Book of abstracts

PHOTONICA2019

The Seventh International School and Conference on Photonics, 26 August – 30 August 2019, Belgrade, Serbia

& Machine Learning with Photonics Symposium (ML-Photonica 2019)

& ESUO Regional Workshop

& COST action CA16221

Editors: Milica Matijević, Marko Krstić and Petra Beličev

Belgrade, 2019

ABSTRACTS OF TUTORIAL, KEYNOTE, INVITED LECTURES, PROGRESS REPORTS AND CONTRIBUTED PAPERS

of

The Seventh International School and Conference on Photonics
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Machine Learning with Photonics Symposium

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NKT PHOTONICS

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REFERENCES
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Conference Topics

1. Quantum optics and ultracold systems
2. Nonlinear optics
3. Optical materials
4. Biophotonics
5. Devices and components
6. Optical communications
7. Laser spectroscopy and metrology
8. Ultrafast optical phenomena
9. Laser-material interaction
10. Optical metamaterials and plasmonics
11. Machine learning in photonics
12. Other topics in photonics

Dear Colleagues, friends of photonics,

We are honored by your participation at our PHOTONICA2019 and your contribution to the tradition of this event. It is our pleasure to host you in Belgrade and in Serbia. Welcome to the world of photonics.

The International School and Conference on Photonics - PHOTONICA, is a biennial event held in Belgrade since 2007. The first meeting in the series was called ISCOM (International School and Conference on Optics and Optical Materials), but it was later renamed to PHOTONICA to reflect more clearly the aims of the event as a forum for education of young scientists, exchanging new knowledge and ideas, and fostering collaboration between scientists working within emerging areas of photonic science and technology. A particular educational feature of the program is to enable students and young researchers to benefit from the event, by providing introductory lectures preceding the most recent results in many topics covered by the regular talks. In other words, tutorial and keynote speakers will give lectures specifically designed for students and young scientists starting in this field. Apart from the oral presentations, PHOTONICA hosts vibrant poster sessions. A significant number of best posters will be selected and the authors will have opportunity to present their work through short oral presentations – contributed talks.

The wish of the organizers is to provide a platform for discussing new developments and concepts within various disciplines of photonics, by bringing together researchers from academia, government and industrial laboratories for scientific interaction, the showcasing of new results in the relevant fields and debate on future trends. In order to boost transfer of light technologies from academia to industry, mixing it with a useful knowledge from IT sector, for the first time we organize a satellite event - „Machine learning with Photonics", which will be realized in the form of a special symposium. The field of machine learning potentially brings a new set of powerful tools to optical communications and photonics. The symposium will comprise several topics related to the applications of machine-learning techniques to the physical and networking layers, as well as to non-telecom applications such as biomedical matter and basic concepts of machine learning principles. We expect that these attractive talks will entice young researchers and engineers from the IT sector and target bigger companies to direct their business plans towards innovations in photonics. Additionally, PHOTONICA2019 will include ESUO Regional workshop and COST action "Quantum Technologies with Ultra-Cold Atoms - AtomQT" with the main objective to promote knowledge in various disciplines of photonics.

In addition, the representatives of the companies related to photonics will have significant role at the event by presenting the new trends in research and development sector. Following the official program, the participants will also have plenty of opportunities to mix and network outside of the lecture theatre with planned free time and social events.

This book contains 181 abstracts of all presentations at the VII International School and Conference on Photonics, PHOTONICA2019. Authors from all around the world will present their work at this event. PHOTONICA2019 will host four tutorial and six keynote lectures to the benefit of students and early stage researches. The most recent results in various research fields of photonics will be presented through eighteen invited lectures and twelve progress reports of early stage researchers. Within the three poster sessions and a number of contributed talks, authors will present 100 poster presentations on their new results in a cozy atmosphere of the building of Serbian Academy of Science and Arts.

Belgrade, July 2019
Editors

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Tutorial Lectures

Molecular membrane organization - a super-resolution fluorescence microscopy study

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Molecular interactions are key in cellular signaling. They are usually ruled by the organization and mobility of the involved molecules. We present different fluorescence spectroscopic tools that are able to determine such organization mobility and potentially extract interaction dynamics. Specifically, the direct and non-invasive observation of the interactions in the living cell is often impeded by principle limitations of conventional far-field optical microscopes, for example with respect to limited spatio-temporal resolution. We depict how novel details of molecular membrane dynamics can be obtained by using advanced microscopy approaches such as the combination of super-resolution STED microscopy with fluorescence correlation spectroscopy (STED-FCS) or spectral detection. We highlight how STED-FCS and spectral STED microscopy can reveal novel aspects of membrane bioactivity such as of the existence and function of potential lipid rafts.

Controlled directional scattering in nano-optics

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Optical nanoantennas attract tremendous attention in modern classical and quantum optics [1]. A widely prevalent class of nanoantennas is isotropic high-refractive index dielectric nanoparticles that support strong electric and magnetic resonances. Simultaneous in-phase excitation and interference of these resonances result in unidirectional scattering of visible and near-infrared light [2, 3]. Controlling the coupling of light to these sub-wavelength nanoantennas allows for tunable directional scattering, paving the way for a variety of far-field and near-field optical functionalities.

Tightly focused polarization-tailored beams feature highly complex spatially-variant three-dimensional (3D) electromagnetic field landscapes, enabling the selective excitation of sub-wavelengths nanoantennas [4, 5]. The capabilities to manipulate the 3D phase and amplitude distributions of the incident electric and magnetic fields at the nanoscale provide the basis for applications of tunable polarization-controlled directional scattering in nano-optics such as nanoscopic position sensing [6], sub-Ångström localization [7] and nanoscale light routing [8].

In summary, future efforts in nanoscale engineering of electromagnetic fields and intelligent design of resonant low-loss high-refractive index dielectric nanoantennas may yield superior functionality for applications of directional scattering in nano-optics. These abilities may have far-reaching implications in modern nanometrology, super-resolution microscopy, nanoscale light routing and beyond.

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Quantum Monte-Carlo methods applied to ultracold gases

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In these two tutorial lectures I will give a brief introduction to quantum Monte-Carlo methods and discuss applications to ultracold gases.

Lecture 1: Quantum Monte-Carlo methods as a powerful tool to investigate equilibrium properties of many-body systems. Introduction to variational Monte-Carlo and diffusion Monte-Carlo techniques for many-particle systems. Calculation of observables and simulations of infinite systems. The sign problem in fermionic simulations and possible approximation schemes.

Lecture 2: I will review some particularly interesting applications of the diffusion Monte-Carlo method applied to ultracold gases. In particular, I will discuss the ground-state properties of the unitary Fermi gas with resonant interactions, the strongly interacting two-dimensional Fermi gas of dipoles and its transition to a Wigner crystal and the Bose polaron problem corresponding to a single impurity atom coupled to a quantum degenerate Bose gas.

Nanophotonics Integration Technology and Applications: Si-Photonics and Nanoscale Light Emitters

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The current optical technology is costly, bulky, fragile in their alignment, and difficult to integrate with electronic systems, both in terms of the fabrication process and in terms of delivery and retrieval of massive volumes of data that the optical elements can process. The integration of photonic systems requires miniaturization of the optical components, similar to the effort that has led to the extensive miniaturization in electronics. For applications involving a photonics layer between different components on the same chip, the photonic components must be comparable in size to the electronic components, and minimally interfere with each other when densely packed. By taking advantage of advances in lithographic tools predicted to reach features as fine as 11 nm by 2020, it is possible to arrange deeply subwavelength features in a patterned material composition to act as a metamaterial with space variant polarizability [1]. Our most recent work emphasizes the construction of optical subsystems directly on-chip, with the same lithographic tools as the surrounding electronics. Such future systems, further require the discovery of new technologies that can operate not only at ultrafast rates (<1 ps), but also at extremely low energies, and with low levels of insertion loss. Additionally, future technologies will need to be highly compact, as well as resilient to temperature change. Moreover, the device designs should provide scalability with respect to the operating wavelength, and the optical carrier should be allowed to range in a broad spectral range to support the necessary aggregate information bandwidth. As specific examples of our most recent work towards these goals, we discuss nonlinear optical devices [1-3], chip-scale integrated Fourier Transform Spectrometer [4] and programmable phase modulation of free-space modes at GHz rates [5].

Nanoscale light emitters are ultra-compact light sources, which can be densely integrated on-chip with potential applications ranging from high-speed optical computing and sensing to chemical detection and nonlinear optical microscopy. In recent years, nanolaser research [6, 7] has shifted in direction from proof-of-concept demonstrations of novel nanoresonator architectures to the development and investigation of nanolasers with high spontaneous emission factors (β). High-β lasers can theoretically achieve ultra-low threshold energy since most of the spontaneous emission (SE) is funneled into the lasing mode [8]. Furthermore, applications centered on high-speed on-chip communication and computing demand research focused on nonlinear dynamical phenomena, direct modulation and array architectures. Therefore, nanolasers also provide excellent miniaturized platforms to explore fundamental physics in the field of nonlinear dynamics [8] as well as the nanoscale optical emitters that are needed for integrated photonic systems.

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Keynote lectures

High performance THz Quantum Cascade Lasers

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Quantum Cascade Lasers (QCLs) are very successful quantum devices which cover a broad spectral range from the infrared to the THz. However, their operation is still limited in terms of operating temperature, output power and beam properties. Therefore, we investigate new material systems, active region and cavity designs.

We use InGaAs/GaAsSb due to the lower effective mass and lower conduction band offset. Record operating temperatures are achieved despite the large interface roughness asymmetries in this material. New doping profiles are introduced which are motivated by the study of symmetric active regions. This has led to a significant improvement of the operating temperature of InGaAs/InAlAs structures. The improved understanding of coherent and incoherent transport in complex heterostructures allowed the realization of high operating temperature GaAs/AlGasAs QCLs suitable for thermo-electric cooling.

Another strategy to improve the performance is to increase the number of cascades in the active region. However, due to the epitaxial growth the maximum active region thickness is limited to around 10–15 μm. To circumvent this growth problem we developed a direct wafer-bonding technique to increase the thickness of the active region by stacking the same active region. With these devices we reach record output power levels of almost 1 Watt and a significantly improved far field. This performance allows real time THz imaging using micro bolometer cameras.

The unique properties of QCLs allow the fabrication of photonic crystals, micro pillar arrays as well as of micro-cavities. Usually, these devices are characterized by narrow spectral windows and cannot take advantage of the larger spectral gain bandwidth offered by Quantum Cascade structures. An unconventional concept which overcomes this limitation is a random laser. We have realized a Quantum Cascade random laser which produces coherent broadband THz radiation as well as an almost diffraction-limited far-field surface emission profile. Our random lasers do not require any fine tuning and thus constitute a promising example of practical device applications.

The excellent properties of THz QCLs and evanescent coupling establish an attractive basis for the realization of on-chip circuits. On-chip generation and detection of terahertz radiation becomes available since intersubband transitions can be used for emission or detection and modulation. We will show a few coupled cavity systems e.g. as emitter – detector system, bi-stable switch or ultrafast modulator.

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Optics in Computing for "More than Moore" performance and "Beyond von Neumann" architectures

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How should someone exploit photonics in computing? Simply replacing the electrical with optical wires and increasing the datarate is the first and obvious answer, but the idiosyncrasy of photons can lead to improved architectures that can offer additional functionality in Datacom and computercom environments. This talk will concentrate on how photonics can bring significant functional benefits in computing architectures, extending along the past and the present of optical interconnect technologies up to the emerging area of photonics for Deep Learning and Neural Network processing machines.

We will cover the important progress made in the field of optical interconnects and related technologies during the last 10 years, discussing the main performance and energy challenges currently faced by the computing industry [1]. The current research efforts for releasing disaggregated DataCenter architectures will be outlined, addressing the employment of high-performance and high-functionality photonics that can ensure the high-bandwidth and low-latency communication metrics required at all hierarchy levels, spanning from rack-to-rack down to chip-to-chip interconnects [1]. We will demonstrate high-port count optical switch layouts based on the Hipoλaos Optical Packet Switch architecture with up to 1024x1024 input/output ports that allow for low-latency values well below the 1μsec target of disaggregated DCs [2]. We will also demonstrate how silicon photonics and electro-optic PCBs can be utilized towards realizing on-board resource disaggregation for multi-socket compute node applications, holding the credentials to replace the dominant QPI interconnect by offering >60% improvement in energy consumption with a single-hop flat interconnect topology for >8-socket connectivity [1].

Finally, we will demonstrate how optics can be incorporated in the emerging paradigm of neuromorphic computing towards offering high-performance at a significantly lower power envelope compared to electronic neuromorphic machines, introducing a new paradigm for the next decade of research in the non-von-Neumann computing landscape. We will present the main principles of neuromorphic photonic architectures together with the first experimental cornerstones along feed-forward, convolutional and recurrent neuromorphic architectures where optical hardware will be demonstrated to perform intelligent tasks in image and bit pattern recognition applications [3].

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The Wonderful World of Flat Bands

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Certain lattice wave systems in translationally invariant settings have one or more spectral bands that are strictly flat or independent of momentum in the tight binding approximation, arising from either internal symmetries or fine-tuned coupling. These flat bands display remarkable strongly interacting phases of matter. Originally considered as a theoretical convenience useful for obtaining exact analytical solutions of ferromagnetism, flat bands have now been observed in a variety of settings, ranging from electronic systems to ultracold atomic gases and photonic devices. I will review the design and implementation of flat bands and chart future directions of this exciting field. In particular I will focus on the field of photonic lattices. Flatband photonic lattices consist of arrays of coupled waveguides or resonators where the peculiar lattice geometry results in at least one completely flat or dispersionless band in its photonic band structure. Although bearing a strong resemblance to structural slow light, this independent research direction is instead inspired by analogies with "frustrated" condensed matter systems. In this talk, I will critically analyze the research carried out to date, discuss how this exotic physics may lead to novel photonic device applications, and chart promising future directions in theory and experiment.

Numerical optimization of resonant nanophotonic devices

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Advanced nanoprocessing technologies allow for the manufacturing of resonant nano-photonic structures with an increasing degree of accuracy and flexibility. In order to design structures for specific purposes, numerical optimization is an important tool. Requiring the solution of Maxwell's equations, the computation of the objective function is in general very time consuming. Therefore, optimization methods must be very efficient in the number of function evaluations required to maximize the device performance.

We have studied the performance of different optimization methods for several design problems in nanophotonics, including the optimization of light extraction from a single-photon-source and a diffractive meta-surface [1, 2]. The comparison shows that Bayesian optimization (BO) can largely accelerate to optimization. Based on the simulation results, BO builds up a stochastic model of the objective function in order to identify promising parameter values. The method, which has gained popularity in the field of machine learning, shows to be also very useful for metrology applications to reconstruct geometrical parameters from measured data.

Further, for a better understanding of the physical behavior of nanophotonic devices, an expansion of the electromagnetic field into so-called quasinormal modes (QNMs) can be instructive [3]. In presence of general dispersive media, current challenges are the derivation of orthogonality relations for QNM expansion [4] and the precise quantification of the coupling of an emitter to a background. To overcome limitations of state-of-the-art methods, we have introduced a new expansion approach [5] for analyzing light-matter interaction in dispersive nanoresonators. The theory is based on Riesz projections, which do not rely on the explicit knowledge of eigenmodes and allow for the precise quantification of the background coupling. We present the theory as well as its numerical realization and review several applications [5-8].

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Nonlinear optical scattering as a tool to study symmetry and dynamical processes

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We will introduce nonlinear optical light scattering as a powerful tool to study metal nanoclusters, plasmonic nanoparticles and dynamical processes such as nanoparticle aggregation and supramolecular organization of polymers. We will demonstrate that nonlinear light scattering can be used to determine structure and symmetry of any material in solution, either as an isolated entity or in an aggregated form. Examples will include the study of gold nanoclusters, aggregation of plasmonic gold nanoparticles and supramolecular organization of polymers. Knowledge of such processes is of crucial importance to obtain a fundamental understanding of metallic behavior in nanoclusters, aggregation effects in nanoparticles and crystallization processes in general. A better knowledge of these processes can also be of great importance to tune the final materials properties for applications.

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Fluorescence Correlation Spectroscopy as a tool in Developmental Biology

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Fluorescence Correlation Spectroscopy (FCS) is a widely used tool for the characterization of molecular dynamics. It relies on the recording of fluctuations in fluorescence from a small observation volume. These fluctuations carry information about the processes that cause them. In its most common form, one observes the diffusion of fluorescent particles in and out of femtoliter-sized confocal volume. The resulting fluctuations carry then the information about the average number of particles in the volume as well as their diffusion coefficient. Over the years many different FCS modalities, using different illumination profiles, recording multiple wavelengths, reducing noise and background of the recordings, have been developed. This provides the user nowadays with a plethora of modalities from which to choose for a particular problem and which can be combined to maximize the information that can be obtained from a particular sample.

Here we will discuss the use of a combination of three different FCS modalities – confocal FCS, confocal Fluorescence Cross-Correlation Spectroscopy (FCCS) and single plane illumination microscopy FCS (SPIM-FCS) – to investigate the dynamics and interactions of Wnt3 in live zebrafish. Wnt3 is a morphogen expressed in the developing brain and the dorsal spinal cord and plays an important role in zebrafish neurodevelopment. The subcellular distribution of this protein and its interaction with receptors are not fully understood. For its study, we used zebrafish transgenics expressing Wnt3-EGFP under a 4kb *wnt3* promoter.

We first investigated by confocal microscopy where Wnt3 is produced and where cells-targets are. We then determined by SPIM-FCS the presence of Wnt3 on cell membranes where it is localized to particular lipid domains. This is important for secretion but also for signaling as its putative Frizzled receptors (Fzd) have been found in such domains [1,2]. Using FCS, we then asked how Wnt3 is reaching its target cells by determining whether Wnt3 is secreted and can be found in the interstitial spaces, between cells, where it can then diffuse to the target cells, or whether it is membrane bound and requires other transport mechanisms (e.g. cytonemes) [3, 4]. And finally, we used FCCS to determine the dissociation constant (Kd) for the Wnt3/Fzd1 pair. Taken together these FCS modalities represent a quantitative approach in analysis of morphogens function in vertebrates *in vivo*.

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Invited Lectures

Measuring electronic properties of free-standing nanocrystals for solar cell absorbers

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We will describe a novel experimental technique that combines surface XPS and gas-phase synchrotron radiation-based XPS/VUV PES, for the investigation of the electronic structure of different nanocrystals that could be low-cost and high-efficient solar cell absorbers [1]. Surface XPS is performed in Notre Dame University (US) using SPECS Surface Nano Analysis GmbH, with a PHOIBOS 150 hemispherical energy analyzer. The synchrotron based XPS/PES is performed at the SOLEIL synchrotron (France). For gas-phase PES, the nanoparticle beam is produced by an atomizer and focused by the aerodynamic lens into the interaction region. On DESIRS beamline, the angle-resolved photoemission spectra were measured by double imaging DELICIOUS3 spectrometer (VMI for electrons and VMI-TOF for ions). On PLEIADES, the $\pm 30^{o}$ aperture wide-angle lens VG-Scienta R4000 electron analyzer was used to record the XPS. The nanoparticles are synthetized both at Vinca Institute of Nuclear Sciences (Serbia) and in Notre Dame. The experimental results are supported by DFT calculations performed at the Institute of Physics Belgrade (Serbia).

Recent results for lead halide perovskites [1] will be presented, as well as preliminary results for lead-free materials such as Ag-Bi-I rudorffite nanosystems. The procedure to synthetize nanoparticles of this material for aerosol generation has been most recently developed at Vinca Institute of Nuclear Sciences. We were able to obtain a complete band alignment to the vacuum of the nanocrystals and investigate their surface properties with high sensitivity.

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SERS spectroscopy: concepts, new materials and application

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The Surface-Enhanced Raman Scattering (SERS) is a special spectroscopic technique which provides an enormous enhancement of the Raman signal from molecules adsorbed on noble-metal surfaces with nanoscale roughnesses. The most beneficial features of SERS are high sensitivity and specificity that makes it possible to use this technique for obtaining detailed information about the structure and composition of a material at the lowest possible concentrations down to single molecule level [1]. Such advantages make SERS spectroscopy perspective for analytical chemistry, food safety, pharmaceutical, medical, forensic science, and many other applications.

The most critical aspect of SERS, before it becomes a routine analytical technique, is the development of new plasmonic nanostructures, called SERS-active substrates. Such materials should have to possess a high sensitivity, reproducibility, stability, simplicity of preparation and compact size [2]. The use of rough surfaces, especially porous materials, as a base support seems one of the ways of fabrication of new SERS-active substrates matching abovementioned requirements. The use of porous materials may offer a high sensitivity because of their larger surface area to host more analyte molecules. Besides, variation of the base support morphological parameters may result in the formation of tailored structures of noble-metal deposits, which offers a high SERS effectivity. Moreover, the metallized porous materials with ordered pore arrangements could result in formation of SERS-active substrates close in parameters to surface-confined material, cheap and easy to produce.

In the present work we report the results on formation of plasmonic nanostructures for SERS based on silvered porous nanostructures and demonstrate the approaches for their analytical and biomedical applications.

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Microwave photonics as a solution for the convergence of radio and optical fiber networks on the physical layer

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The lowest level of communication network, the physical layer, is nowadays a combination of optical fiber transmission technology for fixed network nodes and a wireless radio communication system to also facilitate mobile users. Wired fiber optic connections provide low transmission losses and unique broadband transmission, while wireless links based on radio, micro-wave an even millimeter frequencies provide users with mobility, although these connections are limited in terms of broadband and have a high energy consumption. The next generation of efficient, high-speed, wireless internet with the support of high bandwidth and high mobility is requiring a number of technologies to converge, coexist, interoperate and cooperate. A key field within this next-generation puzzle is the integration of radio networks and optical fiber networks to provide high-bandwidth, scalable and manageable networks with a very simple interface structure.

The convergence of radio access networks and optical fiber access networks [1] in a physical layer is leading to a new technological field called microwave photonics (MWP). It will bring new functionalities to access networks to allow for ultra-high-capacity data transmission with low latency. The advantages of using MWP are multiple. It provides a scalable technology that provides the smooth integration of the optical access network and the transmitting antenna. For remote antenna base-stations the low transmission loss of the optical fiber allows the centralization of the wireless carrier generation, since, without doubt, the advantage of photonics is when generating and transmitting spectrally broad and spectrally efficient ultra-high-capacity data signals.

Nowadays, the research challenge in optical access networks [2] is to incorporate discrete sub-systems into photonic integrated circuits. Similarly, current MWP communication systems are based on optical fiber and discrete components, which limits the high-volume applications and by using integrated MWP in optically supported wireless networks the solutions that are especially suitable for a high-capacity radio system based on micro-wave and millimeter-wave frequency bands can be provided.

This invited lecture will provide an overview of the technological contributions of MWP to the physical layer of next-generation, high-speed wireless networks and present the COST Action CA16220 [3] working group “Integrated MWP for 5G”. The example of the presented solution for combining optical and radio technologies, and thus the transmission of the radio-frequency signal between the central-station and the numerous base-stations, reduces the size and complexity of the remote antenna base-stations. The integrated MWP technology offers cost and energy efficiency based on a reduction in size and complexity.

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Linear and Nonlinear circular dichroism in metal-dielectric nanostructures

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Symmetry is a central component of physical world and many conservation laws in physics are the result of symmetry properties. An example is momentum conservation that is a property of translational invariance. There are systems in which symmetry properties are reduced to a minimum. An example of this are chiral systems which have a property of asymmetry.
Chirality has become a very much studied property due to its potential applications in different areas, as analytical chemistry, crystallography, molecular biology, and new chiral materials may find application for example in polarization control devices. Systems that cannot be superimposed to their mirror image are said to be chiral, the word chirality deriving from the Greek, χειϱ, which means hand, that is the most familiar chiral object (the term was first used by Lord Kelvin). A chiral object and its mirror image are called enantiomorphs or, when referring to molecules, enantiomers.
From the optical point of view, chiral structures possess the ability to rotate the plane of polarization of electromagnetic waves (optical activity), and give rise to dichroism (again from the Greek δικϱως, two-colored) that is the property to split a beam of light into two beams with different wavelengths. A dichroic material is either one which causes visible light to be split up into distinct beams of different wavelengths (dichroic mirrors) or one in which light rays having different polarizations are absorbed by different amounts. When the polarization states in question are right and left-handed circular polarization, one refers to circular dichroism [1, 2].
Optical activity effects arise from different interactions of chiral molecules with left and right-hand circular polarized light. Conventional optical activity effects, such as circular dichroism and polarization rotation, arise from molecular chirality and occur in isotropic bulk liquids (e.g. sugar solutions) and molecular crystals. Circular dichroism may be obtained also by using metamaterials. For example, it is possible to obtain a chiral behavior by engineering the elementary cell of a periodic structure with a chiral arrangement of non-chiral objects (intrinsic chirality or structural chirality).
Recent nanofabrication techniques have made it possible to prepare samples with so-called planar or two-dimensional chirality. Very strong optical activity has been demonstrated in a metamaterial system consisting of molecules that by itself are not chiral, but chirality is drawn extrinsically from the mutual orientation of the wave propagation direction and the two dimensional metamaterial. The effect can be seen when oriented non-chiral molecules make a chiral triad with the wavevector of light (extrinsic chirality). In what follow we describe some properties of chiral metasurfaces [3, 4].

