam.
In this work we present the ability to generate and top-hat beam profiles, using SLM modulator, from with different sized incident Gaussian beams as well as dynamically moving the focal (flat-top) point along the propagation axis.

Laser-Induced Optical Phase Effects in Ion-Implanted Polymeric Nanolayers

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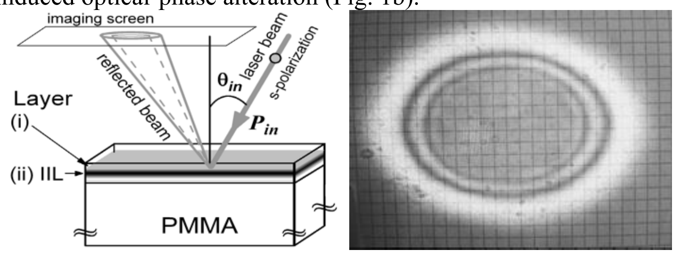
We have studied the laser-induced modification of optical reflection of nanothin (80 – 100 nm) layers of the optically-transparent polymer poly(methyl methacrylate) (PMMA) implanted with silicon ions (Si^+) at energy of 50 keV and various ion fluence in the range from 10^{14} to 10^{17} ions/cm^2. Laser-induced optical-phase effects on the reflection of Si^+-implanted PMMA nanolayers were observed upon their irradiation by a cw diode-pumped solid-state laser with an optical power up to 100 mW (wavelength λ = 532 nm). These effects were attributed to the modification of the subsurface region of PMMA upon the ion implantation and formation of nano-clustered structure with optical properties different from those of pristine PMMA. The ion-produced subsurface organic interface was probed by the method of laser-induced thermal lens.

Being of importance as considering the applications of ion-implanted optically-transparent polymeric nanolayers in photonics, biophotonics, integrated optics and optical communications, the observed effects in Si^+-implanted PMMA were studied and analyzed as a function of the intensity of the incident laser beam, the angle of incidence on the probed interface and the ion fluence used for implantation of the polymer PMMA. The results obtained were linked to the structure formed in the studied ion-implanted plastic nanolayers. The laser-induced optical-phase effects and the corresponding thermal lens were due to the Si^+ ion-produced gradient refractive-index in-depth profile of the subsurface ion-implanted organic-carbonaceous nanolayer (IIL) buried in a depth of about 100 nm within the polymer (Fig. 1a), and its optical absorption, both resulting in a subsequent laser-induced change in the refractive index of the Si^+-implanted PMMA nanolayer and appearance of characteristic interference rings in reflection geometry due to laser-induced optical-phase alteration (Fig. 1b).



(a) (b)

Fig. 1. (a) Schematic of ion-implanted PMMA and laser-induced thermal lens observed in reflection; (b) Image of the far-field cross section intensity distribution of the reflected laser light beam.

Gouy Phase Determination of Different Laser Modes Using Single-Lens Interferometer Techniques

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The Gouy phase shift is an additional phase change that a laser beam undergoes as it passes through its focus, amounting to a total phase shift of π radians. This phenomenon occurs due to the diffraction of the beam, resulting in a slower phase velocity near the focus compared to regions far from it. Understanding the Gouy phase is crucial in applications like laser focusing and optical trapping, where precise control of the beam's phase and amplitude is essential [1,2].
In this work we will present a study for the determination of the Gouy phase of a special class of singular beams. These beams are created by ordering optical vortices (OVs) with identical topological charges (TCs) in ring-like structures of different radii. Besides, the option to control the radius of the ring-like structure, we can also control the number of the OVs in the structures. We generate these beams by encoding the pre-calculated phase distribution of the desired structure on a reflective liquid-crystal spatial light modulator (SLM).
We used the single-lens interferometer technique [3] to determine the Gouy phase of such structures and to compare them with the Gouy phase of a pure Gaussian beam. We have reached the conclusion that both the radii of and the structure and the number of the Ovs in it can change the Gouy phase. We believe that this would appear to be a reliable technique for controlling the Gouy phase of a beam.