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Laser cooling of atoms using a frequency comb

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Despite the prominent role of laser cooling in modern atomic physics, with applications ranging from quantum sensors to high-precision spectroscopy and ultracold chemistry, laser cooling techniques are still limited to atoms with simple energy level structure and closed transitions that are accessible by currently available continuous wave (cw) laser sources. Using mode-locked femtosecond or picosecond lasers with high pulse repetition rates which produce optical frequency combs (FCs) was recently proposed to extend the range of applicability of laser cooling [1, 2]. Due to their pulsed light emission, FCs provide high peak powers needed for efficient frequency conversion via nonlinear crystals or high harmonic generation. Simultaneously, FCs preserve long coherence times needed for efficient laser cooling since their spectrum consists of a series of narrow, phase coherent frequency comb lines. The first experiments that demonstrate FC cooling of atoms and ions have recently appeared in the literature [3-6]. We will present results of Doppler cooling of neutral rubidium atoms on a single-photon transition using a frequency comb – a cooling scheme that is analogous to cw laser cooling as only a single comb line is involved in the cooling process [6].

The talk will also present recent activities at the Institute of Physics in Zagreb aimed towards establishing a national research centre specialized in advanced laser and optical techniques. The CALT – Centre for Advanced Laser Techniques, is a strategic research infrastructure project of the Republic of Croatia funded by the European Regional Development Fund (ERDF). CALT's activities; which comprise research, education, and providing access to laser facilities; will address socially important issues through planned research activities in the four domains: Quantum technology, Plasma technology, Nano and Bio systems, and Ultrafast dynamics. [7].

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Direct recording of signal integration at individual synapses on dendritic spines: a voltage imaging study

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Most of the excitatory synapses that mediate cell-to-cell communication in the mammalian brain are located on dendritic spines. A sophisticated assembly of transmitter receptor and voltage-sensitive ion channel molecules in spines generate electrical signals and mediate plasticity in response to quantal release of chemical transmitters caused by patterned activity in presynaptic axons. Even though spines are widely considered the elementary computational units of the brain, the current understanding of their electrical behaviour is incomplete and controversial. An important question that has not been fully answered is the exact contribution of individual synapses on spines to the electrical signalling in neurons. The first step in this process involves the transfer of excitatory postsynaptic potentials (EPSPs) from the spine head, across the spine neck, to the parent dendrite at the base of the spine. The properties of this transfer define the electrical role of spines, which is currently controversial. Both old and recent results of a number of studies have been interpreted to support the prominent electrical role of dendritic spines. Other studies provided strong evidence that spines have no electrical role. None of these studies is universally accepted as conclusive because most of the available evidence is based on indirect measurements and theoretical considerations. We recently reported electrical signalling in individual spines based on voltage sensitive dye recordings. In basal dendrites of one class of cortical neurons, Layer 5 pyramidal cells, we obtained direct evidence supporting a conclusion that excitatory postsynaptic potentials (EPSPs) propagate from the synapse on spine head to the parent dendrites without voltage loss. This result implies that spines do not serve a significant electrical role. We report here a continuation of this study that includes two additional classes of principal cortical neurons and additional control experiments. The results confirm and strengthen our previous conclusion that spine synapses on basal dendrites of investigated principal neurons are not electrically isolated from the dendrites and do not function as isolated electrical compartments. Furthermore, because many presynaptic neurons fire in bursts, an important question regarding the contribution of single spine synapses to electrical signalling is the mechanism of temporal summation of subthreshold signals. We investigated this question by monitoring synaptic integration optically at the site of origin and electrically at the soma by patch pipette recording. We found that both local and somatic responses to repetitive quantal EPSPs are based almost entirely on AMPA receptor currents and strictly limited in amplitude and waveform by AMPA receptor desensitization.

0D/1D/2D/3D III-V materials grown by MBE for Optoelectronics

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In KIST, 8 (+1) MBE systems are installed for the study of low dimensional structures. With the MBEs, we are in the middle of studying; As/P/Sb-based materials with new properties, High speed III-V 2DEGs/2DHG for physics (mesoscopic physics, Topo. Insul. etc), high speed (> ~20,000 cm^2/Vs), and low power consumption electronics (0.3 V operation), Digital-alloyed 2D structures for 7-10 μm QCL, QWIP, 0.8-1.6 μm LD, PDs, Catalyst free/Au-assisted GaAs/InAs/InP/InSb nano-rod 1D structures for Anyon operation or Nano TR etc., Various kind of semi-conductor QDs grown by SK, MEE, and Droplet methods for 1.3 μm QD laser, QDIP, single photon source of quantum computation/communications.

Scientists have pioneered the first stages of Si electronics, and now a new frontier in semiconductor electronics is arising. We will introduce contemporary issues associated with breaking new ground in the post-Si-era for semiconductors and discuss the research activities in the recently launched Post-Silicon Semiconductor Institute at KIST.

In this presentation, I will show MBE systems & activities with them in KIST and discuss probable co-works.

Laser-induced periodic surface structures: from nanoscaled light localization to applications

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This presentation reviews the current state in the field of Laser-Induced Periodic Surface Structures (LIPSS). These surface nanostructures are a universal phenomenon and can be generated in a "self-ordered" way on almost any material by irradiation with intense linearly polarized laser radiation [1]. During the last decade, research on LIPSS is often accompanying material processing applications on diverse fields since they can be produced following a single-step process enabling surface functionalization through the adaption of optical, mechanical and chemical surface properties. The structural sizes of LIPSS typically range from several micrometers down to less than 100 nanometers exhibiting a clear correlation with the polarization direction of the laser radiation. Various types of surface structures are classified, relevant control parameters are identified, and their material specific formation mechanisms are analyzed for different types of inorganic solids, i.e., metals, semiconductors, and dielectrics, through time-resolved optical experiments [2-4] and theoretical simulations [4, 5]. Finally, technological applications featuring surface functionalization in the fields of optics, fluidics, medicine, and tribology are discussed [6, 7].

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X-ray induced synthesis of novel optical materials at extreme conditions

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We have demonstrated that highly ionizing, highly penetrating, and highly focused synchrotron hard x-rays (>7keV) can synthesize novel materials [1-2] and novel structures of materials [3] via *useful hard x-ray photochemistry*. We have also observed that some of these novel materials may have optical and electrical utility as wide bandgap material [4]. This material is a variant of polymeric CO which we call "doped poly-CO" that was produced by irradiating a relatively stable material (strontium oxalate powder) with synchrotron-produced hard x-rays (>7 keV) at ambient and high pressures generated by a diamond anvil cell (DAC) and a Paris Edinburgh Cell (PEC). We suspect that the sequence of x-ray photochemical reactions that produced the novel material is as follows:

$$SrC_2O_4 \xrightarrow{h\nu} SrCO_3 + CO$$
$$n(CO) \xrightarrow{h\nu} \text{poly-CO}$$

Here, we consider $SrCO_3$ as the dopant. This novel material appears to be very stable and does not decompose over periods of at least two years. It also traps CO_2 inside it for extremely long periods of time (> 2 years) - even when heated to 500K. We have produced doped poly-CO using different cations (Mg, Ca, etc) and using varying pressures. The synthesized products vary with pressure and irradiation flux and energy used and are all recoverable to ambient conditions.

We recently undertook a nonlinear optical study of doped poly-CO to examine its ability to withstand extreme conditions of photon flux in the desire to ascertain its viability as a sensor using 840 nm light as the excitation source. The smaller samples that were produced inside a pressurized DAC (~ 3 nl in volume) and recovered to ambient conditions deteriorated rapidly when irradiated by the high flux laser beam (in seconds). However, we observed that a larger sample (~3 μl in volume) that was synthesized by irradiation of SrC_2O_4 pressurized to 3 GPa in a PEC was not affected by the laser beam and exhibited Second Harmonic Generation (SHG) which was detected at 420 nm. This result suggests that our novel material may have practical relevance as a rugged easy-to-synthesize nonlinear optical generator or as sensor for extreme and ambient conditions.

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Two-photon in-vivo microscopy of capillary blood flow in the kidney

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Dysregulation of capillary blood flow seems associated with several diseases, but the majority of measurements of capillary flow distributions have been performed in the brain or muscle capillary beds. From other organs, e.g., the kidney, there is a lack of empirical data on capillary blood distributions and lack of knowledge about the relationships between capillary blood distributions and disease states. We, therefore, aim to provide measurements of red blood cell (RBC) velocities in renal glomerular capillaries in vivo by using 2-photon microscopy. We further aim to investigate if and how the distribution of RBC velocities in renal glomerular capillaries is affected by STZ-induced diabetes and by ACE-inhibition in age-induced chronic kidney disease (CKD) in Münich Wistar Frömter rats.

These studies required us to establish a setup which both ensured an optically stable position, a physiologically healthy state of the animals and the ability to introduce fluorescent tracers (Setau647- and FITC-dextrans) to visualized capillary blood flow and renal filtration mechanisms.

Three types of image-data were recorded from each rat:

Z-stacks of each glomerulus, in which capillaries were scanned. These data were used as reference data to enable the identification of capillaries.

Linescans along the centerline of individual capillaries. The linescans were combined to xt-images data and analyzed by a structure-tensor method to estimate the velocity of red blood cell movement in the capillary.

Time-series of full frames spanning 30 mins after injection of a bolus of freely filtered FITC-4kD-dextran were used to estimate the glomerular filtration rate of the animal. Automatic detection of the vascular lumen in the frames (segmentation) was performed by machine-learning.

A total of 2582 xt-images (individual capillaries) from 253 glomeruli in 37 rats were analyzed. The use of 2-photon in vivo microscopy enabled us to show, that the blood velocity in glomerular capillaries was less variable in diabetic rats compared to both untreated and acutely hyperglycemic control rats. Moreover, in old rats, inhibition of Angiotensin Converting Enzyme reduced the variability of blood velocities. In conclusion, the distribution of blood in the glomerular capillary bed is a hitherto undescribed parameter in renal physiology, which 2-photon in vivo microscopy has enabled us to identify and study.

Ultrafast non-linear optical and electronic dynamics in transition metals: superplasmonic states and hot electrons for advanced applications

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Over the past 10 years the authors explored ultrafast linear and nonlinear optical and electronic dynamics in strongly electronically-excited transition metals [1-6], including the common plasmonic noble metals. Pump/probe reflectometry and electrical collector techniques were applied to reveal concerted prompt saturation of inter-band absorption and band-filling [1, 2], accompanied by free-electron heating and emission. Ultrafast broadband in situ transmission spectroscopy supported these findings for ultrafast non-linear photoexcitation in noble metals, demonstrating prompt blue-shifting of localized plasmon resonance in colloidal nanoparticles.

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Discrete Flat Band Photonics

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In this talk, I will review the state of the art on the topic of Flat Band (FB) photonic lattices. We will focus on explaining the main conditions for observing localization on those systems, a historical problem in discrete lattices that has been solved using simple geometrical arguments. We will review different experimental realizations and main findings concerning localization and transport on these non-conventional systems. I will show that, by using a highly controlled excitation of higher-order modes, it is possible to experimentally observe dipolar flat band states on a Graphene ribbon lattice. At the end, I will present some recent theoretical findings showing that by exciting the lattices — simultaneously using fundamental and excited states — it is possible to modify original trivial linear properties and observe FB phenomenology. Finally, I will comment some results on nonlinear FB lattices, where the mobility of nonlinear FB states has been predicted numerically.

Multi-spatial mode quantum optics: fundamentals and applications

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Owing to the Heisenberg uncertainty principle, light is subject to unavoidable fluctuations in its phase and amplitude. Quantum opticians have learned how to reduce these fluctuations by squeezing the light, effectively shifting the quantum noise from one quadrature (e.g. the amplitude) to the other one (e.g. the phase). Squeezing can be interpreted as ordering the photons inside the beam.

In recent years, the advent of efficient four-wave mixing in atomic vapours [1] has made it possible to manipulate the quantum fluctuations not only in the temporal dimension but also in the spatial dimensions. A striking realisation has been the production of “entangled images” [2], that is to say beams of light which are entangled "point per point" across their transverse profiles. It has also been possible to transversally order the photons inside the beam, effectively reducing the "quantum roughness" of the beam profile [3].

The introduction of the spatial degrees of freedom in quantum optics lets us envision novel applications for quantum light, for example multichannel quantum information, quantum sensing protocols, and quantum imaging applications. In addition, the emitted quantum light is naturally (near) resonant with an atomic transition and is therefore well suited for applications based on atom-light interaction, for instance atom magnetometers.

After reviewing the fundamentals of squeezed light generation by four-wave mixing in hot atomic vapours, I will show how the spatial properties of such quantum light are well suited to the measurement of the displacement of a laser beam with sensitivity beyond the shot-noise limit. This may bring the advantages of quantum measurement to robust quantum devices based on MEMS [4], such as atomic force microscopes.

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Energy losses and transition radiation produced by the interaction of fast charged particles with two-dimensional materials

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Interactions of graphene and other two-dimensional (2D) materials with externally moving charged particles have been studied in recent years in the context of Electron Energy Loss Spectroscopy in Scanning Transmission Electron Microscope, which has become a very popular experimental technique for exploring the excitation of plasmons in graphene over a broad range of frequencies. On the other hand, the technological need for a stable and tunable source of terahertz (THz) radiation has prompted several recent studies of the electromagnetic radiation from graphene, induced by its interaction with fast electron beams.

We have recently developed a fully relativistic theory of energy losses for a fast charged particle traversing single-layer graphene [1, 2] and multi-layer graphene (MLG) [3–5]. It was shown that the total energy loss of the external particle consists of two components: the energy absorbed by graphene layers in the form of electronic excitations (Ohmic losses), which include the excitation of Dirac plasmon polaritons (DPP), and the energy that is emitted in the far field as transition radiation (TR). The dynamic response of graphene was described by means of a 2D conductivity function, which was modeled using *ab initio* calculations [6] or empirical models [7].

We have studied the effects of varying the charged particle energy and angle of incidence [1, 2], as well as the effects of hybridization between the DPPs in different graphene layers within MLG structures [3-5], in both the Ohmic energy loss distributions and in the angular spectra of TR. In the THz range of energy losses, we have observed intriguing asymmetry with respect to the direction of the incident particle in both the Ohmic losses and the TR spectra from MLG.

In recent work, we have applied our methodology to phosphorene, a single layer of black phosphorus, which exhibits strongly anisotropic optical properties. Describing this anisotropy by a 2D conductivity tensor, we have explored the possibility of directional excitation of the hyperbolic plasmon polaritons in phosphorene, which may arise in the infrared frequency range, by using incident charged particles under oblique angles of incidence upon phosphorene.

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Constant-Intensity Waves in Non-Hermitian Media

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In the framework of non-Hermitian photonics and parity-time (PT) symmetric optics, we will examine a generalization of the concept of plane waves that is possible only in media that have complex index of refraction. Such waves have constant intensity all over the space (CI-waves) and a phase that is directly related to the real and imaginary part of the corresponding non-Hermitian potential. Such waves exist for linear and nonlinear-guided systems in the paraxial regime [1,2,3] as well as, in scattering structures [4,5,6].

The main part of the talk will be thus devoted to the unique properties of CI-waves in nonlinear waveguides [1,2,3], in strongly scattering optical [4], and acoustic [5] non-Hermitian media. New results related to unidirectional invisibility [6] and the existence of CI-waves in two-dimensional scattering media will be presented.

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Mirrorless lasing for remote magnetometry

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The interaction of resonant laser light with atomic vapor is at the heart of one of the most sensitive methods to measure magnetic fields. Alkali-based magnetometers are used in a wide range of applications from biomagnetic measurements to material science. Since initialization and read-out of the resulting atomic spin evolution can be performed optically and therefore contactless, this method offers a unique way of measuring magnetic fields remotely.

Most recently, this technique was used to measure the local magnetic field in the mesosphere [1]. At 85 to 100 km above the earth surface the atmosphere contains some amount of atomic sodium. Shining a resonant laser beam into this layer causes the sodium atoms to emit fluorescence, which can be observed with ground-based telescopes. Astronomers use this light as a reference to sample and compensate the effects of atmospheric turbulence in astronomical observations. In addition, if the laser beam is intensity modulated at a frequency around the local Larmor precession frequency of sodium in the atmosphere, an increase in fluorescence can be observed. The resultant magnetic resonance can be used to infer the strength of the magnetic field.

Fundamentally, the sensitivity of this method depends on the amount of collected photons. For isotropic fluorescence the number of collected photons scales with the solid angle subtended by the receiver. For a 1 m^2 aperture telescope in 90 km distance from the emitting layer the fraction of collected photons is on the order of 10^{-11}. The possibilities of generating directional light emission from the sodium layer [2, 3] could considerably boost the sensitivity of atmospheric magnetometry and enable interesting new applications, like real-time mapping and monitoring of Earth magnetic field in the mesosphere over a wide area.

I will give an overview of the rapidly developing field of remote magnetometry and discuss recent developments by our group and collaborators.

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Superradiant THz Radiation: Sources and Applications

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Control of materials properties by means of high-field THz pulses is an emerging field in ultra-fast science. When the field is tuned in resonance with a chosen low energy excitation, such as a vibrational mode or a magnon, nonthermal nonequilibrium states in the electronic ground state can be prepared and their evolution probed on ultra-fast timescales [1,2]. The electric or magnetic field component of the THz wave can furthermore directly interact with collective phenomena such as free carriers or ensembles of molecules and enable coherent control on sub THz cycle timescales.

Superradiant THz facilities such as the TELBE facility recently emerged as intense, high repetition-rate sources of ideally suited THz light pulses. The TELBE user facility [3] provides tunable narrow-band, multicycle pulses as well as single-cycle pulses with fields beyond 100 kV/cm at unprecedented repetition rates in the few 100 kHz regime and thereby enables to either (i) perform common experiments with superior signal quality, (ii) employ new duty-cycle hungry probe techniques such as time-resolved angle-resolved photoelectron spectroscopy (TR ARPES) and time-resolved scanning nearfield optical microscopy (TR SNOM) or make use of the high repetition rate to perform groundbreaking experiments in complex sample environments such as liquid jets and (pulsed) high-field magnets. The potential of superradiant THz sources is discussed based on recent experiments studying THz control of magnetic properties [4], polar liquids or Dirac electrons in e.g. Graphene [5].

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Mid-infrared silicon photonics for sensing and communications

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Mid-infrared (MIR) silicon photonics has seen rapid development in recent years amidst interest in developing integrated photonic systems that could be used for applications in sensing and communications. In particular there is a focus on mid-infrared absorption spectroscopy, since many gases, chemicals, and biological molecules exhibit strong and unique absorption features in this part of the electromagnetic spectrum (approximately 2-16 μm). Silicon photonics is offering an opportunity to create fully integrated MIR sensing systems on silicon chips, which can benefit from existing silicon manufacturing infrastructure so that sensor chips can be fabricated at low cost in high volumes.

To achieve this low loss waveguide platforms must be developed that span the MIR, and passive components, light sources, modulators, and photodetectors must be developed. This talk will present our group's work on developing new waveguides (e.g. suspended silicon [1], germanium-on-silicon, suspended germanium [2]), modulators, and detectors [3–5] for wavelengths between 2 μm and 8 μm, and will show some preliminary waveguide based sensing experiments.

A second topic of interest for mid-infrared photonics is the development of transceivers for the 2 μm wavelength band, which is being investigated to open up a new communications window that may be needed to alleviate the forthcoming "capacity crunch" in fibre communications. Our work on developing 20 Gbit/s silicon modulators for the 2 μm wavelength [6] will also be discussed.

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Progress Reports

Dynamic Stark shift and multiphoton ionization of sodium by femtosecond laser pulses

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We study the excitation and multiphoton ionization of sodium induced by strong femtosecond laser pulses [1,2]. The resonant dynamic Stark shift (RDSS) of energy levels and momentum distributions of photoelectrons are determined, both using a wave-packet propagation method. This method is used to determine an RDSS data set for transitions 3s → nl ($n \leq 6$) in sodium induced by the laser pulse with the peak intensities up to 7.9×10^{12} W/cm^2 and wavelengths in the range from 455.6 to 1139 nm. The data is applied to analyze the photoelectron spectra (electron yield versus excess energy) of the sodium atom interacting with an 800 nm laser radiation. The momentum distributions of photoelectrons are determined from the calculated electrons' outgoing wave by applying a Fourier transform, and energy spectra are extracted from them. Substructures observed in the recent experimentally measured spectra [3] are successfully reproduced and related to the resonantly enhanced multiphoton ionization (REMPI) via specific (P and F) intermediate states.

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Semiconductor optical amplifiers: modeling and analysis for optical access networks

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The continuous upgrade of the existing communication network infrastructure to support novel advanced broadband services led to penetration of optical technologies to the access layer striving to reach the end-user. To implement a resilient and future-proof network, solutions that support high throughput at high data rates in an energy-efficient and low-cost manner are required. It has been recognized that passive optical networks (PONs) are an excellent candidate for the access layer due to service transparency, energy-efficiency, acceptable cost and high security [1]. On the road towards next generation stage 2 PON (NG-PON2), numerous solutions are proposed, of which vast majority relies on semiconductor optical amplifiers (SOAs), especially, reflective SOAs (RSOAs) implemented in optical network units (ONUs) at user premises [1]. The dynamics of their operation offers multiple operating regimes, both linear and nonlinear, resulting in attractive devices that have a well-established production process and are easy to integrate [2]. Finally, the ability to operate SOAs in any of the O-, S- or C-band, makes them compatible with widely adopted wavelength-division multiplexed PONs (WDM-PONs), together with hybrid wireless/wired Radio-over-Fiber (RoF) networks [3, 4].

To maximize the benefits offered by SOA, both design- and usage-wise, it is necessary to understand the interrelation of its performance metrics parameters, both in steady-state and dynamic regime, and its material, geometrical, and operational parameters. The model proposed in this manuscript is built using a bottom up abstraction approach from detailed material and geometrical parameter dependencies on photon energy and carrier density, and accounts many commonly overlooked effects influencing SOAs performance: nonlinear gain suppression, residual reflectivity of facets, phase modulation, distributed model of modulation current etc. [2] Using the proposed model and its variations depending on the simulation needs, we confirm that commonly introduced approximations are valid only in limited ranges of input optical powers, bias currents and active region lengths. We analyze spectral properties of the SOA output, its steady-state gain vs. input power and bias current characteristic, as well as –3dB small signal bandwidth. We discuss the E/O (re)modulation performance of traveling-wave (TW-) and RSOA at different down- and upstream bitrates for both RZ/NRZ modulation formats. Finally, we present a novel solution for colorless multilevel signal transmitter using two RSOAs with orthogonal optical signals, able to generate 4-QAM optical signal [5].

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Circular dichroism in twisted resonator based chiral metamaterial

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An object is chiral if it cannot be overlapped with its mirror image. One of the manifestations of chirality in optics are chiral metamaterials, responsible for the appearance of optical activity and circular dichroism. These effects originate from polarization rotation which occurs because waves of the opposite handedness propagate with unequal phases and absorption rates through this kind of material [1].

Circular dichroism has an important role in applications of chiral metamaterials related to manipulation of circularly polarized waves. Nowadays, there is a need for development of devices relevant for terahertz and infrared technologies, in particular for spectroscopy, imaging and communications. Numerous designs of chiral resonant elements have been proposed until now, providing components for terahertz wave modulation, switching and sensing [2-4]. Similarly, chiral structures can enhance infrared signal of chiral molecules which enables detection of enantiomers of these molecules by measuring circular dichroism.

In this study, we performed numerical simulations of terahertz wave propagation through chiral metamaterial composed of twisted closed ring resonators [5]. In the absorption spectra, three resonances were distinguished as a result of the existence of electric dipoles and quadrupoles. By this design of resonator, high values of circular dichroism as well as strong local electric field enhancement are obtained. The most significant results are seen at first resonant frequency which appears as a consequence of the gap provided by twisting the ring resonator. Furthermore, we extended our research to infrared range by scaling the chiral resonator dimensions. Values of circular dichroism within this frequency range indicate different performance capabilities when comparing to the terahertz case. In addition, we examined the influence of losses in metal and dielectric on this quantity for both frequency ranges.

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Optical properties and visible-light photocatalytic response of TiO_2 thin films deposited by PVD methods

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Titanium-dioxide (TiO_2) is one of the most used semiconductors in several technological applications due to its high corrosion resistance, photocatalytic activity, long-term stability, non-toxicity and wide band gap [1, 2]. For obtaining TiO_2 thin films, physical vapor deposition (PVD) methods have some advantages over chemical ones, such as: formation of homogenous and uniform layers on larger surface areas, better control of structural properties during deposition, simplification of photocatalytic usage in comparison to nano-particles etc.

Investigation on structural and optical properties of TiO_2 thin layers deposited by three different PVD methods is presented here. Methods that were used for production of thin films are: e-beam assisted evaporation, RF reactive sputtering and ion sputtering. The aim was to compare these three methods and to define conditions for producing thin layers with optical characteristics that are desirable for photocatalytic purposes in visible light region. Besides monitoring the impact of deposition parameters during synthesis of TiO_2 thin films, effects of different annealing conditions were investigated, roles of the oxygen and titanium vacancy places in the crystal lattice, effects of nitrogen doping and role of the nitrogen incorporation sites in crystal lattice on optical and photocatalytic properties were studied.

Structural and optical characterization of TiO_2 and N-doped TiO_2 thin layers deposited by ion sputtering of Ti target in oxygen/nitrogen atmosphere showed that thin layers deposited by this method were the most suitable candidates for photocatalysis in visible light region. Photocatalytic decomposition of Rhodamine-B, organic dye which simulates pollutant, under visible light irradiation source showed that concentration of substitutional nitrogen in TiO_2 crystal lattice has significant impact on photocatalytic efficiency.

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Propagation of single and multi-photon states in integrated laser-written waveguide networks

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Understanding how light propagates in a guided structure, such as an optical waveguide, and how its properties can be manipulated is crucial for development of new light-based technologies, both in the classical and quantum regime. In last decades, areas like quantum information [1] and quantum simulation [2] have had a great impact due to development of quantum sources, integrated circuits and detections systems, making these areas more realistic from an experimental point of view. Ultimately, all these advances in quantum technologies could be determinant in the fabrication of a possible quantum computer, which promises to outperform a classical computer in several tasks like, for example, searching database [1]. To this date, however, none of the available quantum technologies have proven to be a complete and purely quantum platform, as they execute small and simple tasks which can be performed by a classical computer in a more efficient way. Nevertheless, such technologies could be the building blocks of a future genuine quantum platform. To this end we can find different technologies such as ultracold atoms [3], trapped ions [4] and photons [5]. Photons offer significant advantages such as low decoherence, high speed transmission and the possibility to encode information in several degrees of freedom, such as polarization, path or time.

One way to control and manipulate photons is by using integrated photonic waveguides [5], which provides high stability, low noise and small size, making the integrated photonic waveguides a very controllable platform, allowing to study not only the dynamics of photons but it opens also the possibility to study other quantum systems as well through quantum simulations. In order to fabricate this integrated structure with waveguides inside, one possibility is using the femtosecond laser writing technique [6, 7]. This technique has the advantage of creating 3D structures where the waveguides are not forced to stay in the same plane. Using this technique we studied and simulated the dynamics of a quantum system coupled to a fluctuating environment. Under some assumptions the system can be understood as a reduced open quantum system with the presence of decoherence, which can be investigated using photons propagating in waveguide arrays, where the propagation constant is changing along the propagation distance. Experiments using single and multi-photon states were performed and results how the indistinguishability of photons affect the quantum coherence are presented [8].

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Investigations of the application of inorganic substrates based on TiO_2 nanocrystals for the detection and quantification of small molecules with SALDI TOF mass spectrometry

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MALDI TOF (Matrix-Assisted Laser Desorption and Ionization Time-Of-Flight) mass spectrometry is soft ionization technique. In order to prevent/reduce fragmentation of analyzed molecules, induced with direct excitation with laser, samples are mixed with matrix molecules. Matrix has high absorption coefficient in the range of the laser emission. In spite of numerous advantages, there are serious drawbacks of the matrices, especially for the analysis of molecules with low molecular mass (above 1000 Da). In this group of molecules there are various biologically active molecules, so there is a great need to overcome disadvantages of the application of organic matrices. Several alternative approaches have been developed: an organic-matrix-free approach in which the substrates, usually nanoparticles act as a matrix.
The term SALDI (Surface-Assisted Laser Desorption and Ionization) was coined to designate the techniques that use nanostructured substrates. Nanoparticles absorb the laser energy and then rapidly transfer to analyzed molecule. Titanium (IV)-oxide (TiO_2) is considered to be a good candidate for SALDI substrate since it is readily available, chemically stable, non-toxic and inexpensive material. TiO_2 is a semiconductor with high absorptivity of UV light of nitrogen laser (have a large band gap 3.2 eV) which is used in MALDI TOF mass spectrometry, but the method of synthesis of TiO_2 nanocrystal have a great impact on absorption because this phenomenon depends on size, shape and composition of nanoparticles.
The applicability of TiO_2 nanocrystals of different size and shape was tested. Colloidal TiO_2 nanoparticles, TiO_2 prolate nanospheroids and TiO_2 nanotubes were used as substrates for potential SALDI TOF MS quantitative analysis of biologically active molecules with small molecule mass.
First step to test efficiency of TiO_2 nanocrystal for the mass spectrometry analysis of small molecules was to examine their qualitative characteristics as substrates. It is shown that they have high tolerance to increased concentration on inorganic salts and to high laser intensity. Next step was to examine qualitative characteristics of TiO_2 nanocrystals substrates for mass spectrometric analysis based on following parameters: the homogeneity of the distribution of analyte over substrate surface in SALDI approach define reproducibility and accuracy of the measurement, within day precision to compare the accuracy of measurements with respect to signal intensity and potential use of tested systems for quantitative analysis, and day-to-day reproducibility. Based on all results, the great potential of TiO_2 nanocrystals (especially for the TiO_2 prolate nanospheroids) for the quantitative and qualitative analysis of biologicaly relevant small molecules (Mm less than 1000 Da) was demonstrated. [1-4]

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Development of photo-sensitive nanocomposite system for controlled metallo-drug delivery in skin cancer therapy

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There has been a growing demand for development and improvement of cancer treatment in order to overcome disadvantages and limitations of traditional chemotherapy such as resistance, toxicity, and activity against a small number of tumor types. Photodynamic therapy is a rapidly developing cancer treatment that utilizes the combination of photoactive drug and/or carrier and light as an external stimulus to destroy tumors, achieve a maximum concentration of the drug on tumor site, reduce side effects of drug onto the healthy tissue, enable dosage control, and more effective treatment which could improve outcome of therapy [1].

We investigated possibility to use TiO_2 nanoparticles as a carrier for potential antitumor drug [Ru(II)(dcbpy)$_2$Cl$_2$], *cis*-dichlorobis (2, 2'-bipyridyl-4, 4'-dicarboxylicacid) ruthenium(II). Nanocomposite system has been formed by binding of ruthenium complex to the TiO_2 nanoparticles. Components of the system are selected according to their preferences, such as biocompatibility, photo activity, and easy surface modification for TiO_2, and less toxicity, significant activity against cancer metastases, and activity on tumors that were resistant to a variety of standard chemotherapeutic agents for Ru-complexes. Both components of the system are also photoactive, therefore potential for system manipulation and use in photodinamic therapy has been investigated by irradiation with UV and visible light. Additionally, the feasibility of using this system as a light-triggered drug delivery system was shown on amelanotic melanoma cancer line.

The experimental results revealed a potential of nanocomposite system for long-term constant release of complex which is suitable for clinical practice. The further investigation of nanocomposite system indicated that it exhibited UV and red light susceptible drug release behavior [2]. More precisely, the system demonstrated slower complex release upon visible and increased release rate upon UV light illumination which was also in good correlation with the light–dependent cytotoxicity of the system demonstrated on amelanotic melanoma cancer line. The melanoma cancer cell death is enhanced by UV and reduced by red light in the presence of investigated nanocomposite system [3]. All obtained results suggested that nanocomposite system may have a potential use as a light sensitive drug delivery system in photodynamic therapy which could significantly contribute to development of more efficient and less invasive therapy of melanoma which is highly aggressive and deadliest form of skin cancer.

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Lattice dynamics of iron-based superconductors and related compounds

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The lecture focuses on vibrational properties of some unconventional iron-based superconductors and related compounds by means of Raman spectroscopy. In the measured phonon spectra of superconducting $K_xFe_{2-y}Se_2$ and nonsuperconducting $K_{0.8}Fe_{1.8}Co_{0.2}Se_2$ single crystals there are phonon modes originating from metallic/superconducting *I4/mmm* phase and insulating *I4/m* phase with ordered Fe vacancies. Temperature analysis of energy and linewidth of the vibrational modes were done using the model which takes into account lattice thermal expansion and anharmonic effects. The modes originating from the *I4/m* phase are well described by that model. On the other hand, A_{1g} mode energy in the superconducting sample exhibits sudden jump, which was ascribed to the change in the electronic structure when entering the superconducting state. By investigating Raman spectra of $K_xFe_{2-y}Se_2$ single crystals doped with various Co concentrations, the evolution of phase separation was followed. With increasing cobalt content phonon modes from the *I4/m* phase disappear and in Raman spectra remain only two phonon modes originating from the high symmetry *I4/mmm* phase. Broad asymmetric structure in the samples with intermediate Co concentrations was interpreted as a fingerprint of strong crystalline disorder. The presence of only two phonon modes in the end member of this sequence - $K_xCo_{2-y}Se_2$ - excludes the possibility of ordered vacancies. Measured Raman spectra show that ferromagnetic phase transition around 74 K in this single crystal has significant impact on phonon mode behavior. Namely, above the ferromagnetic transition, temperature dependence of phonon energy and linewidth looks conventional. On the other hand, below critical temperature both modes exhibit sudden hardening, A_{1g} mode narrows and B_{1g} one significantly broadens, which is ascribed to the spin-phonon and electron-phonon interaction. Large linewidth of the Raman modes originates from the electron-phonon coupling enhanced by the crystal disorder and spin fluctuation effects.

Development and comparison of the techniques for solving the inverse problem in photoacoustics

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In this work, theory- based simulation models are derived for the photoacoustic (PA) frequency response of both volume and surface optically absorbing samples in a minimum volume PA cell. In the derivation process, thermal memory influence of both the sample and the air of the gas column are accounted for, as well as the influence of the measurement chain.

Within the analysis of the TMS model, the influence of optical, thermal and elastic properties of the sample was investigated, and consequently, two methods are developed for TMS model parameter determination. The first one, a self consistent numerical procedure for solving the exponential problems of mathematical physics, based on regression, is also implemented on experimental measurements, done on macromolecule samples, and the results are presented and discussed. The second one, a well trained three-layer perceptron with back propagation, based upon theory of neural networks, is developed and presented as the proof of concept.

Finally, as part of the extended investigation, these two inverse problem solving concepts are applied, compared and discussed in the domain of polymer sample characterization, and then repeated and proven on semiconductor samples.

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Exploring possibilities of regular self-pulsing in monolithic and external cavity mid-IR QCLs

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Mid-IR Quantum cascade lasers (QCLs), at a low pump excess above threshold [1], show features of Risken-Nummedal-Graham-Haken (RNGH) instabilities [2,3] related to the excitation of coherent Rabi oscillations in the gain medium and therefore might exhibit self-pulsations (SP). The difficulties for practical use of RNGH SP in monolithic mm long QCLs originate from the quasiperiodic chaotic behavior of the pulse train when the coherence length is smaller than the length of the sample, while in the monolithic short cavity (100 μm) QCLs very high pulse repetition rate prohibit practical applications [4-6].

Nevertheless, it was demonstrated both theoretically and experimentally that a QCL in an external Fabry-Pérot cavity (EC) is capable of producing regular self-pulsations of the output intensity at frequencies of approximately 75 GHz [7]. The propagation delay in EC provides QCL with a "memory" mechanism to preserve the regularity and coherence of the pulse train on the time intervals which significantly exceed the sub-picosecond gain coherence and gain recovery times. Our results may point to novel practical approaches to produce regular time-domain SPs and pulse trains in the Mid-IR QCLs.

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Bioimaging of liver cancer cells incubated with partially reduced graphene oxide

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Functional materials based on graphene oxide (GO) and reduced graphene oxide (rGO) have a high potential for application in the fields of biophysics, material science, and biomedical engineering [1]. It is due to their tunable physical properties, high surface area, remarkable photoluminescence, as well as their controllable chemical functionalization [2]. Beyond their applications in nanomedicine for drug/gene delivery, phototherapy and bioimaging, they have shown significant interaction and adhesive properties with proteins, mammalian cells and microorganisms, which makes them potential candidates for multifunctional biological applications. In this lecture, we will present a study of the interaction of partially reduced graphene oxide (prGO) with Huh7.5.1 liver cancer cells. The study was conducted by means of synchrotron excitation DUV fluorescence bioimaging (performed on DISCO beamline of synchrotron SOLEIL) [3]. The prGO sample was obtained by the reduction (to a certain extent) of the initially prepared GO nanosheets. The fluorescence of the GO nanosheets increases with time of the reduction due to a change in the ratio of the sp^2 and sp^3 carbon sites, and the prGO sample was extracted from the dispersion when the intensity of the fluorescence reached its maximum. After that, Huh7.5.1 cells were incubated with GO, prGO and rGO nanosheets and used in bioimaging studies. The presence of graphene materials influenced the fluorescence properties of the cells, and by analyzing fluorescence photobleaching dynamics, we were able to localize graphene nanosheets inside the liver cancer cells.

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Mechanisms and time scales of free-charge generation in organic photovoltaics: hot and fast or cold and slow

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The physical mechanisms and time scales of light-to-charge conversion in photoexcited donor/acceptor organic solar cells have recently been heavily debated. The interpretation of experimental signals stemming from ultrafast spectroscopic experiments suggests that free-charge generation mainly occurs on a subpicosecond time scale following the excitation by virtue of high-energy ("hot") delocalized interfacial charge transfer (CT) states [1]. On the other hand, there is experimental evidence that free carriers are predominantly generated on time scales ranging from tens to hundreds of picoseconds out of the lowest-energy ("cold") CT state, which is strongly bound and localized [2, 3].

We study charge separation in a one-dimensional model of an interface between two organic semiconductors, both on ultrashort and on much longer time scales. We obtain that free charges present on a subpicosecond time scale following the photoexcitation are mainly directly optically generated from the ground state thanks to the resonant mixing between states of donor excitons and free charges [4]. However, on the same time scale, we find that the majority of photogenerated charges still remain bound in form of donor or CT excitons [5]. We obtain that their further separation on longer time scales is weakly electric field- and temperature-dependent and is enabled by the synergy between carrier delocalization and moderate disorder [6].

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Machine Learning with Photonics Symposium
ML-Photonica2019 - Invited Lectures

Greedy Boolean learning in large photonic neural networks

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We have recently succeeded in the implementation of a large scale recurrent photonic neural network hosting up to 2025 photonic neurons. All network internal and readout connections are physically implemented with fully parallel technology. Based on a digital micro-mirror array, we can train the Boolean readout weights using a greedy evolutionary algorithm. We find that the learning excellently converges. Furthermore, it appears to possess a conveniently convex-like cost-function and demonstrates exceptional scalability of the learning effort with system size.

Nonparametric Bayesian methods for networks

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For most of the Bayesian methods data is represented by exchangeable sequences of observations. An infinite exchangeable sequence is strictly stationary and, therefore, a law of large numbers in the form of Birkhoff–Khinchin theorem applies. The close relationship between exchangeable sequences of random variables and the i.i.d. will be described as well as its connection to Bruno de Finetti's development of predictive inference and to Bayesian statistics. Example models will be reviewed; applications of such models include collaborative filtering, link prediction, and graph and network analysis.

Machine learning for photonics

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Machine learning is a colloquial term that encompasses a collection of data-driven methods of various types aimed at understanding, inferring and optimising systems. This includes inferring the state of individual system variables, the interaction strengths between them and the system's characteristic phases. The recent excitement around engineering successes of machine learning led to their application in tackling fundamental questions in various aspects of photonics, especially the interpretation and inference of experimental data. These successes suggest that machine learning techniques may become a standard tool in physics [1] and photonics [2] research. In this talk I will review existing machine learning techniques and motivate the use of principled probabilistic approaches, while explaining recent high-profile heuristics and their limitations. Additionally, I will talk about specific photonics application that could benefit from the use of machine learning techniques.

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Matrix versus Machine Learning for transmitting images through multimode fibers

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Direct image transmission in multimode fibers (MMFs) is hampered by modal scrambling inside the fiber due to the multimodal nature of the medium. To undo modal scrambling, approaches that either use interferometry to construct a transmission matrix or iterative adaptive optics to form an output spot on the camera have been proposed and implemented successfully. The Matrix method is a calibration that consists of measuring experimentally the phase and amplitude of the light at the output of the fiber, by interferometry, for a number of orthogonal patterns approximately equal to the number of modes of the fiber. By inverting the matrix, the complex field at the input is computed that gives the desired intensity pattern at the output of the fiber. In this way, the MMF behaves as a projector.

For a practical implementation, an intensity detection rather than interferometric detection is preferred during the calibration phase. The tradeoff for the simpler detection scheme is to solve a non-linear inverse problem. I will show recent results on using Artificial neural networks to approximate the non-linear mapping between the input and output of the fiber and discuss the pros and cons of machine learning versus a matrix approach.

Fast Compressive Raman Bio-imaging

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Raman imaging is recognized as a powerful label-free approach to provide contrasts based on chemical selectivity. In particular, various examples have shown the potential of using Raman-based microspectroscopy for biomedical applications, such as in cancer and bacteria detection and imaging. Nevertheless, Raman-based microspectroscopy still have several drawbacks related to its 3D hyperspectral data format that will soon be bottlenecks when pushing this technology to clinical and industrial scenarios. The first issue is related to data acquisition: the inherent high data throughput in Raman microspectroscopy poses challenges for dynamic and large-scale specimens imaging, together with its subsequent data storage. The second issue is related to the slow data workflow methodology necessary to present the vibrational spectroscopy images to non-specialists: the large data sets need post-processing to allow for a useful presentation, for instance, by showing the local proportions of chemical components (or endmembers) rather than peak amplitudes of spectra.

Compressive sensing has shown a paradigm shift approach where one can obtain accurate information from fewer samples than assumed by Nyquist-Shannon sampling theorem. A key concept in compressive sensing is to recognize that data sparsity can be exploited to computationally reconstruct data that has been undersampled. Such approach opens interesting perspectives not only to compress data sets during its acquisition, but also to concomitantly speed up the imaging process as less data is needed to obtain useful information.

In this contribution, I will introduce the concept of compressive Raman imaging: by exploiting the sparsity [1, 2] and redundancy [3] in Raman data sets, one can considerably simplify and speed up the spectral image acquisition. I will discuss the different ways of performing compressive Raman, in particular focusing on challenges for bio-imaging, and how we recently tackled them. With these outcomes, compressive Raman imaging soon may be routinely used by non-specialists of vibrational spectroscopy: that is, in a "blind" manner, due to the simpler workflow provided by the compressive Raman imaging framework.

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Defibrillation outcome prediction as a potential guide to resuscitation

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Ventricular fibrillation (VF) represents the most frequent initial rhythm in out-of-hospital cardiac arrest (OHCA). It is characterized by rapid and disorganized contraction of the heart muscle cells which can lead to a sudden cardiac death. Optimizing defibrillation strategy (immediate defibrillation versus cardiopulmonary resuscitation) by evaluating the probability of the successful outcome could significantly enhance resuscitation.

Over the past few decades, different classification strategies were applied to predict the defibrillation outcome of OHCA patients, but none have achieved superior performance to be widely accepted and implemented in automated external defibrillators. All these reported strategies utilized conventional machine learning (ML) approach with feature engineering. Here, we compare the performances of 7 ML algorithms (Logistic Regression (LR), Naïve Bayes (NB), Decision tree (C4.5), AdaBoost M1(AB), Support Vector Machine (SVM), k Nearest Neighbour (kNN) and Random Forest (RF)) [1] with a novel approach based on convolutional neural networks (CNN). For conventional ML approach we engineered 28 "hand-crafted" features using time domain, frequency domain, time-frequency domain and non-linear dynamical analysis of the 4s pre-shock VF signal. The best performing feature combination was chosen using the wrapper feature selection method, which utilizes the classifier in evaluating selected feature subset. In deep learning approach, the CNN was capable of learning useful features from the raw VF signals. We used 3-stage CNN feature extractor, which contained convolution, rectified linear unit activation, dropout (only in training) and max-pooling and 2 layer perceptron for classification.

Our results show that the SVM, kNN and RF outperformed other conventional ML algorithms. The mean accuracy obtained over 10 fold cross-validation of these 3 ML algorithms were: 81.5%, 81.8 % and 82.8 %, respectively. On the other hand deep learning approach demonstrated the superiority over the conventional ML approach with engineered features. Obtained averaged accuracy of 93.6 %, along with sensitivity of 98.8 % and specificity of 88.2 %, which satisfy the condition of at least 50 % specificity at 95 % sensitivity for being considered safe, indicate that the proposed CNN model can be considered as a safe and useful predictor for defibrillation decision.

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Machine learning in photonic communication systems

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Recently, there has been an increasing amount of research focused on the application of machine learning techniques to optical communication and photonics. These applications have varied from component characterization, ultra-sensitive optical phase detection, performance prediction and system optimization, and more recently, within the field of quantum communication and optical fibre sensing. In this talk, a brief overview of the application of machine learning in optical communication and optical temperature sensing will be given. It will also be demonstrated that techniques from machine learning can enable optical phase tracking at the quantum limit which is beneficial for characterization of ultra-low phase noise lasers and frequency combs. Finally, it will demonstrated that deep neural networks are very effective in designing optical fibre amplifiers for the next generation of ultra-wide band optical systems

Pre- and post-transmission digital signal processing using neural networks applied to fiber-optic communication systems relying on power modulation and power detection: Advantages and drawbacks

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Fiber-optic communication systems relying on power modulation and power detection are the least expensive systems for communication through optical fibers. Moreover, when using basic 2-level High-Low power format over very short distances, they are simple systems exhibiting an almost linear power transfer function. Today, we are facing an urge to drastically increase the binary throughput of fiber-optic transceivers while maintaining the total cost of ownership to a bare minimum. Transceivers based on Power Modulation–Power Detection are perfect candidate to meet the price target. However, these systems become highly nonlinear and exhibit a very complex transfer function when operated at higher spectral efficiencies, higher signaling rate, and over the distances of interest.

In this presentation we explain the nonlinearities and complexity of transceivers relying on power modulation and detection. We detail the challenges for reliable communication through this type of channel when trying to deliver high bitrates over a few tens of kilometers.

We discuss the use of neural networks as digital pre-processors and post-equalizers to apply at the communications endpoints, serving to optimize the transmission directly at the bit-level. We present the multiple advantages as well as the numerous drawbacks of this technology when applied at the physical layer of communication systems.

Optimization and configuration of Programmable Photonics ICs

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Programmable Integrated Photonics is a recent area of research that aims to integrate a very-large scale of reconfigurable photonic resources to enable flexible and versatile photonic integrated circuits. In this paper we review the state of the art of general-purpose waveguide mesh arrangements with a special focus on those that allow the synthesis of optical feedback loops. In particular, we describe the necessary control schemes and propose a software framework and algorithms that allow the reconfiguration and optimization of software-defined photonic integrated circuits.

After the description of the algorithms, we apply them to configure a set of optical signal processing applications in the same photonic hardware structure. Particularly, we demonstrate their use for optical beamforming networks, delay lines, optical filters and an additional set of microwave photonic applications.

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Imaging with Scattered Light

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Random scattering of light in complex samples such as biological tissue renders most objects opaque to optical imaging techniques. However, although random, scattering is a deterministic process, and it can be undone, and also exploited by controlling the incident optical wavefront. These insights form the basis for the emerging field of optical wavefront-shaping [1]. Opening the path to new possibilities, such as imaging through visually opaque samples and around corners [2].

However, two major challenges exist in the field today: the first is how to determine the required wavefront correction without accessing the far (target) side of the scattering sample. The second is how to do it faster than the dynamics of the sample decorrelation time.
I will present some of our recent efforts in addressing these challenges [3-11]. These include the use of optical nonlinearities [3], the photoacoustic effect [4-6], and acousto-optics [7-8] to non-invasively focus light or perform imaging scattering samples, exploiting the dynamics of the sample instead of fighting them. I will also show how by exploiting inherent correlations of scattered light, it is possible to image through scattering layers and 'around corners' using nothing but a smartphone camera [9].

If time permits, I will present the use of these principles for endoscopic imaging through optical fibers [10-11].

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Ising Machines and Random Optical Networks by Tumor Spheroides

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We review our work on optical neural networks. We report on the realization of an all-optical Ising machine by spatial light modulation. We also report on the theory of random optical neural networks and a laboratory demonstration to study cancer morphodynamics in tumor spheroids.