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Annihilation of Low-Charged Optical Vortex Beam and Studying of Their Gouy Phase

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Optical vortices (OVs) are intriguing phenomena in nature that attract much attention in many areas of physics. OVs are associated with the presence of a spiral phase dislocation in the wavefront of a light beam that also determines the intensity structure of the beam – the characteristic doughnut-shape intensity profile [1]. Such beams carry photon angular momentum, which can also be transferred to matter [2]. The angular momentum is referred to the topological charge (TC) l, which corresponds to the total phase change $2\pi l$ over the azimuthal coordinate φ. If two OVs with equal TCs are placed on background beam they will exhibit repulsion like electrical charges with same signs, while the TCs with different signs will attract each other which will eventually lead to their annihilation. Intriguingly, when two OVs of opposite TCs are annihilated and subsequently Fourier transformed (focused by a thin lens), the Gaussian form of the background beam is retrieved [3]. Here, using the single-lens interferometer [4], we measured the Gouy phase of different combinations annihilated low-charged OVs. By low-charged OVs, we understand OVs with TCs up to 5. The experimental results showed that not only the Gaussian shape of the initial unmodulated laser beam is retrieved but also that the Gouy phase of the annihilated OV beams is almost identical to this of the pure Gaussian beam. More experimental data will be shown and discussed.

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This work was funded by the Bulgarian National Science Fund (project КП-06-Н78/6). L.S. gratefully acknowledges the Return Grant awarded by the Alexander von Humboldt Foundation.

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Investigation of the $B^1\Pi$, $v'=4 \leftarrow X^1\Sigma^+$, $v''=0$ band in KRb

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The study of the perturbations in the excited $B^1\Pi$ electronic state gives an opportunity of transferring cold Feshback or photoassociated molecules from the $a^3\Sigma^+$ state to the ground $X^1\Sigma^+$ state, using Stimulated Raman adiabatic passage [1,2]. Due to the proximity of the closely lying $c^3\Sigma^+$ and $b^3\Pi$ states, many perturbations, caused by the spin-orbit interaction, are observed [3]. Recently, the fine and hyperfine structure of a particular perturbation in the $B^1\Pi$, $v'=2 \leftarrow X^1\Sigma^+$, $v''=0$ band have been analyzed [4]. Our goal is to extend the analysis to another band and also to include the intensities of the lines, which has not been done so far.
By using Doppler-free saturation spectroscopy technique in heatpipe, we have obtained a high resolution spectrum in the range 15235 – 15255 cm^{-1}. Many lines occur for K_2 and KRb in multiple isotopologues. The obtained results and the current status of the analysis will be presented at the conference.

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Investigation of the Fine and Hyperfine Structure of the $c^3\Sigma^+$ State in KRb

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The study of the hyperfine structure (HFS) in electronic transitions in diatomic molecules is a challenging task due to its experimental and theoretical complexity. We want to study the HFS of one of the $c^3\Sigma^+$ vibronic states of the KRb molecule, because previous studies indicated that the splitting may be much larger than in similar alkali metal diatomics [1]. Another motivation is that the $c^3\Sigma^+$ state serves as an intermediate state for transferring cold Feshbach molecules from the $a^3\Sigma^+$ state to the ground $X^1\Sigma^+$ state [2]. Due to the proximity of the $B^1\Pi$ state, perturbations caused by the spin-orbit interaction are observed. This makes it possible to observe transition to the mixed pair of states from the ground $X^1\Sigma^+$ state.

By using Doppler-free excitation spectroscopy technic in heatpipe we preferentially observe the transitions from the ground state $X^1\Sigma^+$ to the triplet state $c^3\Sigma^+$. The perturbation model used for explanation of the data is that of the effective Hamiltonian. Appropriate matrix [3] is being numerically diagonalized and the calculated term energies are compared to the experimental ones. By a non-linear least square fit constants for the fine structure are obtained. That of the hyperfine structure is also found but it is only a suggested value because the resolving power is not sufficient and only line broadening is observed. The obtained results will be presented at the conference.