Using machine learning to 'predict' extreme events in fiber-optics instabilities from single-shot spectral measurments

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The study of instabilities that drive extreme events is central to nonlinear science. Perhaps, the most canonical form of nonlinear instabilities is modulation instability (MI) describing the exponential growth of a weak perturbation on top of a continuous background. In optical fibres, when driven initially by small-amplitude noise, MI has been shown to lead to the emergence of localized temporal breathers with random statistics. It has also been suggested that these dynamics may be associated with the emergence of extreme events or rogue waves. However, direct measurement in the time-domain of the breather properties is extremely challenging, requiring complex time-lens systems that typically suffer from drastic experimental constraints. Real-time spectral measurement techniques such as the dispersive Fourier transform (DFT) on the other hand are commonly used to measure ultrafast instabilities. Although relatively simple to implement, the DFT only provides spectral information. Here, we show how machine learning can overcome this restriction to study time-domain properties of optical fibre modulation instability based only on spectral intensity measurements. Specifically, we demonstrate that it is possible to train a supervised neural network to correlate the spectral and temporal properties of modulation instability using numerical simulations, and then apply the trained neural network to the analysis of high dynamic range experimental MI spectra and yield the temporal probability distribution for the highest peaks in the instability field.

Mode-locked Fiber Laser Controlled by Machine Learning Algorithms

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One of the modern trends in development of mode-locked fiber lasers is a focus on precise adjustment of temporal and spectral properties of optical pulses at the expense of increasing complexity of system design. Complexity imposes extra requirements on control and feed-back systems design in terms of maintaining accuracy. s. In this context, machine learning (ML)-based approaches offer a nonlinearity-friendly, efficient and flexible alternative to the classical control techniques. First part of this talk describes a possibility to manage temporal and spectral parameters of pulses generated from fiber 8-figure laser. It will be demonstrated that self-tuning adjustment of the two independent gain levels in the laser cavity and application of various objective functions enabled pulse generation with parameters on-demand. Second part is devoted to a problem of implementation a feed-back system linking the laser performance and variable laser cavity parameters. Application of machine learning algorithms allows cutting down a number of necessary measurement equipment to get basic parameters of ultrashort pulses. Processing dispersive Fourier transformed pulse train is enough to determine spectral, temporal and coherence properties of the pulses by solving regression problem via artificial neural network or extremely randomized trees.

Greedy Boolean Learning in Photonic Recurrent Neural Networks

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We demonstrate the implementation of a large scale recurrent photonic neural network with up to 2025 photonic neurons. All network internal and readout connections are physically implemented with fully parallel photonic technology. Based on a digital micro-mirror array, we can train the Boolean readout weights using a greedy version of reinforcement learning paradigm. We find that the learning excellently converges. Furthermore, it appears to possess a conveniently convex-like cost-function and demonstrates exceptional scalability of the learning effort with system size.

Roadmap from Academia to IT industry

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After finishing the PhD, many former students are at the career crossroads - go to post-doc, stay at their current academic institution or make a transfer to industry. This talk will be about the latter for natural sciences PhD students - challenges, benefits, drawbacks and opportunities for transferring to a company after graduation. Due to the recent huge expansion of the IT industry's labor market, this talk will be focused on the opportunities in IT, but this maps to other industries as well (financial, medical, etc.) due to the similar technologies used.

ESUO Regional Workshop
Invited Lectures

CALIPSOplus – a gateway for research at light sources

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The Trans-national Access programme of the project CALIPSOplus (Convenient Access to Light Sources Open to Innovation, Science and to the World) provides supported access of European researchers to European and Middle Eastern light sources [1]. This project is funded by the European Commission within the EU Framework Programme for Research and Innovation H2020.

CALIPSOplus dedicates particular attention to leveraging scientific excellence across the EU and to widening the use of light sources throughout the region. A Twinning programme has been set up aiming at establishing and further developing new scientific communities, particularly from countries without own light source [2]. In the Twinning programme, potential users are partnered with host groups that share their know-how and expertise in applying the available experimental techniques to common research areas. Scientists new to research with synchrotron-based techniques have the opportunity to participate in a fully-financed hands-on introduction to the facilities.

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VUV Angle-resolved Photoelectron Spectroscopy on Isolated Hybrid Nanostructures

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Aerosol photoemission spectroscopy became an important method for studying electronic structure of submicrometer particles without the influence of substrate [1]. It comprises irradiation of the focused particle beam by either vacuum-ultraviolet (VUV) or soft x-ray radiation under high vacuum conditions and subsequent detection and discrimination of the photoelectrons according to their kinetic energies and momenta [2-4]. As intermediates between atoms or molecules and macroscopic matter, nanometer-sized objects exhibit specific electronic and transport properties that strongly depend on their size, morphology and surface chemistry. Modification of nanoparticle surfaces by conjugation with molecules presents a convenient method of altering a wide range of physicochemical characteristics of the nanomaterials, which does not require development of new synthetic procedures. Furthermore, by a proper choice of molecules used in surface modification, additional properties of the hybrid nanostructures can be achieved, which could not be found in the starting materials. In this lecture, we will present the selected results of our investigations on hybrid nanostructures comprised of noble metal and metal oxide nanomaterials functionalized by biologically relevant molecules. Particular attention will be given to the vacuum-ultraviolet angle-resolved photoelectron spectroscopy (VUV ARPES) studies on isolated functionalized nanosystems performed at the DESIRS beamline. The emergence of the photoelectron circular dichroism in hybrid nanoparticles will be briefly discussed.

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Synchrotron SAXS/WAXS on colloidal nanocrystals and supercrystals

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Colloidal nanocrystals (NCs) offer the opportunity for realising novel materials with tailored functionalities. By chemical synthesis, a large variety of semiconducting and metallic NCs can be realized [1] that can be used as efficient light emitters [1, 2] or in novel batteries designs [3].

Especially an inner core/shell structure of the semiconducting NCs leads to a significantly increased photoluminescence output. Here, not only the chemical and the crystalline core/shell profile, but also the NCs' shape determines their optical performance. This relation between structure and functionality we have revealed by combining different scattering techniques at several synchrotron sources with local sensitive microscopy techniques [2, 4].

The NC's shape can also significantly influence the super-crystal structure of colloidal supercrystals [1], where NCs act as building blocks to form 3D nanocrystal solids with designed properties. We have probed recently such a self-assembly with in-situ synchrotron SAXS using nearly monodisperse Bi NCs [5]. By combining synchrotron experiments with simulations, we are able to link the supercrystal structure via the NC-shape to the atomic Bi crystal structure.

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Photoionization spectroscopy and dynamics studies at the Gasphase Beamline @ Elettra

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The high photon intensity and resolution available at third generation synchrotron undulator beamlines is revealing fine details in the soft x-ray spectra of free species in the gas phase - particularly of small molecules. In addition, experimental developments - in particular those of coincidence techniques - permit insight in the important dissociation processes. The high sensitivity allows the extension of the range of targets – including atoms, molecules, radicals, vapors and clusters. Coincidence techniques give access not only to cations and electrons, but also to metastable, neutral and negative ion fragments.

The possibilities offered by different types of experiments will be discussed using results from recent studies. The examples include

- State-selected dissociative ionization of small organic and biologically important molecules in the valence and inner shell region [1, 2]. The results, together with calculations, can be used to disentangle the differences in fragmentation of similar molecules exposed to VUV radiation. In the core region correlations between the core-excited site and the preferential cleavage of specific bonds can be studied.

- Production of negative ions following core ionization of water and small organic molecules [3, 4]. Negative- and (multiple) positive-ion coincidence spectroscopy can be a sensitive probe of weak features in the decay and fragmentation channels of small molecules.

- Detection of neutral dissociation products - fluorescence and metastable states [5, 6] yields detailed information near inner shell ionization thresholds.

Further insights into the dynamics can be obtained from time-resolved experiments. In the range of ionizing radiation processes the application of synchrotron-laser experiments is a natural extension of the laboratory multi-color studies. Preliminary results of an ongoing study of the dissociation dynamics of the gas-phase dye molecules by time-resolved photoelectron spectroscopy will also be presented.

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Applications of synchrotron based spectroscopic techniques in biology

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Development of synchrotron radiation-based spectroscopy and microscopy techniques has opened new possibilities to study the structure and biochemical composition of organs, tissues, cells and biomolecules, which is critical for both basic and applied research [1].

In this talk X-ray absorption spectroscopy and micro-X-ray fluorescence microscopy, using synchrotron radiation at different European synchrotron radiation facilities [2] , will be presented as tools to reveal the mechanisms of metal uptake, accumulation and metabolism in food-chains to better understand metal toxicity and tolerance mechanisms, for the purpose of risk assessment and restoration of heavy metal polluted sites.

In addition, food quality and safety present an important aspect, connected to mineral malnutrition on one site and metal pollution on the other. Cerals as major staple food accumulate only low amounts of essential trace elements like Fe and Zn, while on the other hand they can contain elevated amounts of hazardous Cd. Designing high mineral nutrient and low hazardous element crops present a challenge for modern plant breeders. Synchrotron-based techniques can assist in revealing element accumulation and speciation patterns and help breeders to choose suitable crop genotypes.

The support by The European Synchrotron and FEL user organisation (ESUO) [3] and the project CALIPSOplus under Grant Agreement 730872 from the EU Framework Programme for Research and Innovation HORIZON 2020 for the XAS experiments, and he access to synchrotron radiation facilities of Elettra, PETRA III, ESRF, Alba and Soleil is acknowledged.

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The activities of the European Synchrotron and FEL User Organisation for even brighter European Photon Science

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The European Synchrotron and FEL User Organisation (ESUO) represents about 22 000 users of the European synchrotron radiation (SR) and Free-Electron Laser (FEL) facilities, which offer various kinds of experiments ranging from physics over life sciences up to cultural heritage. Established in 2010 [1], ESUO is composed of national delegates from 30 European member states and associated countries and is headed by an executive board of eight members [2].

The missions of ESUO are the following:

• To represent interests and needs of all SR and FEL users working in Europe

• To support facilities in their ambitions to create equal access opportunities for scientists, based solely on scientific merit, and to make this access as simple as possible

• To enable future strategies/funding schemes, to create equal (transnational) access opportunities for European scientists, independently of their financial resources

• To foster contacts with users in Widening and European neighboring countries, sharing knowledge/expertise

• To strengthen cooperation with National User Organisations

• To initiate collaborations / synergies with user organisations of other analytical facilities

In the past few years, ESUO has contributed to networking activities in the framework of successfully completed European FP7 projects such as ELISA (March 2009-August 2011) and CALIPSO (June 2012-May 2015). Today, ESUO continues advocating the interests of the users in the framework of networking activities that are part of the HORIZON 2020 project CALIPSOplus [3] (May 2017-April 2021, Grant Agreement No 730872). In this context, ESUO is involved in activities aiming at fostering the use of large-scale facilities by scientists from Eastern Europe and the Baltic countries, at promoting gender balance in the user community, and at facilitating the interaction between less experienced and established users. Amongst others, these activities will be presented in the proposed contribution. With the aim to contribute to shaping future research at European synchrotron and FEL user facilities, ESUO is cooperating with the League of European Accelerator-based Photon Sources (LEAPS) initiative [4].

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Application of GISAXS in analysis of nanostructured materials

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We demonstrate the application of GISAXS technique in investigation of three-dimensional lattices of nanostructures [1, 2]. The successful analysis of three-dimensionally ordered nanostructures demands application of suitable model for description of the nanostructure ordering. In opposite case, it is possible to get good agreement between the experimental and the simulated data, but the parameters obtained by fitting may be completely incorrect. In the lecture we examine systems having different types of nanostructure ordering, and we show how the choice of the correct model for the description of ordering influences the analysis results. We compare several theoretical models and show how to use GISAXS in investigation of self-assembled arrays of nanoparticles and also in arrays of nanostructures obtained by ion-beam treatment of thin films or surfaces. All theoretical models are supported by the experimental data, and the possibilities and limitations of GISAXS in determination of material structure are discussed. The free web-platform for analysis of GISAXS data *GisaxStudio* will be presented [3].

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Contributed papers

1. Quantum optics and ultracold systems
2. Nonlinear optics
3. Optical materials
4. Biophotonics
5. Devices and components
6. Optical communications
7. Laser spectroscopy and metrology
8. Ultrafast optical phenomena
9. Laser – material interaction
10. Optical metamaterials and plasmonics
11. Machine learning in photonics
12. Other topics in photonics

Generation of Multimode Squeezing in a Coupled Waveguide Array

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The second quantum revolution aims to take advantage of quantum resources in order to develop novel technologies, such as quantum computers, photonics circuits and high sensitivity metrology [1-3]. In the field of optics, a remarkable example of a quantum resource is the use of squeezed states, which recently made possible the detection of gravitational waves with enhanced sensitivity [4]. These are states of minimum uncertainty that have the property to squeeze the variance of one of the field quadratures at the expense of the increase of the other one [5]. Their potential applications have greatly increased, especially in the field of quantum metrology, where both single-mode and two mode-squeezed states have been used to enhance measurements sensitivity [4, 6]. Generation and manipulation of multimode squeezed states has promising applications in proposals for multiparameter quantum metrology, multi-channel communication and multi-channel quantum imaging [7, 8]. However, the generation of such states remains a challenge. Here we present a simple scheme that generates pure two-mode and three-mode squeezed states by injecting single-mode squeezed light into an array of coupled optical waveguides, achieving genuine bipartite and tripartite entanglement. Depending on the waveguides coupling parameters, we show that the generation of pure single-mode squeezing or pure three-modes squeezing at the output of the array is determined just by the input light polarization. We also explore the effect of losses in our system and show that quantum correlations and squeezing are preserved for realistic parameters. Our results show that arrays of optical waveguides are suitable platforms for generating multimode quantum light, which could lead to novel application in quantum metrology [9].

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Searching for quantum scars in constrained bosonic models

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Recent experiments on arrays of Rydberg atoms have shown that preparing a system in a certain initial state can lead to unusually slow thermalization and persistent density oscillations [1]. This type of non-ergodic behavior has been attributed to the existence of "quantum many-body scars", i.e., atypical, weakly-entangled eigenstates of the system that have high overlaps with a small subset of vectors in the Hilbert space. Periodic dynamics and many-body scars are believed to originate from a "hard" kinetic constraint: due to strong interactions, no two neighbouring atoms are both allowed to be in an excited Rydberg state. Here we investigate quantum many-body scars in a 1D bosonic lattice model with a "soft" constraint: there are no restrictions on the allowed boson states and the particles can hop freely, but the amplitude of a hop depends on the occupancy of the hopping site. We find that this model exhibits similar phenomenology to the Rydberg atom chain, including weakly entangled eigenstates at high energy densities and the presence of a large number of exact zero energy states, with distinct algebraic structure. We discuss the relation of this model to the standard Bose-Hubbard model and possible experimental realizations using ultracold atoms.

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Degenerate Fermi gases of polar molecules with tilted dipoles

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A recent experimental realization of an ultracold quantum degenerate gas of $^{40}K^{87}Rb$ molecules [1] opens up a new chapter in exploring strongly dipolar Fermi gases and many-body phenomena arising in that regime. This includes the deformation of the Fermi surface (FS) for polarized systems, where the electric dipoles have a preferential orientation, which can be achieved using an external field. Compared to atomic magnetic species [2, 3], this effect is significantly increased in ultracold Fermi gases of polar molecules, and the stability of the system is expected to strongly depend on its geometry. Here we generalize a previous Hartree-Fock mean-field theory [2] for the Wigner function, which now takes into account that the cloud shape in the ground state is determined not only by the trap frequencies, but also by the dipoles' orientation. In the special case of a spherically symmetric trap, the cloud is elongated in the direction of the dipoles, similar to the FS. We report here [4] a universal stability diagram for dipolar fermions and calculate the corresponding FS deformation for an arbitrary orientation of the dipoles, demonstrating the great promise for the exploration of quantum degenerate molecules in electric fields, where the strong dipole-dipole interaction dominates. These results are important for designing future experiments with polar molecules, as well as for the interpretation of measured data, including the dynamics and the time-of-flight expansion.

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Probing fractional Hall states in driven optical lattices

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Driven optical lattices enrich the set of quantum models that can be simulated in cold-atom experiments [1, 2]. General arguments suggest that the interplay of strong interactions and driving in a thermodynamically large system introduces heating, leading to a featureless infinite-temperature state in the long-time limit [3, 4]. Recently, several papers have focused on a possibility of prethermalization, arguing that some strongly correlated states can be probed on experimentally relevant timescales, before reaching the infinite-temperature limit [5, 6]. We investigate ways to prepare and probe fractional Hall states in a few-particle bosonic sample in a driven optical lattice.

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Exploring the Fermi-Hubbard model with a quantum gas microscope

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Ultracold fermions in optical lattices have emerged as a powerful tool in the quantum simulation of the Fermi-Hubbard model. With access to full density and spin resolution [1], our ^{6}Li quantum gas microscope has enabled the study of the interplay between spin and charge in doped antiferromagnets. In 1D, the phenomenon of spin-charge separation decouples the spin and charge degrees of freedom, creating holons and spinons. We probe this phenomenon by locally addressing an antiferromagnet to form holons and spinons and dynamically observing their propagation [2]. In 2D, the competition between the spin and charge degrees of freedom leads to the formation of a polaron. We identify the formation of such a polaron by looking at the dressed spins around a dopant [3].

To cool, trap and image the ^{6}Li atoms, we use six ECDL lasers at 671nm. We develop an all-solid state narrow linewidth laser source with high power at this wavelength. The source is based on an optically amplified, frequency-doubled 1342nm home built linear laser. Optical amplification is achieved in five stages, using a $Nd:YVO_4$ crystal. Such a laser system would increase stability of our experiment.

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Transient properties of electromagnetically induced transparency in spherical quantum dot with hydrogen impurity

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The electromagnetically induced transparency (EIT) is the effect based on the destructive quantum interference of the probability amplitudes, corresponding to the possible paths of excitations between specific atomic levels by coherent laser fields. It makes the otherwise opaque medium transparent with respect to the weak resonant laser in the presence of the strong control laser field [1, 2]. The study of the transient properties of the EIT corresponds to the study of the time response of the medium interacting with laser fields. This study is important due to the application of the EIT in all-optical switches and transistors [3, 4].

In this work, the temporal behavior of the level populations and susceptibility to the probe laser of the GaAs spherical quantum dot (QD) with an on-center hydrogen impurity is studied when the EIT effect is achieved. The interaction of the QD with the weak probe and strong control laser is described through the three-level ladder-type model and the density matrix approach is used to describe the dynamics of the system. In order to obtain corresponding density matrix elements, Optical Bloch equations are solved numerically with the chosen values of laser intensities and for different values of the QD radius, for the case of zero detuning of both fields.

It is found that the quantities under consideration show the oscillatory behavior before reaching their stationary values. The oscillations in the populations are more prominent for the QD with the large radius and the transient regime becomes shorter with increasing the QD radius. The duration of the transient regime for the imaginary part of the susceptibility is almost the same for all the values of the QD radius we considered here. For the chosen values of the parameters, the duration of the transient regime for both populations and susceptibilities of the order of nanoseconds is obtained. The value of the imaginary part of the susceptibility in the stationary regime increases with the decrease of the QD radius, which is in accordance to the results from our previous work [5]. Moreover, it is observed that with increasing the value of the QD radius, the imaginary part of the susceptibility takes the positive values, meaning that there is the gain in absorption of the probe laser before its stationary value is achieved.

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Pulse propagation through rectangular quantum dots under conditions of electromagnetically induced transparency

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The electromagnetically induced transparency (EIT) is an atomic coherent effect that makes opaque medium transparent. In its simplest form, it involves a three-level system, having two dipole-allowed transitions and the third being forbidden. This system is driven by two laser fields, probe and control, which can establish the coherent superposition of the probability amplitudes and make quantum interference possible. As a result, a transparency window in the absorption spectrum of the probe field can occur [1, 2].

The EIT effect, and the probe pulse propagation under the EIT regime is investigated in cold-atom, gaseous and solid-state systems. Among these, semiconductor heterostructures, such as quantum dots (QD), have an advantage compared to other media, since their properties can be predefined in order to be suitable for different applications. This property makes them a very useful medium for the realization of the EIT [3].

In this work, the realization of the EIT in a rectangular QD with a single electron is investigated. The density matrix approach, Optical Bloch equations and the perturbation method up to the fifth order are then used to determine the absorption of the probe field as a function of the probe field detuning and QD dimensions, for both cryogenic and room temperatures. Under the conditions of the EIT, the continuous wave control field and pulsed probe field are used in order to study the influence of the media on the probe field. This is done by solving the Maxwell-Bloch equations with the help of the Fourier transform method [4].

It is found that, depending on the size of the QD dot, the lowest three energy levels can form either V, or ladder configuration. In both configurations, the EIT is achieved by lasers of suitable intensities and polarizations. The influence of the initial probe pulse half-width and dephasing rates on the propagation of the probe light is investigated. It is shown that by changing these quantities the group velocity of the probe laser pulse as well as the pulse shape can be controlled, which is in accordance to the results from the previous work [5].

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Ground state and collective modes of dipolar BECs

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We study the effects of the dipole-dipole interaction on the ground state and collective modes of quasi-one-dimensional dipolar Bose-Einstein condensates of atomic gases of chromium ^{52}Cr, erbium ^{168}Er, and dysprosium ^{164}Dy. Through extensive numerical simulations and detailed variational treatment, we analyze the dependence of condensate widths on the dipole-dipole interaction strength, as well as the interaction-induced frequency shifts of collective oscillation modes. Furthermore, we show that the Gaussian variational approach gives a good qualitative description of the system's ground state, and an excellent quantitative description of the condensates' low-lying excitation modes.

Field-Induced Narrowing and Broadening of a Magnetic Resonance in a Bichromatic Microwave Field

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We report on theoretical and experimental work with bichromatic driving of a spin system by two equally strong, nearly degenerate fields. Such perturbation enables addressing populations of individual spin states, characterization of their interaction with thermal bath, and measurements of their relaxation/decoherence rates.

With such addressing in an open two-level system we observe nested composite magnetic resonances with widths having nontrivial dependence on microwave (MW) field intensity: while the width of one of the MW-resonances undergoes strong power broadening, the other one exhibits peculiar MW-field-induced stabilization.

Our theoretical modelling based on coherent population oscillations [1] very well explains these observations and relates the phenomenon with the dynamics of the bright and dark superposition states and their interaction with the reservoir. Specifically, we have found that the analysis of the structure of the composite resonances and their power broadening offer a sensitive way of studying the relaxation/decoherence mechanism of spin ensembles. Since the Fourier transform of the composite resonances represents multiexponential decay of populations and coherence of the system [2], the developed methodology provides a useful alternative to standard time-resolved studies of spin dynamics. This two-field methodology enables addressing of individual spin states and studies of their interaction with environment which is impossible with standard measurements where the resonances are jointly affected by both relaxation rates. In particular, relaxation rates of the unperturbed populations of individual states and their coherence can be determined with high accuracy.

To verify theoretical analysis, we have performed experiment with ensemble of nitrogen vacancy (NV) color centers in diamond crystal excited by a green light and perturbed by two microwave (MW) fields of comparable strengths and nearly resonant frequencies. By studying the composite resonances we have demonstrated that their components are indeed very differently perturbed by MW field: while one component is strongly power-broadened, the other is nearly broadening-free. We regard this behavior as *field-induced narrowing* or *stabilization* of spin states by strong driving field and interpret it as analogy to the well-known quantum interference effect with dark and bright state superpositions. We also demonstrated light-power narrowing of these composite resonances.

Although the reported theory and measurements are focused on spin ensemble in NV diamond, the analysis and discovered phenomena are quite general and may be applied for precision characterization of spin dynamics of various paramagnetic samples.

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Ultrafast All-Optical Switching due to Photon-Avalanche-Like Effects in Quantum Wells

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In this study, several new features of nonlinear optical excitation of materials with quantum wells (QWs) under short laser pulses are treated. The following processes were considered in previous works:
a) "traditional" photon-avalanche (PA)-like processes (type I) in systems of impurity ions [1] and in deep QWs [2]: for this type of processes the photon absorption and the energy transfer between electrons are involved in different elementary events;
b) type II PA-like processes: single- or many-photon [3] absorption and the energy transfer are involved in one elementary event in bulk crystals with special types of the energy band structure [4], wide-gap crystals with high concentration of deep impurities [5], and QWs [6];
c) efficient up-conversion and light-with-light controlling due to both type I and type II PA processes in deep QWs [6].

Quantum-mechanical calculations of the probabilities of elementary processes involved in phenomena under consideration were performed within second or higher-order perturbation theory. The results of these calculations were applied to analyze kinetics of non-equilibrium electron-hole pairs producing, optical transmission, and optical switching the media between states with essentially different optical and/or electrical properties.

General nonlinear oscillation analysis is applied where laser radiation intensity j is considered as a bifurcation parameter [7]. In general, theoretical description of type II PA dependence from bifurcation parameter value is observed.

It was shown that in all cases under consideration a rather narrow region of laser intensities j appears where both populations of electron states and optical transmission dramatically change even at small change of j. A number of crystals and heterostructures, whose electron band structure and geometric parameters allow the above-described transient nonlinear processes of photoexcitation and optical switching, are described in detail.

Typical times τ and densities of light energy E for all-optical switching are estimated as $\tau \sim 0.1 \div 10$ ns and $E \sim 0.1 \div 10$ pJ/cm^2, respectively.

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Comparison of mid-infrared nonlinear crystals efficiency

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The development of laser sources in the mid-IR range is of great interest for gas analysis, atmospheric sensing, laser chemistry, isotope separation and other applications, since it contains molecular absorption bands of both components of the atmosphere and its pollutants. Nonlinear optical materials are required to shift the output of powerful and efficient near-IR laser sources to this wavelength range (or to enrich and to widen spectral range of existing mid-IR lasers). At the present time, a large number of various nonlinear crystals have been developed and investigated, some of which are presented in [1]. Also new and improved materials are developed in order to meet the demands of a growing number of applications [2].

When selecting the most suitable nonlinear crystal for a particular application, one should take into account its properties such as transparency in spectral range of interest, adequate birefringence for phase matching, large effective nonlinear coefficient, high optical damage threshold, and others. Thus, selecting the most efficient crystal for a particular laser system is a nontrivial task, and it often requires complex calculations.

A simple integral criterion [figure of merit (FOM)] for selecting nonlinear crystals, which considers the fundamental parameters determining conversion efficiency, was offered in [3]. The criterion allows one to compare crystals with only linear or quadratic combinations of fundamental crystal properties.

We studied this integral criterion with the experimental data on the broadband sum-frequency generation of the mid-IR CO laser radiation in several nonlinear crystals ($ZnGeP_2$, GaSe and other) [4]. Taking into account effective nonlinear coefficient, refractive index of the crystal, spectral and angular phase-matching bandwidths, the FOM provided the best agreement with the experiment. It was shown that the integral FOM can be applied for qualitative, and even quantitative, comparison of the nonlinear crystals. The FOM, which also takes into account the optical damage threshold, can be applied for high-power laser systems in the case of extremely high intensity.

In the next research stage, we applied the integral FOM for a study of other the mid-infrared nonlinear crystals to find out the most efficient one. We considered both traditional (e.g. $AgGaS_2$, $HgGa_2S_4$) and new (e.g. $BaGa_2GeSe_6$, $CdSiP_2$) crystals. The calculations showed that the most efficient crystal for broadband mid-IR frequency conversion was $ZnGeP_2$.

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Waveguiding in Mathieu photonic lattices

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Nondiffracting beams are highly applicable in optics, photonics and atom physics, peculiar because their transverse intensity distributions propagate unchanged for hundreds of diffraction lengths and allow creating 1D and 2D photonic lattices in photosensitive media [1]. Among the variety of different nondiffracting beams [2-5], Mathieu beams solve the Helmholtz equation in elliptic cylindrical coordinates [4, 6-7]. Mathieu beams are classified according to their symmetry properties as even and odd and their transverse discrete intensity distributions can be shaped by their order and an ellipticity parameter. These real-valued beams are characterized by only discrete spatial phase distributions. By complex superposition of appropriate even and odd Mathieu beams, elliptical Mathieu beams are obtained, showing remarkable continuously modulated spatial phase distributions that possess orbital angular momenta, associated with transverse energy flow.

We exploit Mathieu beams as lattice-writing light to fabricate discrete waveguide structures and investigate their nonlinear self-action in these structures, leading to morphing discrete diffraction. We investigate Mathieu beams of different orders in a photorefractive SBN crystal, experimentally and numerically. We link linear discrete diffraction with nonlinear self-effects and demonstrate a gradual transition from one to two dimensions [8]. The self-action of a zero-order Mathieu beam in a nonlinear medium shows characteristics similar to discrete diffraction in one-dimensional waveguide arrays. Mathieu beams of higher orders show discrete diffraction along curved paths, showing the fingerprint of respective two-dimensional photonic lattices.

Linear propagation of elliptic Mathieu beams enables a nondiffracting transverse intensity distribution with transverse energy redistribution along elliptic paths compensated in each point. In contrast, their nonlinear self-action in SBN breaks this sensitive equilibrium. We demonstrated a new type of rotating beam formation arises with high-intensity filaments corresponding to the energy flow in an enforced preferential direction [9]. This process is beneficially applied to realize chiral twisted photonic refractive index structures with a tunable ellipticity.

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Strain of MoS2 mapped with second harmonic generation microscopy

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2D materials are an extremely intense and current field of research. After the experimental realization of graphene and the immense body of results that highlighted its spectacular properties, attention has started to shift to other 2D materials, namely those that might be of interest for various applications in flexible electronics, optoelectronics, sensing, and in other industrial branches. 2D semiconductors in particular are now drawing the interest of researchers, due to the existence of a bandgap.

Although the potential for applications is enormous, production processes for these materials are still being studied and refined. Chemical vapor deposition (CVD) is widely regarded as a good candidate growth process for wide-scale applications. Nevertheless, it is well known that CVD yields materials that consist of grains with varying orientation and size. Due to the ultrathin nature of these materials, studying the crystallographic orientation and grain size is not trivial.

Optical methods provide a useful tool to study the properties of 2D materials with high resolution. In particular, second harmonic generation (SHG) has been used to map crystal orientation of CVD-grown 2D semiconductors on standard growth and use substrates [1]. Further studies have shown high-resolution strain mapping using the same principles of nonlinear optics [2].

Here we show SHG microscopy studies of crystal orientation and the presence of strain of MoS2 grown on quartz. We show that the growth substrate as well as the speed of cooling during growth can have an influence on strain, and we propose to engineer strain by selecting or patterning the substrate, or tuning the growth process. Strain control on the nanoscale is an enabling tool for the emerging technology of straintronics.

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CO laser sum frequencies spectrum tuning by $ZnGeP_2$ crystal temperature tuning

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The mid-IR range is the “molecular fingerprint” region. Therefore, a development of mid-IR coherent sources is very important for gas analysis, laser chemistry, medical and other applications. Such application as remote multi-component spectroscopy of the atmosphere requires a broadband mid-IR sources with several narrow high brightness spectral lines.
Multi-line Q-switched CO laser can emit on more than 200 spectral lines in the 5.0-8.2 μm range simultaneously in a single pulse [1]. Moreover, its spectrum can be significantly extended and enriched by frequency conversion (sum and difference frequency mixing) in nonlinear crystals [2, 3]. For example, broadband three-stage frequency conversion of multi-line CO laser radiation in a single $ZnGeP_2$ crystal was performed in [2]. In the [3] broadband intracavity sum frequency generation of multi-line CO laser in a nonlinear crystal was performed when the nonlinear crystal operated both as a frequency converter and an output coupler. That was very attractive schematic, but phase-matching conditions could not be controlled due to the uncoated nonlinear crystal operated as an output coupler.
In this work, we study the phase-matching (and spectral, respectively) control of the CO laser sum frequency generation through the $ZnGeP_2$ crystal temperature control. Experiments were performed with repetitively pulsed low-pressure Q-switched CO laser. It emitted 0.5-μs (FWHM) pulses with the pulse repetition rate of 100 Hz. Peak power of a single pulse reached 3 kW at average output power of 150 mW. The emission spectrum of the CO laser consisted of 73 spectral lines in the wavelength range from 4.9 μm to 6.2 μm. The CO laser beam was focused into 17-mm length $ZnGeP_2$ crystal by lens with focal length of 20 cm. The crystal was heated up to 145 ^{o}C by custom-made thermostat figured as thermoelectric Peltier sandwich.
The crystal at room temperature was installed at phase-matching angle of 47.2^{o}. The sum frequencies spectrum measured in this case fills 2.56-2.74 μm wavelength interval with power maximum near 2.63 μm. The sum frequencies spectrum measured at 145 ^{o}C crystal temperature was shifted to shortwave spectral part. The spectral displacement was about 0.07 μm. Additional crystal heating in the experiment was limited by the ability of our thermostat.
Thus, we experimentally demonstrate CO laser sum frequencies spectrum tuning by $ZnGeP_2$ crystal temperature tuning. Our estimation indicates that to get spectrum tuning from 2.5 to 3.7 μm, the $ZnGeP_2$ crystal should be heated to about 400 ^{o}C.

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An analysis for fiber optical parametric amplifier in presence of attenuation and random dispersion fluctuations

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Fiber optical amplifiers (FOPAs) based on four-wave mixing is analyzed theoretically, and numerical simulations of the gain are performed for single-pump and two-pump FOPAs, respectively. It is assumed that the pump and signal waves undergo attenuation with random perturbations in the zero-dispersion wavelength (ZDWL). The impact of fiber attenuation is included with special attention on the wavelength dependence of attenuation. In order to study the impact of random fluctuation in ZDWL on gain, the fiber is segmented with random fluctuation of ZDWL that is assumed to follow Gaussian distributions. The fiber attenuation result in reduce of signal gain and the fluctuations in ZDWL leads to variation of gain spectrum.

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Amplitude squeezing by four wave mixing in hot potassium vapor

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First evidence of squeezed states of light obtained by four wave mixing (FWM) process in alkali vapor was initially presented by Slusher et al. [1] in 1985. Since then squeezing of light in such a medium has occupied interest of many research groups. We experimentally demonstrate relative amplitude squeezing of light (spectral noise power below standard quantum limit) by the use of non-degenerate FWM process in potassium vapor. We use double lambda scheme on D_1 line, with two nearly co-propagating laser beams, pump and probe. Similar schemes were used for experiments in Rb [2] and Cs [3], with the maximal level of squeezing of ~ 9 dB observed in Rb vapor. Potassium has a smaller hyperfine splitting of the ground level compared to other alkali atoms. The research performed so far suggests that this could lead to higher levels of squeezing.

The amplitude difference squeezing can be controlled by the proper choice of the experimental parameters: pump power, one- and two- photon detuning, vapor density, angle between the beams. Their values control nonlinearity, the beam absorption and gain, which are of great importance for the generation of strong quantum correlations. FWM parameters in previous measurements in K [4] are not in agreement with the optimal ones we predicted in our resent work [5]: small probe absorption, similar gains of probe and conjugate, and identical intensities of twin beams at the balanced detectors. Indeed, at FWM parameters quite different than in [4], we obtained higher level of squeezing. Results of measured levels of squeezing at different conditions for FWM will be presented.

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Evolution of laser pulse propagation in Four Wave Mixing atomic medium

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Electromagnetically induced transparency (EIT) and EIT based Four Wave Mixing (FWM), the two effects of quantum coherence and nonlinearity induced in atomic systems, are important because of related phenomena, like slow and storage of light pulses. From the practical point it is important to ensure parameters of EIT and FWM so that pulses propagate through medium without (any) distortion.

In this work we investigate propagation of probe and conjugate pulses through potassium vapor, which is made FWM medium by a double Λ atomic scheme. We are interested in finding conditions when initial Gaussian probe pulse begins to brake, bringing multiple pulses at the exit of the K cell. In our previous works with FWM in potassium we studded slow light and therefore worked with conditions that ensure preservations of Gaussian pulse at the exit of the K cell [1].

We are interested in pulse propagation dynamics that leads to pulse splitting in hot alkali vapor. Understanding mechanism which governs the final shape of the pulse will help to tailor FWM parameters optimal for slowing and storing Gaussian pulses, with minimum distortion and broadening. Theoretically and experimentally we investigate propagations of 80 ns Gaussian probe pulse through double Λ type atomic media, when the second leg of the lower Λ scheme is the strong cw pump laser.

We developed detailed numerical model to describe the FWM in hot potassium vapor, using Maxwell-Bloch equations (MBE). Potassium atoms in vapor cell have large Doppler line broadening, of the order of 800 MHz. The model carefully takes into account pump photon detuning from the D1 line due to Doppler effect, in addition to the detuning set for the pump laser (valid for zero velocity atoms). We select a number of velocity groups of atoms and form separate density matrices for each group and a corresponding set of Bloch equations. At initial time and position (entrance to the cell) for starting point of propagation, for a given pump and probe detuning, we first solve the MBE with all derivatives over time set to zero. Thus, obtained spatial dependence of atomic polarizations is initial condition for the probe pulse at the cell entrance. Comparison with experiment has shown that small steps between two velocity groups are necessary, of the order of 10 MHz. The total number of atom velocity groups, and the type of uneven distribution of groups along the Doppler profile, is the compromise between proximity of results to results of the experiment, and reasonable computer time.

We will present results of the model and of the experiment for ranges of one photon pump laser detuning, two pump-probe laser beams detuning, potassium density, when slowed probe and conjugate pulses start to deform from Gaussian, and begin to split.

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Double-periodic solutions and Talbot carpets of extended nonlinear Schrödinger equations

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We present analytical and numerical double-periodic solutions of the one-dimensional nonlinear Schrödinger equation and its extended versions [1] (up to the fifth-order dispersion), in the form of Talbot carpets [2]. The breathers of different orders and rogue waves are obtained using numerical simulations, starting from the initial conditions calculated by the Darboux transformation. To suppress undesirable aspects of modulation instability leading to the homoclinic chaos, we applied Fourier modes pruning procedures. This way, we are able to preserve and maintain the twofold carpets periodicity. The novelties of our work are analytical Talbot carpets for Hirota-quintic equation and ability to obtain them dynamically by controlling the growth of the Fourier modes. In addition, the new period-matching procedure is described for periodic rogue waves [3] that can be utilized to produce Talbot carpets without mode pruning.

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Numerical study of the supercontinuum generation in the telecommunications windows in photonic crystal fiber

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This research explores a supercontinuum (SC) generation in silica based highly nonlinear photonic crystal fiber of near infrared window, suitable for application in the field of telecommunications [1]. Results obtained here could be of interest in attempts to improve the characteristics of multi-wavelength sources for dense wavelength division multiplexing (DWDM) systems. We study numerically SC dynamics in both spectral and temporal domain in three different optical windows, at referent wavelengths of 835nm, 1300nm and 1550 nm. The dependence of SC properties on the input pulse power, shape and the value of the chirp is investigated in details. It has been shown that the most intense spread of SC spectrum at fiber output is obtained in the third optical window, while the input signal shape, power and duration stayed unchanged [2]. The shape of the initial pulse was the most influential in the second optical window, where the simulated SC has flat and smooth profile, covering the wavelength range from 1000 nm to 2000 nm. In addition, we examine the SC spectrum coherence in all of the three optical windows with respect to different input pulses. On the other hand, the richest SC dynamics is observed in the first window, where the appearance of high intensity events of the rogue wave type is reported [3].

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Localized modes in two-dimensional "plus" lattice

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We have proposed a design of new photonic lattice which does not exist in nature but might be easily fabricated by femtosecond laser inscription technique. The novel two-dimensional photonic lattice comprises of square elementary plaquette inscribed in dodecagon elementary plaquette. Unit cell of the lattice consists of five linearly coupled sites distributed at the edges and in the center of a "plus" sign. Existence and stability of linear and nonlinear localized modes in the uniform and binary "plus" lattice are numerically investigated.

The energy spectrum of linear lattice is characterized by a flat band (FB) and four dispersive bands (DB). The FB intersects with two neighboring DBs at four Dirac points at the end of and one in the middle of the Brillouin zone [1]. The lattice binarity provided the opening of gaps between DBs. At the end of the first stage of our study, we can report the existence of FB modes, i.e. compactons, which in the presence of nonlinearity lose the stability owing to the Fano-resonances with the extended states from DBs [2]. In addition, we found a pair of new nonlinear localized mode families in gaps opened by binarity, which could be stable in certain regions of the nonlinearity parameter. The next challenge is related to searching for edge modes and energy transport characteristics in the lattice.

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Spontaneous isotropy breaking for vortices in nonlinear left-handed metamaterials

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We explore numerically and analytically the pattern formation and symmetry breaking of beams propagating through left-handed (negative) nonlinear metamaterials. When the input beam is a vortex with topological charge (winding number) Q, the initially circular beam acquires the symmetry of a polygon with Q, 2Q or 3Q sides, depending on the details of the response functions of the materials. Within an effective field-theory model, this phenomenon turns out to be a case of spontaneous dynamical symmetry breaking described by a Landau-Ginzburg functional. By considering the loop corrections in the effective Landau-Ginzburg theory we can even obtain quantitatively accurate predictions of the numerical results [1].

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Designer kit for an affordable and compact 0.1 – 1 TW laser

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Cost-effective and compact next-generation lasers with TW level of peak power are in demand for emerging applications in biology, medicine, microelectronics, space technology and materials science. Since the first Optical Parametrical Chirped Pulse Amplifier (OPCPA) was reported [1], many advanced architectures of high peak power lasers have been developed [2]. Typically, TW-class lasers take up a lot of space, and development and maintenance costs limit their use. Therefore, such systems are commonly used by many scientists with limited access time. As for Europe, access to Extreme Light Infrastructure (ELI) remains difficult outside of the Czech Republic, Hungary and Romania. For widespread use of high peak power lasers, it is vital to pay attention to reducing the size and cost.

We have developed and tested an advanced architecture for high peak power lasers based on easily reproducible modules: fiber seed laser front-end, two-cascaded double-pass chirped pulse amplifier (CPA) based on Yb:YAG rods with low doping level, grating compressor, supercontinuum generation in YAG, second harmonic generation (SHG), four stages of non-collinear optical parametric amplifier (NOPA), and chirped mirrors compressor. Using the same Yb:YAG DPSS-source of output pulses with a pulsewidth of 1.1 ps for pumping NOPA and supercontinuum generation provides internal synchronization and, thus, greatly simplifies the scheme. Particular attention is paid to improving the energy conversion efficiency by reusing depleted pump in SHG and NOPA, as well as maintaining a wide spectral bandwidth due to M-shaping of picosecond pump pulses. The pulsewidth after compression reaches 15 fs, and the output energy is mainly limited by the number and power of laser diodes used for pumping, providing the output peak power of the laser system from 0.1 to 1 TW. The experimental scheme is assembled on an optical table measuring 1 x 3 m^2, all components used are commercially available, and the repeatability is confirmed by student interns.

We also demonstrate the generation of a multi-octave supercontinuum with a long-wavelength wing up to 2500 nm with an energy and beam pointing stability exceeding the pumping source. This makes it possible to apply a similar architecture when developing a sub-TW laser in the spectral region of 2 microns for the high order harmonics generation (HHG).

High energy, high repetition rate ultrashort laser pulses allow to create point x-ray sources and, thus, significantly increase the contrast and resolution of medical X-ray tomography. At present, such lasers are usually based on relatively outdated Ti:S with a limited repetition rate or based on OPCPA with limited conversion efficiency. Possible alternative concepts for obtaining high-energy ultrashort laser pulses will be discussed.

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Light propagation along helical waveguides: Variational approach

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We investigate numerically and analytically light propagation in a single spiral waveguide formed in a nonlinear dielectric medium, in the regime of low spatial frequency of the waveguide rotation [1]. The procedure for finding exact fundamental solitonic solutions is based on the modified Petviashvili's iteration method [2]. We present a general variational approach for computing soliton parameters analytically. In the particular case of media with cubic-quintic nonlinearity, analytical expressions are in very good agreement with numerical findings.

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Localized modes in two-dimensional octagonal-diamond lattices

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Two-dimensional octagonal-diamond (OD) atomic lattices have been explored in recent times to study phenomena related to topological phase transitions induced by spin-orbit interaction and gauge fields [1], and magnetic phases and metal-insulator transitions with Hubbard interaction [2, 3]. It can lead to the appearance of nontrivial nearly flat band states with particular topological properties [4]. Here we study the octagonal-diamond photonic lattice formed of linearly coupled waveguides, proposed by [4] as a possible experimental realization of an artificial flat-band system.

We investigated analytically and numerically the existence and stability of linear and nonlinear localized modes in a two-dimensional OD lattice. The primitive cell consists of four sites, linearly coupled with each other with the same coupling constant, including two diagonal couplings. The eigenvalue spectrum of the linear lattice consists of two flat bands and two dispersive bands [4]. The upper dispersive band intersects the upper flat band in the middle of the Brillouin zone, as well as the second flat band at the end of the Brillouin zone. In the linear case, there are two types of localized linear solutions, which are composed of eight sites each, having either monomer (+ - + - + - + -) or dimer (+ + - - + + - -) staggered phase structure [4]. In the presence of Kerr nonlinearity, both focusing and defocusing, compacton-like solutions [5] may exhibit instabilities due to intersections of the upper dispersive band and the flat bands. We also discuss the possibility of finding soliton solutions in the frequency gaps occurring between the flat bands and the isolated dispersive bands.

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Necklace beams in media with cubic-quintic nonlinearity

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We investigate numerically the stability and evolution of two-dimensional soliton-like structures in the form of necklaces in media with cubic-quintic nonlinearity. Numerical procedure applied to the propagation equation is the split-step beam propagation method based on the fast Fourier transform (fourth-order symplectic algorithm). Using a variational technique [1], optimal propagation parameters for the long-lived stable solutions are determined. Analytical expression is in good agreement with numerical findings.

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Solitary and traveling wave solutions for the Davey-Stewartson equation using the Jacobi elliptic function expansion method

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The Davey-Stewartson (DS) system of equations was first developed in order to study the evolution of a three dimensional wave packet on water of finite depth [1]. It is an important nonlinear system because it is one of the rare two-dimensional nonlinear systems for which the inverse scattering transform has been found [2]. Solutions based on the Jacobi elliptic function were already found in [3] for a DS-type equation. These solutions are obtained combining the 12 different Jacobi Elliptic functions (JEFs).

In this paper, we will examine the generalization of the JEF-expansion method used in [4] through which spatio-temporal solitary and traveling wave solutions were obtained to the Nonlinear Schrödinger equation, both with and without chirp. Using the principle of harmonic balance, the matching conditions reveal that wave-amplitude field has terms of the JEF of degree from -1 to 1, while the mean flow field has terms of degree from -2 to 2. The asymmetry between the coefficients for the two transverse derivatives [5] is resolved with an asymmetry in the ansatz similar to the one in [6]. Three classes of solutions are obtained: the most general case, one which restricts both fields to terms with a positive degree and one which restricts the wave-amplitude field to odd degree terms and the mean flow field to even terms. Nonsingular solutions are obtained for both traveling and solitary waves and both with and without chirp.

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Self-organization of soliton-tweezers in suspensions of nanocomposites and graphens

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Laser beams and pulses are powerful tools for tweezing, photobiomodulation, and manipulation of soft matter including colloidal nanosuspensions, emulsions, foams, as well as all kinds of biomedia like myosin, kinesin, ribosomes, liposomes, bacterias, viruses, blood, and a variety of living cells in body water [1]. The laser modifies the nonlinear mater passing through. Simultaneously, the modified mater acts to the light altering it by a feedback mechanism. Therefore, light is controlled by light through interaction with nonlinear mater. Laser stability and precision are of crucial importance not only for brain surgery but also for nondestructive diagnostics using this feedback mechanism. In order to achieve the necessary dynamical stability, the promising mechanism is the self-structuring of the light into localized solitons via nonlinear interaction inside the colloidal nanosuspensions and other varieties of soft matter. Tweezing solitons stable propagation is self-organized by the balance of antagonist effects, *i.e.*, beam self-focusing and self-defocusing [2]. The high frequency pressure force of the laser field either attracts or repels the nanoparticles from the field region, depending if their optical index of refraction is larger or smaller than the background one [3]. In both cases, the nanoparticles density modification results in the nonlinear increase of effective index of refraction inside the beam making it self-focusing. We use this self-focusing effect to establish theoretically, numerically and experimentally the self-organization of soliton-tweezers as a novel kind of dynamically reconfigurable self-collimated tweezing facilities. Such soliton-tweezers will be able to photobiomodulate and manipulate, in a noninvasive way, micro and nanoparticles in body water and other soft mater of interest for medical and biological applications. Based on the synergy between theory and experiment via numerical simulations, other nanocomposites and colloidal nanosuspensions involving graphene and various two-dimensional materials will be tweezed using spatiotemporal dissipative solitons and multidimensional vortex solitons [4, 5].

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Cubic Quintic Ginzburg Landau Equation as a Model for Resonant Interaction of EM Field with Nonlinear Media

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Complex Ginzburg–Landau equations (GLEs) adequately model the dissipative structure generation and propagation in plenty of systems including nanophotonics, nanoplasmonics, plasmas, and fluids, as well as superconductivity, superfluidity, elementary particles, and biological systems [1]. The self-organization of solitonic dissipative structures relays on the balance of antagonistic effects, with gain compensating losses, and nonlinearity-induced self-contraction arresting diffraction and/or dispersion [2]. Cubic-quintic GLE model is often used to represent gain as cubic and loss as quantic nonlinearity. In this work we discuss the possibility of using cubic-quintic GLE for modelling resonant interaction of an electromagnetic field with nonlinear media.

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An estimation of far field intensity distribution for photonic crystal fibers based on empirical relations

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Far field intensity distribution is reported for a varied configuration of air holes in the cladding of the solid-core single-mode photonic crystal fibers (PCFs) [1-6]. Recently, an analytical approach based on the V parameter (normalized frequency) and W parameter (normalized attenuation constant) frequently used in the design of conventional optical fibers has been developed for index-guided PCF [7-10]. Using the simple empirical relations for V parameter and W parameter of PCF, the dependence of the far field intensity distribution on two structural parameters - the air hole diameter and the hole pitch was presented. The results can be utilized in design and development of sensor system based on PCFs for potential applications involving structural health monitoring, medicine, environment and the biological and chemical areas.