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Picosecond Laser Ablation of Metals in Air and Water Environment

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Reports on laser ablation of materials by picosecond (*ps*) pulses can rarely be found in the open literature; the researchers have mainly been focused on ablation by femtosecond (*fs*) pulses, although the last few years saw an increase of the interest in this area. However, these works have dealt mainly with the target morphology and the efficiency of the process itself, rather than on the material ejected/ablated from the target. In this work, we addressed the processes of fabrication of nanoparticles/nanostructures of metals by applying picosecond laser ablation and the results thereof. The samples were prepared by using a Nd:YAG laser working on its fundamental wavelength at a 1 kHz repetition rate and a pulse duration of 10 ps. Two sets of experiments were performed, namely, the depositions were carried out in air at atmospheric pressure and in water environment. The subjects of investigation were noble metals, namely, Au, Ag, Pd, and Pt. We studied the microstructure, morphology, and physicochemical stage of the surface of the as-deposited samples, as well as their optical properties. It was found that the picosecond laser ablation of noble metals performed in air at atmospheric pressure results in the fabrication of nanostructures composed of nanoparticles. These particles are crystalline and spherically shaped with a pronounced bimodal distribution. Also, the Au, Pd and Pt nanoparticles tend to agglomerate into chains. The Ag, Pd and Pt nanoparticles' surfaces oxidize (passivate), but the particles themselves are made of pure metal. Further, the Ag nanoparticles' oxide shells do not affect their plasmonic properties. A bimodal particle size distribution is also characteristic of ultrashort pulse ablation of metals in liquid/water. Particles with pronounced spherical shapes are obtained by ablation of Au, Pd, and Pt targets, while ablation of an Ag target results in irregularly shaped particles. It was found that the noble-metal particles in water are negatively charged, which presupposes their inability to agglomerate. However, the Au and Ag colloids are stable over time, while the colloids with Pd and Pt particles visibly agglomerate.

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Laser Light Diffraction Through Electro-Optically Oriented Films

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The work is an investigation of an electro-optical (EO) effect in nematic liquid-crystal films of practical significance. The studied EO effect is due to electro-optically controlled microperiodic modultion of the nematic director in such films (thickness of 25 μm) with a planar orientation. The effect is induced by applying direct-current (DC) electric field and is based on the interaction of coherent light with DC voltage-induced texture in the films. The electrically-controllable light-diffractive effect is observed when the films are illuminated by coherent light and subjected to a weak DC voltage (~ 4 V). It allows an efficient EO control of the laser beam transmission through planar nematic films and to achieve a high optical contrast ratio in transmission. This is demonstrated for films of the nematic liquid crystal material pentylcyanobiphenyl (5CB) [1]. The DC field-induced regular modulation spatial patterns of optical phase shift in planar nematic films can be used for DC voltage-controllable amplitude modulation of laser light. In planar 5CB films at DC voltage from 4 V to 10 V, the intensity of the diffraction splitting of the transmitted laser beam can be linearly commanded by the applied DC field, and such EO behavior is of practical significance. The studied effect can be the basis of others effects and applications, in particular, in liquid crystals-based composite and hybrid materials.

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Lidar Remote Sensing of Desert Aerosol Loads over Sofia, Bulgaria

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In April 2019, a dynamic blocking synoptic pattern, known as an omega block, created conditions for a strong northeastward circulation of air masses rich in moisture and dust, which resulted in an extreme large-scale Saharan dust episode over the Mediterranean and Europe. Using lidar remote sensing in combination with in-situ measurements, satellite imagery, and modeling data, we investigated and characterized the impacts of related dust intrusions on the atmosphere over Sofia, Bulgaria [1]. The optical and microphysical characteristics of the desert aerosols, such as the backscatter coefficients (BSC) and backscatter-related Ångström exponents (BAE), were measured and vertically profiled. Additionally, the frequency-count BAE distributions were obtained as qualitative representations of the particle size distributions. The largest values of the aerosol BSC show that the dust density stays high even after the dust plume has been spread widely over the Mediterranean and Europe, demonstrating the dust event's extraordinary scale and strength. The dust-dominated aerosol layers' topological and dynamic characteristics were also identified. Lidar and in-situ data were synergistically combined and calibrated to yield height profiles of the aerosol/dust mass concentration. We calculated calibrating conversion coefficients and used the in-situ data to retrieve vertical aerosol mass concentration profiles directly from the aerosol BSC profiles, avoiding the need for intermediate determination of the aerosol extinction profiles. This was made possible by the relatively high homogeneity of the aerosol mix dominated by dust and its relatively narrow BAE distributions, favoring the use of a constant lidar ratio. Satisfactory compliance was observed when comparing the retrieved mass concentration profiles with the ones from the dust modeling in terms of the profile shapes, aerosol mass concentration values, and boundaries of the layers' heights. The results obtained show that the presence of desert air masses had a significant impact on the local meteorological conditions, especially on the temperature and atmospheric water content, as well as the aerosol composition and structure of the troposphere above Sofia during the dust event.