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Effects of temperature on luminescent properties of $CaGdAlO_4$:Er,Yb nanophosphor

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$CaGdAlO_4$ crystal doped with Er, Yb or other rare earth is commonly used as infrared lasing material [1-4]. In this study we analyze effects of temperature on luminescent properties of nanocrystalline $CaGdAlO_4$ doped with Er^{3+} and Yb^{3+} cations. Material was synthesized by combustion method, as described in [5].

Our experimental setup is presented in detail in [6]; and its use for analysis of thermometric phosphors in [7-9]. However, in this study, because $CaGdAlO_4$:Er,Yb is upconverting material, we have used pulsed laser diode excitation at 980 nm. The structure of material was observed by high resolution scanning electron microscope (SEM). The experimental setup for luminescence measurement as a function of temperature is described in [10].

By using the results of our measurements of $CaGdAlO_4$:Er,Yb nanophosphor in temperature range from 300 K up to 680 K we have determined temperature sensing calibration curve and absolute and relative sensitivity of this material. The relative sensitivity is about 0.7 % K^{-1} on room temperature and decreases with temperature increase. Comparing this results with characteristics of other thermographic phosphors we conclude that synthesized $CaGdAlO_4$:Er,Yb nanophosphor is appropriate material for remote temperature sensing.

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Confinement Effects on Absorption of Molecular Crystalline Nanofilms

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In the presented research, we analyzed the already used model of ultrathin (nanoscopic) film [1, 2] as spatially very limited and perturbed boundary conditions (along a single spatial direction) of molecular crystalline structures of anthracene type. This type of crystal, when the sample is spatially unlimited, behaves as absolute absorber of a close infrared portion of the electromagnetic field spectrum [3].

When the dimensions of the sample are reduced to nanometer size, drastic changes in its optical properties are created. These altered-quantum properties of the respective films mostly depend on nanoscopic film thickness (quantum-dimensional effects), but also on the existence and intensity of altered boundary conditions on the film surfaces (confinement effects).

The theoretical analysis of the optical properties (by the dielectric response) of such samples was carried out utilizing the Frenkel's exciton model [3] and the adapted method of two-time retarded Green's function [4]. The four-layered nanofilms [1, 2] with different boundary conditions on surfaces and surface layers were researched. Several discrete resonant absorption lines were obtained as a consequence of appearance of localized exciton states in the surface areas [1, 4]. Their number and frequency position depend on five boundary parameter values. A very interesting and significant result was obtained: practically monochromatic absorption may occur [5]. Unlike the corresponding bulk-samples that are absolute absorbers in a near infrared region, in observed ultrathin films will appear selective and discrete reflection and high transparency.

These results can greatly contribute to the development of optical nanoengineering, especially in the design of new optical imaging equipment in nanomedicine and for the tracing or adequate movement monitoring of the nanoparticles – drug carriers and deliverers [2, 6].

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Chemical doping of Langmuir-Blodgett assembled few-layer graphene films with Au and Li salts aimed for optoelectronic applications

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For mass production of graphene, simple and low-cost methods are needed especially in the cases where high-quality films are not crucial for the desired purposes. Thus, liquid-phase exfoliation (LPE) is a perspective way of obtaining stable dispersion of few-layer graphene sheets (GS) in the solvent [1]. A promising pathway to achieve high degree of ordering of graphene sheets prepared via LPE-process is to utilize Langmuir-Blodgett assembly (LBA) technique. Thin-films are self-assembled from LPE dispersion by LBA technique at the water-air interface. LBA method is a suitable method for production of large-scale, transparent, thin solution-processed graphene films [2, 3]. Chemical doping of graphene films allows to tune its work function (WF) and therefore gives LPE GS films the ability to serve two different roles in electronic and optoelectronic applications, both as an anode and as a cathode.

Here, we demonstrate the method for the forming and doping of LPE graphene sheet films (LPE GS) in one-step by metal standard solutions. Doping of the graphene film occurs at the moment of its formation from the LPE graphene dispersion by LBA method at the air-metal standard solution interface. n-doping is achieved by Li standard solutions (LiCl, $LiNO_3$, Li_2CO_3), while Au standard solution ($H(AuCl_4)$) leads to p-doping. WF of the film was decreased with Li based salts, while Au based salts increase the WF of the film. The maximal doping in both directions allow a significant range of around 0.7 eV for the WF modulation. The results were obtained for 0.1 mol/dm^3 concentration of dopants. Roughness of the LPE GS films does not change by the doping, except that doped films contain occasional agglomerates. FT-IR measurements point out that the charge transfer process is enabled by physical adsorption of the metal salts and that the graphene basal planes stay chemically unchanged by metal doping. No significant shifts of any characteristic Raman peaks of graphene were detected after chemical doping. Calculated values of the intensity ratio between D and D' peak indicate that the edges are the dominant type of defects in the undoped and metal salt doped LPE GS films. Electrical properties of the films were significantly influenced by changing the dopant (Au or Li). A significant suppression of the field-effect mobility and the increase of the sheet resistivity were observed in the case of the Li standard solution doping of the film. This indicates that adsorbed Li anions act as scattering centers for the charges. Lithium nitrate provides the largest work function modulation (by 400 meV) and the least influence on the sheet resistance of the film. Therefore, it was selected as the best choice for n-type doping.

Since, the proposed one-step method for chemical doping of graphene films allows to tune WF in a large range, it extends the potential use of these materials in low-cost optoelectronic applications, as in low-power lighting, sensors, transparent heating, and de-icing applications.

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Mechanochemical Preparation and Application of Graphene Oxide for obtaining 3D Graphene-based Hydrogel/Aerogel

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Past few decades, graphene oxide (GO) has attracted significant attention due to its excellent mechanical robustness and flexibility, high specific area, tunable electrical conductivity, chemical stability and high biocompatibility. The interesting properties of graphene oxide can be utilized for various other applications such as electronic and energy storage devices, biosensors and optical materials.

GO is single-atom carbon layer, combination of unsaturated benzene and aliphatic rings containing a range of reactive oxygen functionalities. It has wide range of useful physicochemical properties which directly depend upon its structure.

Nevertheless, large-scale production of high-quality GO is still a challenging task and since industrial-scale chemical synthesis of GO are inherently generating large amount of toxic byproducts, it is more than necessary to find a cheaper and cleaner way of its production [1].

Recently mechanochemical reactions have emerged that offer advantages over traditional solvent-based chemistry reflected in better yields and selectivity, better energy- and atom-economy and reduced waste generation [2].

Here, we report versatile and eco-friendly approach to prepare high quality GO by use of mechanochemical ball milling of graphite in presence of $KMnO_4$ and a stoichiometric amount of sulfuric acid.

Furthermore, we also present it is possible to obtain 3D graphene-based mesoporous frameworks via an eco-friendly hydrothermal process using such mechanochemically prepared GO. Graphene hydrogels are a new class of 3D carbon monoliths holding promise for applications as diverse as electrochemical energy storage, CO_2 capture, tissue engineering and pollutant adsorption. They consist of entangled layers of graphene, albeit they also partially retain the excellent properties of a monolayer grapheme [3].

Prepared materials were characterized using powder X-ray diffraction, thermogravimetric analysis (TGA), FTIR spectroscopy and SEM/EDS microscopy.

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Sol-gel tantalum pentoxide thin films with tunable refractive index for optical sensing applications

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Ta_2O_5 is a multifunctional material that is broadly applied in electronics and photonics. One of the properties that makes it suitable for photonic applications is its high refractive index value. This allows its modulation in broad range in order to tailor the film's refractive index to fit particular applications needs.

Present study aims at developing thin films of sol-gel Ta_2O_5 with tunable refractive index that are used as an active medium for VOCs (Volatile Organic Compound) detection. In order to tune the refractive index, mesoporosity is introduced through soft templating approach where series of co-polymers (Pluronics) are utilized as a structuring agent. Thin films are prepared by spin-coating method using tantalum sol synthesized from $TaCl_5$ as a precursor and ethanol as solvents. The high temperature annealing (320°C) finalizes the tantalum oxide lattice formation and decomposes the template being used. The morphology of the films has been studied by Transmission Electron Microscopy (TEM) and the amorphous status of the films has been confirmed by Selected Area Electron Diffraction (SAED). Optical parameters of the films have been calculated by non-destructive UV-VIS reflectance measurements and non-linear curve fitting method. The porosity evaluation is done by Bruggeman effective medium approximation. The films have been exposed to acetone vapors as a commonly studied VOC. The reaction of the film due to vapors' exposure is recorded as a change in the reflection spectra of the film. The adsorbed acetone quantity has been estimated. The response time of the films due to vapors' exposure has been discussed. Computer-aided modeling of smart structures such as Ta_2O_5 - Bragg stack has been done based on the film having the highest reaction in order to increase the response of the sensing media.

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Macroporous silicon photonic crystals for gas sensing purposes

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Photonic crystals (PC) have been extensively studied and applied in many fields such as filtering or sensing [1]. Most of the reported are 2D slab-based silicon on insulator photonic crystals, which have demonstrated ultra-high q-factors, among other interesting optical features. However, these types of PC mainly work in the near infrared region (NIR) where most of the gases present secondary absorption peaks, several order of magnitude weaker than the principal ones, located in the mid infrared range (MIR). In order to work in this region and thus, for a better gas detection, we propose the use of macroporous silicon 3D photonic crystals fabricated by photo-electrochemical etching [2]. This versatile technique allows to grow silicon/air modulated in-deep pores, the vertical periodicity of whom depends on the separation between them, also called pitch. In our case, we work with 700 nm pitch, an ideal value for rising a photonic bandgap in the range of [3.5-8] μm. By inserting a cavity in the middle of the pores, it is possible to create a resonant narrow pass-band –seen in the transmission spectrum as a peak. The obtained quality factors allow spectroscopic gas sensing because mostly the whole resonant peak can fill inside the absorption spectra of many important gases.

In this sturdy we report the use of this technology as a platform for spectroscopic NDIR gas sensing, based on the light absorption at a certain wavelength, as Beer-Lambert law describe. Therefore, we take advantage of a technology which offers low losses, high durability and high throughput to fabricate precise, fast and robust gas sensors.

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Optical and Structural Investigation of Cr_2O_3 Thin Films: the Effect of Thickness on Their Applicability in Differential Photodetectors

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We report an experimental study of Cr_2O_3 thin films (60, 300, 350 nm) deposited on silicon and glass substrates using the Balzers Sputtron II System. The structural and optical properties were investigated by means of AFM, XRD, UV-VIS, Raman and infrared spectroscopy, in order to determine the suitability of the as-obtained films as potential active layers in novel differential inorganic photodetectors. AFM measurements revealed that all films are well-deposited, without the presence of any cracks or voids. The crystalline peaks in the XRD spectra belonged to the trigonal Cr_2O_3 structure. UV-VIS measurements revealed a strong red shift in the absorption maxima with reducing film thickness. IR and Raman spectroscopy show a dependence of the characteristic vibrations on film thickness as well as on the substrate. In conclusion, our results indicate that the Cr_2O_3 film of 300 nm thickness is so far the most promising candidate as photoactive semiconducting layer in differential photodetectors.

Optical and mechanical properties and electron-phonon interaction in graphene doped with metal atoms

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Graphene, the first experimentally realized 2D material with outstanding mechanical and electrical properties as well an excellent optical transparency [1, 2, 3], is predicted to have many applications in various scientific fields [4, 5]. Furthermore, there are numerous ways for modifications of pure graphene that allow precise tuning of its properties or observation of some new effects, including the applied strain, various types of controlled defects, exposure to electrical or magnetic field, or doping. It is known that graphene with alkali metal atoms adsorbed on its surface becomes superconducting with critical temperatures up to 11K [6, 7, 8].

The question remains what happens with optical and mechanical properties of such structures, can we preserve or enhance these superb properties while making graphene superconducting at the same time.

Here we investigate structures based on graphene doped with several metal atoms. Using the Density Functional Theory, we analyze the optical and elastic properties of those structures and calculate the electron-phonon interaction. We discuss the influence of adsorbed atoms on these properties.

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The influence of nanosheet size on formation of graphene films by Langmuir-Blodgett deposition from the liquid phase

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Graphene as a 2D material has numerous applications. The material is an efficient electrical and heat conductor with high mechanical stability and optical transparency. Because of these characteristics, it can be used in sensors, solar cells, microphones, light-emitting diodes, batteries, transparent conductors and for many other applications. The favored commercial method of producing graphene is chemical vapor deposition (CVD). This technique is costly, due to the significant metal waste involved. Liquid phase exfoliation (LPE) is a promising alternative method for mass production of graphene, although it is challenging to obtain high quality thin films from LPE graphene. Langmuir-Blodgett assembly (LBA) is a way of obtaining low-cost, high-quality thin films from LPE graphene [1], however the graphene dispersion needs to be carefully prepared in order to successfully apply LBA. Here we study the influence of exfoliation parameters on nanosheet size, and in turn of the sheet size on quality of LBA films, with a focus on applications in transparent conductors. A certain amount of graphite is added to N-Methyl-2-pyrrolidone (NMP), which is used as the solvent, and the entire solution is sonicated. In order to control the nanosheet dimensions, we employ cascade centrifugation (CC) [2]. The first step in CC is 1 krpm. At this speed, the sediment contains any unexfoliated graphite layers and the supernatant has the remaining graphene sheets. The following steps are in the range from 2 to 5 krpm. For each step, bigger sheets remain in the sediment while smaller ones stay in the supernatant. In order to characterize the nanosheets we use AFM, UV-VIS spectroscopy and optical microscopy. The resulting dispersion is used to assemble graphene films using the Langmuir-Blodgett method. We examine the influence of nanosheet thickness and lateral size on film quality for applications in transparent conductors.

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Structural properties of Eu^{3+} doped YVO_4: Far – infrared spectroscopy

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The yttrium orthovanadate (YVO_4) belongs to the group of important metal vanadates, MVO_4 (M = Bi, Y, Fe, Cr, In, etc.) because of its wide range of applications, especially in photonics. Photocatalytic properties of doped YVO_4 and its enhanced luminescence properties when doped with rare – earth (RE) ions, make this structure very popular and very common semiconductor in photochemistry. Excellent thermal stability, robustness and other physicochemical properties of YVO_4 ensured it to be one of the most used materials in optical devices [1-3].

In this paper, two methods were used to prepare Eu^{3+} doped YVO_4 nanopowders – Solution Combustion Synthesis (SCS) and Classical Ceramic Method (CCM).

Far-infrared reflectivity spectra of so-prepared samples were measured at room temperature in spectral range 80 – 600 cm-1. The Maxwell – Garnett formula [4, 5] was used to model dielectric functions of Eu^{3+} doped nanopowders as mixtures of homogenous spherical inclusions in air. Two methods of preparation were compared and influence of rare – earth dopant ions was discussed. UV – VIS measurements were used to calculate band gaps of prepared nanopowders.

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Tunable quantum phase transitions in asymmetric $HgTe/Cd_xHg_{1-x}Te$ double quantum wells

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The quantum spin Hall (QSH) effect is a unique phase of matter characterized by a pair of helical edge states protected by time-reversal symmetry. The existence of this phase was first theoretically proposed for graphene [1]. However, experiments showed that spin-orbit interaction in low-mass C atoms is too small to open an energy gap [2]. Therefore, greater attention is paid to materials that are composed of heavier atoms in which relativistic effects are more pronounced. A notable example is thin HgTe/CdTe quantum well (QW) where the QSH effect was theoretically predicted [3] and experimentally realized [4]. By using effective models it has been found that double symmetric $HgTe/Cd_xHg_{1-x}Te$ QW may also possess a topological nontrivial phase [5, 6]. Structures of this type exhibit interesting 3/2 pseudospin based physics similar to that in bilayer graphene without valley degeneracy [6].

We investigate the electronic properties of double asymmetric $HgTe/Cd_xHg_{1-x}Te$ QW with [001] orientation. The electronic structure is calculated within the framework of the Kane $\mathbf{k} \cdot \mathbf{p}$ theory [7]. We choose the common eight-band basis set that describes the coupling between the Γ_6, Γ_7, and Γ_8 bands. We assumed that the model parameters change abruptly along the structure. Also, the difference between the valence bands in HgTe and CdTe is assumed to vary linearly with mole fraction. The theoretical model is based on the Burt envelope function approach on expansion in plane waves is used in our numerical calculations.

The results obtained for the electronic structure indicate that a quantum phase transition can occur in asymmetric double QW when a perpendicular electric field is applied. Besides an external field the phase transition could be controlled by varying geometric parameters of the wells and the mole fraction in barriers.

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"Point-by-point" inversion vs. parametrized fitting of ultrathin film's dielectric function measured by rotating polarizer ellipsometry

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With the emergence of nanotechnology, spectroscopic ellipsometry (SE) got an important role in optical characterization of ultra-thin nanostructured films [1]. Using this technique, various relevant characteristics such as film thickness, surface roughness and optical functions can be determined, but only by proper modeling of the near-surface region of multilayer samples.

In this work, we investigated the extraction of optical properties of ultrathin (~5 nm) films composed of a single layer of core-shell CdSe-CdS nanoplatelets on SiO_2(85 nm)/Si(bulk) substrate. The ellipsometric spectra were measured using SE in rotating polarizer ellipsometry (RPE) configuration. We compared two standard approaches for SE thin film analysis: "point-by-point" inversion and model based (parametrized) data fitting [2]. While the model based data fitting is quite effective in the case where the shape of film's dielectric function is easy to anticipate, one should be careful with analysis of nanometer scaled film thicknesses. Since they are very thin, reasonable goodness of fit could be misleading. On the other hand, "point-by-point" inversion suffers from the fact that the neighbouring wavelengths do not support each other, eventually leading to lack of Krammers-Kroning consistency [3]. It also strongly depends on measurement precision and sensitivity which is critical in RPE configuration in case of Δ being close to 0 or 180° [4]. For both approaches, pre-knowledge about the underlying substrate is essential. Having all this in mind, the combination of both "point-by-point" inversion and parametrized fitting should be applied.

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Influence of In^+ ions implantation in GaAs and Si on their optical characteristics

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In this work we studied the influence of In^+ ion implantation on structural and optical characteristics on semiconductors with direct (GaAs) [1] and indirect (Si) [2] band gap. A plenty of information on physical properties of various semiconductor materials can be obtained from optical spectra. In order to determine optical parameters, refraction index and extinction coefficient, we employed spectroscopic ellipsometry as a very useful technique. The parameters of the implantation process and the optical properties of the implanted GaAs and Si wafers are discussed with particular emphasis on the SWIR (Short Wavelength Infrared) region.

In^+ ions were implanted into n-type GaAs (100) and n-type Si (100) at an acceleration energy of 60 keV with doses of $1x10^{14}$ ion/cm^2, $5x10^{14}$ ion/cm^2, $1x10^{15}$ ion/cm^2 and $2x10^{15}$ ion/cm^2 in both cases.

The change of the optical parameters in the subsurface region of the GaAs and Si wafers caused by implanted In^+ ions is observed comparing the values of ellypsometric data and energy gap (Eg) of unimplanted and implanted wafers.

In order to evaluate the crystallinity of the samples we used TEM microscopy.

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Wavelength Converter Materials for Photovoltaics Containing Rare-Earth Ions

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Wavelength converters have been proposed as one of the ways to achieve higher efficiency in third generation solar cells [1]. The idea is to shift the wavelength of the light absorbed by the solar cell to the spectral region where the device is most efficient. Higher energy photons are often absorbed unproductively near the front contact of the solar cell. By the application of photoluminescent materials these photons are transformed into longer wavelength ones, which contribute more effectively to the generated photocurrent.

In this contribution wavelength converter materials containing luminescent rare-earth ions are examined on the example of Tb^{3+}. Results on the preparation and luminescent properties of thin films containing Tb^{3+} prepared by magnetron co-sputtering are presented. On the other hand the improvement that a wavelength converter containing Tb^{3+} can produce on the efficiency of a thin film silicon single junction solar cell under AM 1.5 solar radiation is assessed by model calculations. Improvement of between 1 and 2.3% in the efficiency of the solar cells is estimated. These results compare favorably to recent experimental data on the enhancement of the efficiency of silicon-based solar cells using flexible transparent luminescent films containing trivalent rare-earth ions [2].

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Negative thermal expansion of pullulan multilayers

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The change of temperature leads to thermal expansion. Most materials expand, but, some materials contract upon heating, characterized by negative thermal expansion [1]. Such negative thermal expansion material have various applications such as photoelectric devices, fillers in controlled thermal expansion composites, aerospace technology, as dental fillings [2].

We combine holography and phase separation [3] to design complex photonic structures that exhibit negative thermal expansion behavior. The structures were recorded in pullulan, (linear polysaccharide) doped with ammonium dichromate, and consist of a multilayer composed of pullulan and air.

We study optical response during heating and cooling of the synthesized pullulan nanostructures. The reflection wavelength of the hologram was used to characterize the temperature dependence of their shrinkage and swelling behavior. By heating and cooling the sample partially reversible shifts of the photonic band gap could be observed. We have observed that heating leads to a reduction in the thickness of the structure, resulting in the reflectance peak shift towards shorter wavelengths. With temperature decreasing the band gap position shifts back towards longer wavelengths. We reveal temperature sensitive responses of the structure, which are the consequence of the mechanical deformation of air nanolayers upon heating or cooling. The temperature change leads to the increased permeability of air molecules through the pullulan nanolayers, which causes mechanical changes.

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Large-scale deposition of self-assembled thin films from liquid phase exfoliated h-BN

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Degradation processes, such as exposure to oxygen, humidity, temperature and ultraviolet (UV) illumination makes the intrinsic lifetime of the various optoelectronic devices, such as organic or 2D materials based solar cells, without encapsulation very short [1]. Hexagonal boron nitride (h-BN) is among the most interesting 2D materials, due to its exceptional properties as an inert passivation layer that can protect devices against environmental and chemical effects. A large area, high quality, inexpensive method for depositing thin h-BN has not been reported to date [2]. Here we demonstrate uniform large area h-BN thin films deposited from solution on solid substrates. h-BN was exfoliated from powder using liquid phase exfoliation (LPE) and deposited on a substrate using the Langmuir-Blodgett self-assembly technique (LBSA) [3]. The optical and structural properties of our thin films were characterized with UV-VIS spectrophotometry, Raman spectroscopy, X-ray photoelectron spectroscopy and optical and atomic force microscopy. Our fabrication method results in films with an optical band gap of 5.45 eV, high substrate coverage and an average thickness of 4 nm. The method features uniform deposition over large areas on any kind of solid substrate. Our inexpensive, facile, reproducible and reliable assembly method bridges the gap for use of h-BN as an ultrathin protective coating on various materials that are subjective to molecular degradation.

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Atomic layer deposited Al-doped ZnO for flexible optoelectronics

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With the emergence of flexible electronics, transparent conducting oxides (TCO) alternative to ITO (indium tin oxide) have attracted increasing attention because their constituent raw materials are nontoxic, abundant and with low cost. TCO materials [1] are utilized as electrode materials in a wide variety of optoelectronic devices, including photovoltaic cells, flat panel displays, and organic light-emitting diodes (OLEDs).

Atomic layer deposition (ALD) has been the thin-film deposition method of choice for a number of challenging applications in microelectronics, and it should be a highly relevant technology for the transparent flexible electronics as well [2]. A high-performance conducting Al-doped ZnO (AZO) thin film electrodes are deposited on mica substrates by alternating diethylzinc $Zn(CH_2CH_3)_2$, DEZ; $Al(CH_3)_3$, TMA and deionized water (H_2O) precursors in an ALD reactor (Beneq TFS-200) at 150-200 °C. Structural, electrical, and optical properties of deposited AZO films on mica are measured towards the TCO application. It is found that AZO/mica retains its low electric resistivity, even after continuous bending of up to 1000 times due to the unique layered structure of mica.

Moreover, AZO/mica –based flexible light valve device using polymer dispersed liquid crystals (PDLC) has been fabricated, supported by video demonstration of the device functionality. The measured driving voltage and response time values reveal the great potential of AZO/mica for integration into the next generation ITO-free flexible and stretchable devices.

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Analytical model of amplification in strained Ge

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Strained germanium attracts a lot of attention as a potential gain medium for monolithically integrated laser sources compatible with Si technology. The first observation of lasing in strained germanium was reported almost a decade ago [1]. However, the mechanism of lasing was not clear. Indeed, the measured amplification on inter-band transitions in Ge with strain level corresponding to that of [1] was found to be more than an order of magnitude smaller than pump-induced absorption for injected carrier densities about 10^{20} cm^{-3} [2]. Rigorous numerical calculation [3] have shown the possibility of non-monotonous pump power dependence of gin in strained germanium positive gain in germanium not associated with heating [3]. However, numerical calculations do not answer the questions: what are the parameters that determine the optimum level of pumping and what is the condition of positive gain in strained Ge.