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Roughness and Wettability Control of Laser Textured Glass for Development of Antibacterial Surfaces

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Diseases mediated by antibiotic-resistant bacteria are becoming an increasing problem in hospitals, kindergartens, and public areas. According to the World Health Organization, drug-resistant pathogens are one of the global problems of society, as they lead to longer hospital stays and increased number of deaths. Glass, along with plastics and metals, is one of the most common basic materials for producing a great variety of frequently touched surfaces like windows, tableware, laboratory and hospital glassware. The traditional surface deposition with chemical compounds for achieving bactericidal action does not provide a long-lasting effect and, can even induce side effects, due to the interaction of the substance with the surface material. Ultra-short laser-based surface texturing on the other hand possesses numerous advantages over other modification techniques. The contactless technique is characterised by high precision and tunability of the laser radiation parameters, and it provides a possibility for diverse micro and nano surface designs. The connection between surface roughness, wettability properties, and bacterial size dimensions is essential for bacterial attachment to diverse surfaces - the reduction in the initial attachment of microbes to the surface is the key to preventing biofilm formation and bacteria proliferation. The interplay between wettability and surface roughness is the basis of achieving this goal. In this study, we achieved laser-induced periodic surface structures (LIPSS) on glass, by optimizing fs laser parameters applied. Preliminary results of precise control of surface wettability and roughness of glass slides are demonstrated. It is identified that the morphology and wettability of laser-induced surface structures created can be efficiently tuned by adapting the laser processing parameters to create structures, which could possess antibacterial qualities.

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Characterization of Metal-Doped β-TCP Scaffolds Modified by Ultra-Short Laser for Improved Antibacterial Performance

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Bacterial infections are a major cause of implant failure in orthopedic applications, highlighting the need for materials that combine excellent biocompatibility with robust antibacterial properties. Beta-Tricalcium Phosphate (β-TCP) is widely used for bone regeneration, yet it remains vulnerable to bacterial colonization. Femtosecond (fs) laser technology offers a novel approach for surface treatment of materials, enabling precise modifications without significant thermal effects or alteration of intrinsic properties. Incorporating antibacterial ions such as copper (Cu), strontium (Sr), silver (Ag), and magnesium (Mg) into β-TCP can further enhance its antimicrobial efficacy. In this study, fs laser processing was applied to β-TCP pellets doped with Cu, Sr, Ag, and Mg ions. Various laser energies, scanning velocities and patterns were employed to optimize the surface characteristics. The modifications were analyzed using Scanning Electron Microscopy (SEM), Optical Profilometry, and Water Contact Angle (WCA) measurements. SEM results demonstrate the formation of Laser-Induced Periodic Surface Structures (LIPSS) - like features, which are known for their inherent antibacterial properties. Additionally, optical profilometry results, indicate that under all tested conditions, it was monitored an increase in surface roughness. The latter effect may potentially disrupt bacterial adhesion and inhibit biofilm formation, indicating a potential augmentation in antibacterial efficacy. Furthermore, measurements of WCA suggest a potential increase in hydrophilicity, which could facilitate the efficient release of antibacterial ions and possibly enhance antibacterial potential. This study demonstrates that fs laser treatment, in conjunction with doping β-TCP with antibacterial ions, is a promising strategy to enhance the biocompatibility and antibacterial properties of β-TCP, addressing the critical issue of bacterial infections in orthopedic implants.