In this paper we build an analytical model of lasing in strained germanium. Within this model, the dependence of the inter-band gain and of the intra-valence band absorption on frequency, temperature and chemical potentials of electrons and holes are described by analytical functions with a small number of parameters that can be calculated numerically or obtained from experiment. We show that different analytical approximations are valid for the maximum of the inter-band gain in the different areas of the plane of dimensionless chemical potentials of electrons (ζ^*) and holes (η^*), thus creating the gain map. The growth of the inter-band gain with the increase of the hole chemical potential is relatively fast at the onset of the population inversion and slows down in the areas with $\zeta^*+\eta^*>1$, as in this case population inversion is close to its maximum value. The main mechanism of absorption at inter-band frequencies in moderately strained germanium is due to transitions between the heavy hole and split-off subbands. The absorption coefficient grows exponentially with increase of η^* as long as the energies of heavy holes required for this transition exceed their chemical potential by more than the thermal energy. This difference of the dependences of the inter-band gain and inter-valence band absorption on the hole chemical potential explains the non-monotonous pump power dependence of material gain in strained germanium. We analyze the boundary of the zone of the positive total material gain in the (ζ^* η^*) plane and formulate lasing conditions in strained germanium: we determine the minimum strain sufficient for lasing in undoped material, the minimum doping level required for lasing as a function of strain, and the optimum pump power as a function of strain and doping level.

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Intersubband transitions in spherical quantum dot-quantum well nanoparticles

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In this paper, we present results about electronic spectra and optical properties of one-electron spherical quantum dot-quantum well (QDQW) structure. Investigated structure consists of CdSe core surrounded by ZnS shell and caped by infinitely high electron potential barrier which can be a good model for any enough high potential barrier.

This specific QDQW structure is determined by CdSe and ZnS properties (effective masses and conductive band offset) and the structure composition.

We present calculation results for one-electron ground (1*s*) state and the first excited (1*p*) state transition. For this transition we have calculated oscillator strengths and linear and third-order nonlinear intersubband absorption optical coefficients for various structure compositions i.e. different CdSe core radius and ZnS barrier width.

Change in core and shell dimensions induces change in one-electron wave function i.e. localization and energy of electron states, for both 1*s* and 1*p* state. As a result, intersubband 1*s*-1*p* transition of this system is greatly dependent on the structure composition. For very small core radius, less than 0.7 nm, and core radius over 1.5 nm the most probable intersubband transition is 1*s*-1*p*, but in the region between 0.7 and 1.5 nm core radius, transitions from 1*s* to other *p* states dominates. Investigated properties depend mostly on the core radius. These results connect structure of the dot and optical properties of this particular structure. Also it is illustration about behaviour of similar systems.

Diatom frustules: A biomaterial with promising photonic properties

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Diatoms are an ecologically successful group of unicellular microalgae with a wide distribution into almost all aquatic ecosystems as well as a large share, both in the organic carbon world primary production and the released oxygen from photosynthesis process. Arguably, the most interesting structural feature of these microorganisms is their siliceous cell walls called "frustules". These frustules are produced through elegant biomineralization processes. Beside other interesting facts about diatoms, recent studies suggest that their frustules show amazing optical properties including the light focusing in centric diatoms [1], photonic crystal properties [2] and UV-induced photoluminescence. It has been suggested that these properties are correlated with photo-regulation processes in the living cells by e.g. keeping the photosynthetically active radiation near the chloroplasts, and protecting them from harmful wavelengths and high light intensities. Moreover, the frustules may play a role in low light environments by redistributing the light inside the cells. Due to these reasons, manipulation of the optical properties of diatom frustules might be also beneficial in optical application, and e.g. lead to more efficient solar energy harvesters, with diatom solar panels proposed for the production of both electricity as well as biofuels. The power of diatoms to work with light is both fascinating in itself, and can be a source for the development of new technologies [3]. In this poster, we illustrate the state-of-art for this recently arisen topic, and present our contribution to expand studies towards a clearer understanding of diatom frustule photonics, their roles in photobiology as well as in future optoelectronic applications.

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Wearable laser Doppler flowmetry implementation for the analysis of microcirculation disorders

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Microcirculation plays an important role in maintaining the normal functional state of the body and is one of the first links involved in the development of various pathological processes [1, 2]. The laser Doppler flowmetry (LDF) is one of the most common methods to assess the blood microcirculation system state. Currently, there is a surge of interest in wearable electronic diagnostic devices, including ones that implement the LDF. The aim of this work was to assess the possibilities of using the novel wearable blood perfusion sensor system to evaluate impaired microcirculation in diabetes.

The studies were approved by the Ethics Committee of the Orel State University. The study involved 37 healthy volunteers, divided into 2 groups accordingly to their age, and 18 patients with type 2 diabetes (9men, 53.2±11.4 years). The 1st group of volunteers consisted of 16 subjects (8 men) with the age of 19.6±0.6 years, the 2nd group included 21 volunteers (10 men) with age of 52.6±10.2 years. All other parameters of these two groups except age did not have statistically significant differences. A novel wearable distributed multipoint LDF system consisting of four "AMT-LAZMA 1" devices (Aston Medical Technologies Ltd., UK) was used to analyse microcirculatory blood flow. The system consists of peripheral blood flow analyzers and can be used to record the microcirculation index simultaneously from several points of the body. Volunteers sat with their hands at heart level. The analyzers were located on the dorsum of the wrists and on the volar surface of the middle fingers. Each study consisted of a 10-minute recording of the LDF signal simultaneously from 4 points and subsequent data processing.

The highest level of microcirculation was registered in the second control group, and the lowest - in the younger group of healthy volunteers. The microcirculation index in patients was significantly higher than in the young control group but less than in the second one. The result may be associated with age-related changes in the blood microcirculation. In previous works, an increase in perfusion with age was explained by morphological changes in the microcirculation system [3]. Microcirculation disorders have also been demonstrated in patients with diabetes, due to various reasons [4].

The study has shown that the use of a wireless wearable fibre-free LDF device is a very convenient solution for use in a point-of-care diagnostics. A promising direction in the development of the sensors is the analysis of the microhemodynamics parameters synchronization while simultaneously measuring the signal from symmetrical parts of the body.

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The use of microbial rhodopsin proteins in differential photodetection

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Microbial rhodopsin proteins are often seen as the "eyes" of microbes, as they not only resemble the light receptors in our eyes in structure, but also undergo light-induced structural changes that can lead to signaling cascades within microbes to lead them toward favorable territories, or to the production of ATP (the unit of energy in a biological cell). The absorption of light by the retinal chromophore in the protein moiety leads to its photo-isomerization, which can lead to the temporary release or uptake of a proton or ion by the protein [1]. Thus, under constant illumination, the chemical doping of a protein film in buffer solution can be achieved. Implementing such a protein film as the photoactive layer in a recently developed photodetecting device architecture, in which a thick liquid insulating layer (I) is inserted between the photoactive layer (S) on a metal electrode (M) and the counter electrode (M), leads to a clear differential photocurrent response, typical for the MISM device architecture [2].

Here, we will present our recent results into the use of 3 microbial rhodopsin proteins in such MISM photodetectors. We will discuss not only the device performance, in terms of responsivity, bandwidth and signal stability, but also what information we can gain through our studies under a range of conditions (temperature, pH, illumination wavelength), about the biomolecules themselves.

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Optical fiber grating sensors for the measurement of superficial temporal artery pulsations

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The measurement of arterial blood pressure waveform can provide important data about arterial health, from which general cardiovascular health can be estimated. The arterial blood pressure wave is created by heart contraction which then propagates along the arterial tree. Along its path, the pressure wave causes the distention of arterial walls which consequently can be palpated and measured as micro-movements on the surface of the body.

The most frequently used places on the body for recording of the blood pressure waveform are in the fingers and above the radial artery on the wrist. However, since waveforms recorded on the periphery of the body alter from central ones, there is the necessity for non-invasive measurements closer to the ascending aorta [1]. The purpose of this study was to evaluate the possibility of utilizing the superficial temporal artery (STA) as a potential candidate for obtaining arterial waveform recorded non-invasively by fiber grating sensors. The STA is a terminal branch of the external carotid artery and it represents the major artery of the head. The sites over the main branch (near the ear) and the frontal branch of the STA (near ocular area) are easily accessible ones with negligible amounts of fat and muscle tissues.

Assessment tests were carried out by using fiber grating sensors (fiber Bragg grating (FBG) and long-period grating (LPG)) as sensors of the arterial distention movement. Here we were focused on the possibility to record the STA pulsations in healthy volunteers when the sensors were just placed on the skin over the STA and fixed with the tape or elastic bandage. Our results show that with this type of application, LPG technology outperformed FBG in a sense of sensitivity and signal to noise ratio. The reason possibly lies in the fact that cladding modes generated by an LPG are much more affected by arterial distention than back-propagating core modes of an FBG [2]. By using LPG sensor we were able to record STA pulsations in all volunteers.

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One-step fabrication large area of microlens arrays

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The microlens arrays (MLAs) are greatly used in medical lasers, optical fiber sensors, light-field cameras, biochemical systems, biological structures... Numerous methods such as: hot embossing, thermal reflow, droplet process, grayscale photolithography… are used for the microlens fabrication [1-4].

One step fabrication of low-cost concave microlens arrays on tot'hema tartrazine sensitized gelatin layer (TTSG) was developed. The layer is easy to prepare, elastic, biocompatible, thermally stable and nontoxic [5, 6]. MLAs were produced by direct diode-pumped solid state laser writing, operating at 473 nm. In addition, the microlens diameter, depth, and distance between two adjacent microlenses were controlled by changing the laser power, exposure time and dye concentration. The large area of hexagonally or square-packed microlenses was made for a short time. The concave MLA is suitable as a master mold for the further fabrication of convex arrays onto the polydimethylsiloxane (PDMS) or dental composite. The results were showed that the closely packed microlenses possess high-quality surface morphology, good optical and imaging properties. Using MLAs clear and uniform images were observed. Potentially applications MLAs are artificial compound eyes, Gabor superlens, optofluidic system, etc. [7].

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Nonlinear microscopy and time resolved fluorescence spectroscopy of *Chelidonium majus* L.

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Greater celandine (*Chelidonium majus* L.) is a well-known healing plant. It has segmented laticifers filled with yellowish - brown content that is rich in biologically active substances (alkaloids, flavonoids and phenolic acids) [1, 2]. The concentration of these components can change significantly, depending on the time of year, from flowering period in spring to the fruit - bearing time in autumn [3]. Flavonoids (plant pigments) are responsible for the yellow color of the greater celandine flower [4]. The antioxidant activity was also correlated with the concentration of total phenolics (including flavonoids), which is the highest in the spring months [4].

This study presents the analysis of the physical phenomena diagnosed in Chelidonium majus components. Time resolved optical characteristics were analyzed by using TRLS (Time Resolved Laser Spectroscopy) experimental setup. Nonlinear optical properties of the plant have been studied using two-photon excited autofluorescence (TPEF), second - harmonic generation (SHG) and upconversion luminescence (UCL) simultaneously. The benefits of using UCL for biological applications are in reducing the photobleaching and providing photostability. Upconversion emission is also more efficient than the TPEF and SHG. Moreover, UCL could be achieved with a low power continuous wave (CW) laser.

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Multi-spectral Unmixing using Principal Component Analysis (PCA) for an Accurate Fluorescence Detection in Fluorescence Endoscopy

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This paper introduced a way to reduce a noise signal from multi-spectral images in fluorescence endoscopy using Principal Component Analysis (PCA). The white light endoscopy has been widely used for diagnosing colorectal cancer. However, this conventional endoscopy in morphology was insufficient to differentiate colorectal cancer. Multi-wavelength molecular fluorescence imaging techniques could provide the detection of specific fluorescence targeted molecules on cells in cancer pathogenesis. Recently, a fluorescence endoscopy with a function of multi-wavelength molecular fluorescence imaging has been reported to detect lesions in a colon [1]. However, autofluorescence regarded as a noise signal caused a problem to decrease imaging resolution in fluorescence image of a tissue. Autofluorescence is the light that naturally occurred when specific wavelengths were absorbed in intrinsic fluorescent molecules of a tissue. This autofluorescence reduces the detection accuracy of the actual fluorescence information in a tissue since this was spectrally overlapped with the fluorescence signal which we want to detect [2]. In order to overcome the problem, we studied on removing a noise signal like autofluorescence from the fluorescence signal of a tissue. We designed the optical system for multi-spectral fluorescence imaging that makes it possible to discriminate autofluorescence of a tissue. We utilized PCA method for more accurate multi-spectral unmixing to reduce autofluorescence [3]. PCA is a well-known multivariate statistical analysis and is commonly used as feature extraction method in data science. Traditional methods such as linear spectral unmixing [3] were difficult to perform multi-spectral unmixing because the method requires knowing not only the spectral characteristics of each fluorescence element, but also the relative proportion of each element in spectral image. However, PCA can discriminate each element by extracting principal components with dimensional reduction though the characteristics of fluorescence elements are not given. Our experiment is performed on two samples, i.e. fluorescein sample and no fluorescein sample to prove the reduction of a noise signal considered as autofluorescence in the fluorescence endoscopy. We observed that multi-spectral unmixing using PCA could effectively discriminate autofluorescence in fluorescence endoscopy images. We believe that PCA could be a good unmixing technique to be applied in multi-spectral fluorescence endoscopy in the sense that PCA can identify sample fluorescence information in the fluorescence imaging.

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Revealing the optical response of *Stegastes apicalis* fin parts using fluorescence spectroscopy

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Many biological species exhibit fluorescence, during the interaction with external light, and different radiation processes such as fluorescence and phosphorescence play a significant role in intra and interspecies communication [1]. The different tissues generally emit lower-energy light (usually in the visible range of the electromagnetic spectrum) upon illumination by higher-energy light (typically, in the blue, violet or ultraviolet). In this work, we reveal at the first time the optical response of the *Stegastes apicalis* fin part combining fluorescence steady-state and time-resolved measurements.

Stegastes apicalis (Australian Gregory) settles the Great Barrier Reef off Australia's east coast, a unique ecosystem with many different and highly colorful organisms [1] at a depth of 1-5m. Up to now, many UV-A absorption pigments were found in different fish species that live in the Great Barrier Reef [2], and they are essential for various biological phenomena such as predator-prey interaction or species recognition.

The presented time-resolved fluorescent measurements additionally unveil the existence of complex excited state dynamics of the nano-probe (dye) embedded within the fish fin of *Stegastes apicalis*. Complex optical response is caused by a structural characteristic of fin parts associated with photo-physical properties of pigments [3].

Bleaching the fin parts with H_2O_2 also reveals the effect of chemical environment on the stability of the excited state visible through the changes of the spectra maxima and values of the decay time.

Besides the importance to reveal the photo-physical response of *Stegastes apicalis* fin tips, the interaction between incident UV-A and fluorescent tissues, probably also influences evolution strategies in diverse ecosystems such as the Great Barrier Reef in Australia.

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Ultrastructural investigation of perineuronal nets in tenascin-C deficient mice by super-resolution microscopy

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Perineuronal nets (PNNs) are specialized formations of condensed extracellular matrix (ECM) which surrounds cell bodies and proximal dendrites of different neuronal subpopulations. Their ultrastructure includes ECM constituents spatially organized into polygonal mesh shapes. PNN are primarily involved in the control of central nervous system plasticity and their degradation can reactivate structural plasticity.

Tenascin-C (TnC) is an ECM glycoprotein which plays a significant morpho-regulatory role during development and tissue remodeling. Our aim was to examine how TnC deficiency affects the changes in hippocampal PNN ultrastructure, after inducing plasticity changes by rearing TnC deficient (TnC-/-) and control wild-type (TnC+/+) mice in enriched environment (EE) for 8 weeks.

PNNs were fluorescently labeled with *Wisteria floribunda* lectin (WFA) and imaged using 3D Super-resolution Structured Illumination Microscopy (SR-SIM). This technique provided 150 nm resolution in lateral and 300 nm resolution in axial direction, thus enabling quantitative analysis of PNN ultrastructure by collecting topological parameters and WFA staining intensity.

Preliminary results showed more prominent changes in WFA signal intensity than in topological parameters. In the CA1 region of the hippocampus, WFA signal intensity was significantly increased in $TnC^{-/-}$ mice reared in EE as compared to the same genotype reared in standard condition (SC). In addition, the increase in WFA signal intensity was observed in the dentate gyrus of $TnC^{-/-}$ mice compared to $TnC^{+/+}$ mice, both reared in EE. Interestingly, regarding the ultrastructural organization of PNNs in dentate gyrus, $TnC^{-/-}$ mice reared in SC had more diffuse mesh than $TnC^{+/+}$mice reared in SC. In the CA2 region, $TnC^{-/-}$ mice reared in SC showed a decrease in WFA signal intensity compared to $TnC^{+/+}$ mice reared in same conditions. Finally, no significant differences between genotypes or rearing conditions were found in the CA3 region.

Our preliminary data imply region-specific contribution of TnC in shaping the ultrastructure of PNNs in the hippocampus.

Measuring temperature changes of butterfly's wing through deformation: a holographic approach

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Natural colors originate from either chemical or physical properties or both combined. Colors of chemical origin are caused by pigments and dyes, while structural colors arise from light interference [1]. The latter, is due to the interaction of visible light, with nanometer-scale features of biophotonic structures. The Morpho (*Morpho didius*) butterfly's wing scale appeared as an example of the most beautiful biophotonic architecture. This particular wing is densely covered with iridescent scales (structures which look as micro-cantilevers). Furthermore, tiniest features of this biophotonic structure match the mean free path of air molecules at atmospheric pressure (approximately 100 nm), which is an essential condition to observe the photophoretic effect.

Thermal transport induced by laser radiation produces an additional thermophoretic force that deforms the wing scales [1]. Resulting deformation was monitored by real time digital holographic interferometry [2]. This deformation of wing scales can be used as a novel method of detecting low level thermal radiation. In our experiments we reached a temperature detection sensitivity of 2.9 mK, with the detection threshold of several μJ/cm^2, depending on the wavelength [3].

ACKNOWLEDGEMENT: Here in this work, the concept of holographic detection of thermophoretic force is conceptually highlighted, experimentally confirmed and discussed.

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Laser-generated nanoparticle-coated microrelief against the formation of bacterial biofilms

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For decades, antibiotics were effective against the pathogenic microorganisms, but nowadays they are becoming useless. The over-extensive and sometimes unnecessary and careless prescription (or self-prescription by patients) of antibiotics, their adding to food and the livestock raised the resistivity of the bacterial strains, which lead to their mutation and acquired immunity to the several kinds of drugs. As confirmed by the World Health Organization [1], antibiotic resistivity of bacterial strains is becoming a grave problem in the modern world, and new methods against pathogenic microorganisms are in need. Laser-fabricated surface relief is actively used for the antibacterial applications, such as silicon (Si) microcones and metal nanospikes, which induce the bacterial death due to mechanical damage of the cell membrane [2]. Other way of laser ablation products use against pathogenic microorganisms include the application of nanoparticles (NPs), which induce bacterial death through the activation of super-oxidative stress, destroying the cell DNA [3]. A new type of antibacterial coating, combining the microscale roughness and the nanoscale chemotoxic effect, would allow a possibly faster and more effective effect on the biofilm formation. Therefore, in this work we present the results on biofilm growth prevention by using Si ripples, covered with Se, Te, Sb or Ag NPs.

Laser radiation of a fiber laser Satsuma (Amplitudes Systems) with λ = 1030 nm (energy up to 6 μJ, pulsewidth 0.3 ps) was focused on the surface of a polished Si target under the 2-mm layer of deionized water via an F-theta lens (F = 100 mm), and was raster-scanned twice across the 7x7 mm^2 areas with 100 lines/mm filling, scanning speed 12 mm/s and repetition rate 160 kHz. The resulting Si ripples were then covered with colloidal Se, Te, Sb and Ag NPs and air-dried, after which the testing of their antibacterial properties was performed on the *S. aureus* strain in form of biofilm. Culture of each bacterium, which was grown in a nutrient medium (lysogeny broth), was diluted with fresh LB 1:100. A Petri dish with 2 ml of broth culture was placed under an investigation glass. For biofilm formation, the plates were incubated for 4 h at 37 °C. A 'Live/Dead Biofilm Viability Kit' coloration set was used to differentiate between viable and non-viable bacteria in the biofilms. To visualize the bacterial biofilms, the fluorescent dyes - 3 μl SYTO®9 and 3 μl propidium iodide - were diluted in 1 ml of distilled water. Samples were analyzed using the fluorescence microscope Nikon H600L with a fluorescent lens.

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Cellular noise of butterfly wing scales as a potential true random number generator

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In this paper, we study possibilities to exploit biological variability on a cellular level (cellular noise) [1] as a potential source of true random numbers.

Here we show that the Butterfly wing scales are an excellent model system for studying cellular noise due to their durability and availability in nature [2]. They are nano-patterned, biophotonic, particles (NBP), producing randomly distributed interference and diffraction effects.

We performed structural characterization of Butterfly wing scales using SEM. Optical microscopy is used to determine their randomized local spectra, diffraction pattern, and nonlinear optical response.

Colorimetric image processing techniques are used for to analyze optical pattern. Variation in color intensities is a consequence of cellular noise and interaction of light with NBPs. The pattern is randomly distributed along a growth axis of a wing scale.

Images obtained by optical microscopy are analyzed pixel distance intensity values are binarized and represented in a form of binary arrays.

Binary arrays are tested as a random number generator using the NIST suite [2]. The first estimate shows that it is most likely a random process, which has the potential to be used as a true random number generator.

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In vivo Third Harmonic Generation Imaging of *Phycomyces blakesleeanus*

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Third Harmonic Generation is a nonlinear optical effect in which the incident laser beam interacts with a medium producing the light of exactly three times shorter wavelength than the incidental one. THG is generated in medium that have third order nonlinearity, but it is particularly pronounced at the interfaces where the steep change of refractive index takes a place [1]. THG phenomenon is employed in laser scanning microscopy that utilizes ultrashort laser pulses for imaging. The THG microscopy is a label free techniques that provides important information on the sample such as membrane imaging and lipid droplets distribution [2]. It is mostly used for *in vivo* imaging of small model organisms like zebrafish [3] and C. Elegance [4].

We present THG imaging of filamentous fungus organism *Phycomyces blakesleeanus,* combined with Two Photon Excitation fluorescence (TPEF). The hyphae were grown in various conditions on glass coverslips coated with collagen and concanavalin A. For THG imaging of label-free, 16-24 hour old hyphae, we used 1040 nm, 200 fs pulses from Yb KGW laser, while for TPEF, Ti:Sa pulses at 730 nm, 160 fs duration, were used. Both laser beams were focused with the same objective lens, Zeiss Plan Neofluar 40x1.3. Detection of THG was performed by PMT through Hoya glass UV filter with peak transmission at 340nm, while for TPEF 400-700 nm band pass filter was used. THG images revealed the chitinous cell wall and the membrane that are clearly separated. The appearance of the cell wall was confirmed by colocalization with TPEF images. Most prominent observation on the THG images is presence of numerous, seemingly randomly dispersed, round shiny features throughout the cytoplasm, for which we suspect that could be lipid droplets as indicated in Débarre et al., 2006.

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Long-period grating sensors for the measurement of apexcardiogram

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Apexcardiogram (ACG) represents record of low-frequency vibrations of the precordium caused by heart contractions. The information obtained from ACG is mostly related to left ventricular contractions. The most common position for its measurement is in parasternal area of chest wall, above the apex of the heart. The measurement of ACG can provide date significant in timing of systolic events of the cardiac cycle. Particulary, ACG is used as aid in timing of the opening snap of the cardiac valves, for the identification of the exact timing of the third (S3) and fourth heart sounds (S4) and for early diagnosis of the mitral valve stenosis or regurgitation [1].

The frequently used methods for non-invasively recording of ACG include using of electro manometer sensor, piezoelectric microphone sensor and crystal-microphone sensor for measuring mechanical displacements of chest wall [2]. The disadvantages of these sensors are potential noise caused by electrical interference and technical difficulties in their application on body surface. The goal of this study is to evaluate possibility of using long-period grating (LPG) sensor as potential non-invasive method for ACG recording. The advantages of utilizing LPG sensors are their low cost, utilization simplicity, and insensitivity to electrical interference.

The study protocol includes measurements on group of healthy volunteers utilizing a single LPG sensor. LPG sensor is positioned in paternal area of chest wall, above the apex of the heart and fixed with the elastic bandage. It is used as a sensor of mechanical pulsation on the body surface. All healthy volunteers are asked to hold their breath in mid-expiration phase for at least 10 seconds in order to avoid the interference of the ACG with a breathing signal. Our results show that we are able to record signals with morphology of normal ACG repeatably on each healthy volunteer, and with the significant signal-to-noise ratio. Hence, we can conclude that LPG sensors can be used for recording ACG by measuring mechanical low-frequency vibrations of the precordium on the body surface above the apex of the heart.