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Impact of Canadian Forest Fire Smoke on the Atmospheric Aerosol Features over Sofia, Bulgaria, Characterized by Sun Photometer and Lidar

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The biomass-burning aerosol situations (events) over Sofia are due to short-range or long-range transport of smoke from closer and/or distant fire outbreaks and domestic heating. Being a relatively strong absorbent of radiation, the smoke may play an essential role in the exchange of solar and terrestrial radiative energy. Also, being a heavy air pollutant, it can cause serious health problems. The greenhouse gasses released along with the carbonaceous particles are also a factor leading to unfavorable climate changes. Therefore, the biomass-burning aerosol events, like the other aerosol phenomena, attract the attention of investigators worldwide, and are the subject of comprehensive research using various ground-based, air-borne, ship-borne and space-borne experimental facilities.

The purpose of the present work is to thoroughly study the features of the aerosol situation over Sofia, Bulgaria, on 3 October 2023 using lidar and ceilometer data on the aerosol stratification as well as sun/sky/lunar photometric data on the aerosol optical and microphysical properties. The results from the data analysis were additionally checked, using information from satellite observations of fire outbreaks around the world, air mass back-trajectory recovering models, desert-dust spread predicting models, and weather information. The interest in the aerosol event under consideration was conditioned by the extreme fire activity worldwide during 2023, including the weeks around 3 October, and by the intense flow of arriving air masses on that day originating from or having passed over areas of strong fire outbreaks in Canada.

The analysis of the data obtained showed that the conditions on 3 October 2023 were those of an aerosol event with dominant content of aged (primarily from Canada) and fresh (primarily from Europe) biomass burning particles, urban and continental aerosol, and possibly a lower content of marine aerosol and Saharan dust.

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Optical Investigations of Surface Plasmonic Resonance of Complex Liquids

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The surface plasmonic resonance (SPR) was applied to study the physicochemical characteristics of phospholipide (PL) 1-Stearoyl-2-oleoyl-sn-glycero-3- phosphocholine (SOPC), grown as a bilayer on a solid substrate. Putting into practice the known Kretschmann SPR configuration, consisting of prism/gold layer/PL layer, we created plasmon excitation, respectively SPR, by illumination of the gold surface with p-polarized light at an angle $\prod_{s,p}$. Using the relation of the incident light angle and that of the PL monomer with respect to the bilayer’s normal, we found a shift $\delta\prod_{s,p,}$ indicating the gold/PL interface refractive indices variation. Considering the PL monomer as a rod-like structural unit, in analogy with a liquid crystal one, we used elastic characterization of tilted smectic C and its splay elastic constant, responsible for the interdigital degree of freedom of the PL monomer inside the bilayer membrane. We have indicated the bilayer’s tilt dependence of both splay deformation and free energy density of the PL membrane.

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Photoactive Spirooxazines for Laser-based Sensing of Heavy-metal Ions in Solutions

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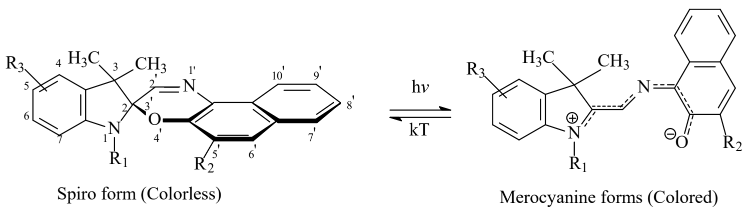
Here we report novel spirooxazines (SO) bearing different substituents in their naphthoxazine and indoline ring molecular systems (Scheme 1). Such SOs were designed aiming their application for detection of heavy metal ions in solutions at a concentration less than 10^{-5} M. We studied the effects of both the molecular structure of the synthesized SOs and their solvation in various solvents (organic and inorganic) on the absorption properties and the complexation of the SO molecules with some metal ions, including harmful heavy metal ions.



$R_1 = CH_3, C_4H_9, C_4H_8SO_3H$, R_2 = OH, 2-benzothyazolyl, R_3=CH_2=CH_2=CH_2=CH_2
Scheme 1. Photochromism of substituted spirooxaxines

Complexation of SOs with selected metal ions in appropriate solvents, including also water, is the possibility to stabilize the coloured MC form. The interaction of SO having sulfobutyl substituent on the indoline fragment of the molecule with Cd(II), Ca(II), Mg(II), Zn(II) or Pb(II) leads to formation of colored complexes of metal ions with merocyanine form of the compound. The obtained results on the photo-physical characteristics, photo-transformations and complexation of the synthesized SOs can be useful and can be applied in the highly sensitive and selective analytic techniques for metal ion sensing, detection of chemical compounds of ecological interest, as well as for the monitoring of drinking water.

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Optical Characterization of Squaraine Dye Sensitized TiO_2/GO Nanocomposites for Photocatalytic Application

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A novel (3-oxo-4[(1,3,3-trimethyl-3H-indol-1-ium-2-yl) methylene]-2-[(1,3,3-trimethylindolin-2-ylidene) methyl] cyclobut-1-enolate) squaraine dye sensitized TiO_2/GO nanocomposite was facilely prepared by hydrothermal method. The photocatalytic activity of the three-component TiO_2/GO/SQ composite was presented by the degradation rate of methyl orange (MO) under visible-light irradiation. XRD, XPS, SEM, TEM, PL and VIS spectroscopy were employed for sample characterization. The optical results indicated that the presence of the photosensitizer and GO improved the optical properties of TiO_2 in the visible range. The photoresponse range of TiO_2 extended to visible-light region is of great importance for the enhanced photocatalytic activity [1]. A squaraine dye excited by visible light is capable of transferring electrons to TiO_2/rGO material, which contributes to increasing the degradation rate of MO.

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Electromagnetic Cloak of Invisibility with Metamaterials

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The work presents a theoretical model based on transformation optics for so-called Electromagnetic Invisibility using Metamaterials. It is essentially a design of an artificial composite material (metamaterial) with complex distribution of the refractive index that is capable of hiding an object from the electromagnetic waves traveling over its surface and near surroundings, by bending the optical space around the object - the waves entering the space can recover their original wavefront in the nearfield after the object.
The model is based on cylindrical symmetry in 3D in which the object can be invisible for electromagnetic waves, but the current work presents only analytical model of a 2D circular cut that can be easily translated to spherical or cylindrical 3D space by rotation or translation of the coordinates. All the calculations are performed with monochromatic, linear polarized electromagnetic wave with a frequency of 4 GHz, referring to high frequency radio invisibility, but the same model is also applicable to the near infrared and visible spectrum.
For calculations and numerical simulations Wolfram Mathematica and COMSOL Multiphysics software packages are used.

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Fluorescence and Raman Spectroscopy of Essential Oils

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Essential oils (EOs) are used since ancient times for the treatment and relief of a number of diseases and conditions, because they have antiviral, anti-inflammatory, antifungal and antibacterial, organoleptic, antimicrobial and regenerative properties. They are complex mixtures of various volatile organic compounds, which have a characteristic smell [1]. EOs are lipophilic and not soluble in water, but can be dissolved in alcohols. Essential oils are extracted from a plant or a specific part of it (flowers, leaves, roots, bark) by steam distillation, cold pressing or an extraction process. Due to their biological properties, EOs are commercially important for the pharmaceutical, food, perfumery and cosmetic industries. Essential oils demonstrate fluorescent properties and characteristic Raman spectra. Thus, spectral measurements are potentially useful for the detection and quality control of essential oils, imaging and for studying their synergy [1].
We report the use of fluorescence and Raman spectroscopy, as rapid and less expensive methods suitable for the characterization, discrimination, and quality control of essential oils. By scanning excitation and emission wavelengths with certain step between them, the results that we obtain can be displayed graphically as a contour plot against fluorescence intensity for each excitation – emission wavelength pair. The 3D contour plot so cold Excitation Emission Matrix (EEM) is useful tool for applications needed to discriminate similar compounds with multi-component analysis. On the other, hand the Raman spectra acts as a fingerprint for every single chemical substance, based on the polarizability of the molecule with respect to its vibrational motion [2,3]. The combination of these techniques gives us specific spectral peculiarities suitable for classification and quality control of essential oils.

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