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Effects of cerium-dioxide nanoparticles in cervical cancer cells studied by Raman spectroscopy

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Study of the interaction between nanoparticles and human cells is usually performed using customized biochemical assays that mostly offer measurements of a single quantity/property and use labels. Raman spectroscopy on the other hand offers integral insight into complex information on biomolecular composition and molecule conformation inside cells by measuring vibrational spectra from the entire cell [1]. Furthermore, it does not require dyes nor other labels and sample preparation is very simple, which reduces time consumation and possibility of cell damage during preparation.

Cerium-dioxide (CeO_2) nanoparticles are known for their controversial dual activity in numerous studied cancer cell lines: while protecting some cell types from oxidative damage, their cytotoxic effect in other cell lines is also reported [2, 3]. Here, effects of two types of CeO_2 nanoparticles: uncoated and dextran-coated, were studied in HeLa cells, a cervical carcinoma derived cell line. Nanoparticle-treated cells were probed by routinely used biological assays for cell growth and viability, based on dying with Sulforhodamine B and Trypan Blue, respectively [3]. The tests have shown that the nanoparticles have more prominent effect on cell growth than on viability. In the light of this information Raman spectroscopy was employed in order to investigate the changes in biomolecular content of the cervical cancer cells after treatment with nanoparticles and find connection between these changes and the resulting cell status. Raman spectra of nanoparticle-treated and control (untreated) cells were obtained using 532 nm laser line as an excitation probe. From each experimental group, at least 250 cell spectra were measured. Principal component analysis (PCA) covering the spectral regions (700-1800) cm^{-1} and (2800-3200) cm^{-1} has extracted the differences between vibrational spectra features of nanoparticle-treated and control cells, but also between spectra of cells treated with uncoated and coated CeO_2 nanoparticles. These changes have been associated with induced alterations of prominent groups of biomolecules, DNA, lipids and proteins. Reduced total DNA content and/or breaking of O-P-O bonds leads to the decreased vibrational intensity of 785 cm^{-1} peak which differentiates to a large degree treated and control cells. Amide I vibrational band (1600-1670) cm^{-1}, characteristic for peptide bonds and modulated by proteins secondary structure, differentiates between cells treated with coated and uncoated nanoparticles. Correlation of the spectral information with the results of biological assays was performed.

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Femtosecond laser for dentinal hard tissue ablation

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In this study we present testing and optimization of the use of femtosecond laser (FS) in diagnosis and treatment of caries in hard dentinal tissue [1]. We use non-invasive optical methods based on Nonlinear Laser Scanning Microscopy - NLSM, to visualize dentinal tissue "in vitro", noninvasively without damaging the sample.

In our home-made experimental set up for NLSM, we used two modalities for imaging: Two Photon Excitation fluorescence (TPEF) and Second Harmonic Generation (SHG) in reflection arm. A mode locked Ti:Sa laser emitting 160fs pulses in the range 700-900nm is used as the light source for these two modalities. For SHG imaging the laser is tuned to 840nm and 420nm narrowband (10nm) filter is used, while for TPEF the laser was set to 730nm and broad band (400-700nm) filter was used. SHG imaging is used for the label free visualization of caries related collagen degradation [2]. At the same time, fs laser does not cause tissue damage and can be controlled to work only on a chosen surface, avoiding collateral thermal and mechanical damaging of underlying healthy tissues.

We use results obtained by these microscopic techniques as the input diagnostic parameters for microscopically precise ablation of carious lesions. Fs pulses of higher power are used for minimally invasive, highly precise and selective removal of NLSM-diagnosed caries dental tissue, by the ablation process [3]. The procedure needs to be optimized in order to be able to be transferred potentially to clinical practice.

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Antibacterial coatings based on polymer-metal nanoparticles

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At present, one of the problems of a global scale is the fight against pathogenic microorganisms. Especially resistant are pathogens capable of forming biofilms. Biofilms are resistant to the action of various stresses, including the action of antibiotics, disinfecting chemicals. Therefore, the search for alternative ways of dealing with pathogenic microorganisms is on the agenda of modern medical microbiology. Recently, nanotechnology has played a large role in applications for medicine and microbiology [1-2]. Nanoparticles (NPs) are increasingly used to target bacteria as an alternative to antibiotics [3].

In this work, polymer / metallic nanoparticle coatings were obtained by laser ablation. Thin metal (Ag, Cu, Au) thin films produced by magnetron sputtering in an argon atmosphere on polymer substrates were used as targets. Laser ablation was performed with the use of an Yb^{3+}-doped fiber laser HTF Mark, Bulat (λ = 1064 nm, pulsewidth FWHM τ = 120 ns). Laser pulses with pulse energy E=0.2 mJ, coming at f = 20 kHz, were focused by the objective of the galvanoscanner into a 30-μm wide (1/e-diameter) spot on an inverted polymer substrate with a metal film and scanned across 10x10 mm^2 area with 14-lines/mm filling. Thus, polymer / metal nanoparticles in the form of a coating were transferred to a glass slide with a biofilm lying at a distance of 3 mm from the sample. Disk diffusion test was used to assess antibacterial properties of the studied coatings. The obtained nanocoatings demonstrate the excellent antibacterial properties relative to Gram-positive pathogen Staphylococcus aureus. In addition, Cu/polymer NPs showed higher antibacterial effect compared to the other metallic NPs.

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Laser irradiated thioridazine: application in fighting multiple drug resistance acquired by bacteria

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Given the high costs and slow pace of drug discovery and development, repurposing of available drugs to treat multidrug resistance in bacterial pathogens became an attractive pathway. Thus, the use of already tested compounds, with lower overall development costs and shorter timelines becomes interesting. In this respect, phenothiazines are good candidates in drug repository, possessing antimicrobial activities, as well [1]. More, when exposed to 266 nm laser radiation their antimicrobial activity is improved several times and the toxicity is decreased [2]. Related to exposure to laser radiation, an important issue in drug discovery and development process is the drug analysis. This is performed mostly using HPLC systems, the process being expensive and time consuming. Faster and cheaper approaches are needed in order to identify and characterize the drugs. A promising solution is the high-performance thin layer chromatography (HPTLC), an offline method that is superior to other analytical techniques in terms of total cost and time for analysis. HPTLC plates were investigated using a single-track scanner that employed a monochromatic light generated by picosecond laser, where an optical fiber was used for the collection of reflected light in conjunction with a spectrograph (fluorescence) and oscilloscope (fluorescence lifetime). This approach simplified data acquisition and allowed easy application of modern approaches for separation and optical characterization of mixtures with antimicrobial properties.

Thioridazine solutions dissolved in ultrapure water were irradiated with 6.5 mJ, 266 nm pulsed (6ns, FWHM) laser beam for time intervals between 1 and 240 minutes. Antimicrobial activity was tested in vitro by performing susceptibility tests on micro-organisms using minimum inhibitory concentration. The techniques used to characterize the photoproducts were absorption spectroscopy, HPTLC steady-state and time resolved fluorescence, and FTIR.

Irradiated thioridazine proved to be suitable candidate in fighting antimicrobial resistance. The analyses techniques proved to be suitable means to identify the photoproducts formed during irradiation; they provided information about transformations that occur in molecular structure during irradiation. The results have shown that exposure to 266 nm laser radiation generates photoproducts that contain sulfoxide and phenol groups in their chemical structure.

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Multiple parameter fiber-integrated sensors based on diced Fabry-Perot micro-resonators

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Fiber-optic sensors have gained much attention in diverse areas such as environmental and industrial process monitoring, biology, chemistry and medicine due to their excellent characteristics which include small size, easy fabrication, high sensitivity, bio-compatibility and immunity to electromagnetic interference [1]. Among them, fiber sensors based on Fabry-Perot (FP) interference are advantageous for measuring physical parameters of fluids and gases such as refractive index (RI), temperature and pressure. Furthermore, all-fiber geometry allows for multi-parameter and distributed sensing by multiplexing of several sensors in a single fiber.

In this work, we report on both a single- and a dual-parameter fiber-integrated FP micro-resonator sensor formed by single-step diamond blade dicing through the core of an optical fiber using a precision wafer saw [2,3]. A standard step-index silica fiber (SMF-28) and a cut depth of 80 μm were used. Fiber cavity lengths of 40 μm and 90 μm were chosen to keep the diffraction losses within the cavity low while preserving at the same time sufficient mechanical rigidity. To avoid back-reflections the free fiber end was cut at an angle. In the dual-parameter sensor [3], a rectangular parallelepiped Si piece (60 x 50 x 75 μm^3) that serves as a temperature sensing element was glued into the fiber cavity. For both sensors the measurement setup consists of a broadband fiber-coupled superluminescent diode with a center wavelength of 1.55 μm, an optical spectrum analyzer, and a fiber circulator for collection of the back-reflected light. The single-parameter sensor with only one FP cavity [2] was used to measure RI of sucrose solutions as well as of air. Its performance was examined by tracking the peaks of the FP spectrum using parabolic fitting to the spectral minima and averaging over several calculations in order to increase accuracy. With the single-resonator RI sensor, 10^{-5} refractive index unit (RIU) steps of test solutions were accurately measured with experimental sensitivity of 1160 nm/RIU.

To extract the small changes of the optical path lengths changes of the dual-parameter (RI and temperature) sensor [3], phase tracking of the cavities' characteristic Fourier transform components was performed [4]. This sensor exhibited temperature sensitivity of the Si resonator of 0.097 rad/°C (85.2 pm/°C) and a RI sensitivity of the open cavity of 290 rad/RIU (1130 pm/RIU), and was capable of simultaneous measurements of temperature with an accuracy of 0.01 °C and temperature compensated 10^{-3} RIU changes of liquid samples.

To summarize, we presented two miniature FP interference-based fiber-integrated sensors which possess high resolution and sensitivity and have a total length of only ~100 μm. Our next steps will be focused on further increase of sensors' functionality by combining a bigger number of sensing elements in a single fiber, by testing evanescent field sensors produced by shallower diamond blade fiber cuts, as well as by using various functional materials for filling the diced FP and evanescent field sensing cavities.

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Quasinormal modes of finite linear arrays of spherical silicon nanoparticles

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The most important problems connected with the design of integrated photonic circuits are miniaturization of photonic elements and efficient transport of electromagnetic energy. Standard dielectric waveguides can support nearly lossless light propagation, but they usually suffer from the diffraction limit, which requires that the transverse size of a waveguide must be larger than half the wavelength of the guided wave, making its miniaturization difficult. The approach which exploits non-propagating (evanescent) fields rather than propagating light waves, provides a way of circumventing the diffraction limit [1]. Recently it has been shown that one-dimensional chains of dielectric nanoparticles can be used to fabricate high quality waveguides [2,3].

In this paper the quasinormal modes of finite length silicon nanosphere linear arrays have been systematically studied numerically using three-dimensional finite element method (FEM), taking into account material dispersion characteristics. Since the inclusion of chromatic dispersion complicates the problem considerably, most of the existing studies do not take these effects are not considered. Quasinormal modes not only contribute to the understanding of complicated waveguide spectral features, but they also have practical advantages from the numerical point of view, since a full eigenmode calculation is generally faster than a large number of single-frequency simulations [4].

Calculations were carried out by COMSOL FEM packages for a wide range of distances between the spheres. It is shown that spectrum depends on the number of nanospheres in the system, in a similar manner as in the case of microrings, we studied in our previous paper [5]. The differences for the cases of odd and even numbers of spheres, and its implications on actual applications, are discussed in details.

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Differential Photodetectors: From Photonic Devices to their Use as an Analytical Platform

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The addition of a thick insulating layer (I) between the semiconductor (S) layer and the metal (M) electrodes in a conventional MSM photodetector induces a differential photoresponse due to capacitive charging/discharging of the insulator layer by the photo-induced polarization of the active semiconductor layer in the MISM device [1]. The magnitude of the photoresponse in such differential photodetectors can be greatly enhanced by using high-*k* electrolytic insulator layers (I'), such as ionic liquids, through the strong influence of the highly energetic SI' interface on charge separation and stabilization. The move towards liquid insulating systems not only allows direct illumination of the active layer without the need for transparent electrode contacts, but also extends the choice of photoactive materials to include biomolecules, which benefit from a fluid environment [2]. Upon further insertion of a low-*k* polymer dielectric (I'') at the opposite MS contact, yielding a "floating" photoactive layer, the resultant MI'SI''M architecture ensures purely non-Faradaic operation, and allows the responsivity and bandwidth to be mutually improved, thereby breaking the responsivity-bandwidth trade-off that limits the MISM architecture [3].

This talk will focus on our recent results in differential photodetection utilizing organic, biological and, more recently, inorganic active layer materials, including viable strategies for their optimization and their applicability for motion detection. Furthermore, using a number of examples, their merits as an analytical tool for the characterization of (novel) (bio)materials will be discussed.

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From single-pixel to multi-pixel differential photodetectors

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In recent years, increasing attention has been directed towards organic or alternative materials for (opto-)electronic devices, due to their merits such as low-cost, wavelength-tunability, potentially greener raw materials, as well as the possibility of fabricating flexible devices [1]. Because of their distinct properties and modes of operation, their implementation into real devices has moved from conventional device architectures towards novel devices, which build on their strengths. Within several strategies, in 2010 a novel photodetector device architecture was proposed, in which an insulating layer (I), was inserted between the semiconductor layer (S) and one of the metal electrodes (M) in a conventional device architecture. Especially when moving towards liquid insulating layers, those MISM architectures could achieve comparably high responsivities, even for materials of comparably low carrier mobility. Notably, through the formation of electric double layers (EDLs), it could be shown that charge separation could be enhanced through the existence of a strong electric field at the SI interface [2]. Furthermore, the information about the surface polarization at the SI interface could be transferred, without significant voltage drop, over comparably long distances, leading to the development of e.g. planar devices architectures, which have no need for transparent electrodes in their design [3].

In this poster, we will present our first experimental results about the operation of multi-pixel EDL-MISM devices, showing that the merits of MISM can be maintained in a multi-pixel array, and present a discussion of several unique phenomena observed in this architecture.

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Method to realize a non-reciprocal wave retarder

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With the exception of Faraday rotators, standard non-absorbing, lossless optical elements used in polarization optics are reciprocal, in the sense that their function is invariant upon time inversion. Consider for instance a standard optical rotator, which rotates a linear polarization by an angle θ irrespective of the direction of the input polarization. Such an element can be easily realized by combining two half-wave plate retarders [1] whose principal axes are oriented under a mutual angle $\theta/2$. If used in the reversed direction the rotator brings back the polarization to its original direction and fulfills therefore reciprocity. Similarly, any standard wave-plate retarder is reciprocal because the wave retardance does not depend on the direction of propagation of the light.

In the present work we theoretically propose and experimentally verify a new method to realize non-reciprocal wave retarders, for which the retardance differs in the forward and backward directions. The method is based on a combination of two rotators sandwiched between quarter-wave plates. One of the rotators is reciprocal, as described above, while the other is a non-reciprocal Faraday rotator. The cascade of these two elements leads to an overall polarization rotation that differs in forward and backward direction. The combination of a rotator by an angle θ between two crossed quarter-wave plates gives rise to an effective retarder with a retardance $\varphi=2\theta$. We can use this property for instance to realize a retarder with a retardance π in the forward direction (half-wave plate) and $\pi/2$ in the backward direction (quarter-wave plate) or any other combinations of retardance values.

We will present details of the theoretical background of the new method as well as its experimental verification. Non-reciprocal elements are important in various fields of optical research and technology, including telecommunication, optical information processing, laser technology or quantum optics.

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Broadband polarization beam splitting based on three coupled anisotropic waveguides

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In the last few years adiabatically evolving systems inspired by adiabatic quantum dynamics processes were shown to allow a robust (broadband) light transfer among optical waveguides [1]. An example of such a process is the STIRAP-like (STIRAP = STImulated Raman Adiabatic Passage) light transfer [2,3]. It consists of a system of three waveguides with space-dependent mutual coupling arranged in a counter-intuitive order. So, by a proper choice of the parameters, a light beam injected into the first waveguide can be fully transferred to the third one irrespective of its wavelength over a broad spectral range. A key parameter for this process to occur is the refractive index contrast of the waveguides which governs the coupling coefficients. Based on the above phenomenon, here we propose a method for realizing broadband integrated polarizing beam splitter (PBS) in waveguide systems with strongly anisotropic refractive index contrast. In such systems the STIRAP-like light transfer takes place for the polarization associated with the lowest index contrast, but is inhibited for the other polarization. In our case, the TE polarization is considered to have the smallest index contrast. So, an unpolarized light injected into the first waveguide, the TE component of the beam must be coupled and must exit the third waveguide. The TM component must remain in waveguide1. As little light as possible should be lost to the second waveguide. Calculations by means of the coupled mode theory and numerical simulations by the Beam Propagation Method (BPM) indicate that an anisotropy factor of 5 (ratio between TM and TE index contrast) is sufficient for a robust discrimination between the TE and TM polarization into two different output waveguides around 1550 nm. The spectral bandwidth of such PBS is about 500 nm for these conditions and increases with increasing anisotropy factor. Various methods to achieve such anisotropic contrast waveguides, can be considered among which are local electric field-induced waveguides in photorefractive materials that exploit the anisotropy of the electro-optic response. Another possibility involves the creation of waveguides with an anisotropic core induced by the fabrication process for instance by a combination of ion indiffusion and proton exchange in $LiNbO_3$. A third possibility would involve waveguides with isotropic core but anisotropic cladding, for instance using liquid crystals. The system which is going to be presented in this conference is a first step to conceive such a broadband PBS and is a further demonstration of the strong potential of analogies between quantum physics and optics to conceive robust photonic devices.

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High-beam quality sealed-off laser systems oscillating in middle infrared spectral range on strontium atomic transitions for application in material science and medicine

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Laser application in various fields in science and technology, including medicine and human health, is one of the leading problems in laser physics. The ultimate aim of laser ablation is to efficiently remove a defined amount of material with the least amount of collateral damage and smear layer. By means of a free electron laser (FEL) with variable wavelength in the middle infrared (MIR) spectral region between 3 and 20 μm, it has been found that the laser radiation at 6.45 μm is the most effective tool for soft tissue and bone ablation with minimal thermal damage and smear layer [1,2]. Application of FEL in clinical systems for precise laser ablation of soft tissue and bones is inhibited by its size, cost, and considerable overheads. Further use of 6.45-μm radiation in medicine requires the development of an alternative laser source delivering 6.45-μm radiation with output parameters capable of soft tissue and bone ablation and having much greater clinical relevance. Multiwatt high-beam-quality strontium (Sr) atom laser with Sr, strontium dibromide ($SrBr_2$) and strontium dichloride ($SrCl_2$) vapour oscillating at 6.45-μm laser line could be successfully applied instead of FEL. The use of strontium halide instead of metal strontium is imposed by the high chemical activity of strontium, resulting in reduction in the laser tube lifetime. Nevertheless, investigation on Sr atom laser with Sr vapour continues, because of the higher energy laser characteristics in comparison with the obtained ones at the use of $SrBr_2$ and $SrCl_2$ [3-5].

Various types of Master Oscillator – Powerful Amplifier (MOPA) laser systems are developed and investigated, using sealed-off laser tubes with different inserts, confining the active zone (BeO and Al_2O_3), and thermal insulation (Al_2O_3 powder and AL_2O_3:ZrO_2 fibrous insulation). Active zone sizes (inner diameter and length) and thermal insulation thickness are also varied. Laser oscillation with superior high-beam-quality (near diffraction limit) is obtained at two Sr^+ and several Sr atom lines in the MIR spectral range with different levels of average output power, which is maintained constant for hundreds of hours in a sealed-off regime.

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Two different types of S-Shaped J-V characteristics in organic solar cells

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In this paper S-shaped characteristics of organic solar cells are analyzed by a drift-diffusion model which includes surface processes on the anode and cathode through boundary conditions. The model is described in [1] and it is extended by the transfer matrix calculation of interference effects [2], the Scharfetter and Gummel discretization [3], and the boundary conditions that take into account the finite surface recombination velocities and thermally activated charge carrier densities at contacts [4]. The surface recombination velocities for electrons and holes on both contacts have been varied as well as the injection barriers for both types of carriers.

By reviewing the literature [4, 5], two different types of S-shaped J-V characteristics in organic solar cells can be distinguished. The first type of the S-shaped J-V characteristic that is more often seen in literature, manifests S-shape bending in the vicinity of the voltage axis, after which it rises almost exponentially [4, 5]. The other type of S-shaped J-V characteristic proceeds to grow monotonically after bending and it has only one saddle point [5]. According to our analysis, the first type of S-shaped J-V curve is associated with the surface recombination rate and it can be reproduced by our model if surface recombination velocity for any type of carrier on any contact is assumed to be comparable or smaller than its average diffusion velocity. The other type of S-shaped J-V curve seems to be a consequence of the injection barrier for electrons. When the injection barrier for electrons is lower than 0.2 eV, the calculated J-V characteristics don't have the S-shape. For the electron barrier heights around 0.2 eV, the S-shape bending of the J-V curve is observed and it occurs for all larger barrier heights. According to our simulations, the barrier height for holes is not responsible for the S-shape, but together with the electron barrier height affects the organic solar cell open circuit voltage (V_{oc}).

The validity of our model is confirmed by comparing the simulated J-V curves with the experimentally obtained data. The model has been applied to the ITO/PEDOT:PSS/P3HT:PCBM/Al and ITO/PEDOT:PSS/P3HT:ICBA/Al solar cells. For the P3HT:PCBM based solar cells regular J-shaped J-V curves were measured, while for the P3HT:ICBA solar cells the J-V characteristics with anomalous S-shape behavior were recorded. All experimentally obtained J-V curves were reproduced very well with our model. It seems that the ITO/PEDOT:PSS/P3HT:ICBA/Al solar cell S-shaped J-V curve originates from the electron barrier height on the cathode contact, rather than from the low surface recombination velocities on the electrodes.

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All niobia Bragg stacks for optical sensing of vapors

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Vapor responsive Bragg stacks are prepared using alternating spin-coating of dense and porous niobium pentoxide (Nb_2O_5) thin films with quarter-wavelength optical thickness. The difference in refractive index (optical contrast) is achieved by generating porosity in one of the stack's building blocks. Purposely, soft-templating method is used where micellar solution of triblock copolymer (Pluronic) is utilized as an organic template. After annealing at moderate temperatures (320 ^{o}C) the template destroys and the residuals evaporate leaving empty pores in the film. When stacks are exposed to vapors a condensation in the pores take place, the refractive index of the film increases resulting in shift of the band gap of the stack thus enabling optical sensing of vapors.

The surface morphology and structure of single films are studied by Transmission Electron Microscopy (TEM) and Selected Area Electron Diffraction (SAED), respectively, while optical characterization is performed by combination of ellipsometric and reflectance measurements. Sensing behavior and selectivity of the stacks are tested by transmittance and reflectance measurements prior to and after exposure to different volatile organic compounds (VOCs) and humidity. Color coordinates are calculated from measured spectra in order to verify the possibility of color sensing of vapors.

Further, an incorporation of "defect" layer (layer with non-quarter-wavelength optical thickness) in the multilayered structures is simulated theoretically and realized experimentally aiming at improvement of the optical response of the stacks. The potential of all niobia stacks as chemical vapor sensors with optical read-out is demonstrated and discussed.

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Organic solar cell physics analyzed by Shockley diode equation

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The drift-diffusion model [1] is widely used for modeling the operation of organic solar cells (OSCs). Although this model describes the operation of OSCs very well, there are still some missing explanations and open issues concerning photogeneration of charge carriers, their transport and especially recombination [2]. The drift-diffusion model is not phenomenological and it is difficult to trace the impact of each process on OSC J-V curve using this model. Also, there are some elements of OSCs that can't be taken into account by the drift-diffusion model such as serial resistance and leakage currents (shunt resistance).

As a first step, we have modeled the ITO/PEDOT:PSS/P3HT:PCBM/Al solar cell with a simple one-diode equivalent circuit. The parameter values were extracted from the measured dark J-V curve that was fitted with the least square method. With the same set of parameters, varying only shunt resistance, the J-V curve for illuminated OSC was successfully reproduced. According to this result we came to the conclusion that our OSC follows diode behavior in a great extent. Thus, its operation can be described by Shockley diode equation.

In a second step, we have calculated the ITO/PEDOT:PSS/P3HT:PCBM/Al solar cell J-V curve with the drift-diffusion model. The model is the same as in [3] with Dirichlet's boundary conditions and the transfer matrix calculation of interference effects added [4]. Two different types of recombination, monomolecular and bimolecular, were considered. By comparison of simulated J-V characteristics with the Shockley diode equation we have analyzed photogeneration, transport and recombination contribution to the OSC J-V characteristics. The short circuit current was taken as a representative of photogeneration and ideality factor was used for recombination analysis. Diffusion transport was investigated by the inverse saturation current.

Finally ITO/PEDOT:PSS/P3HT:PCBM/Al solar cell diode parameters obtained by comparison of the measured J-V curve with the one-diode equivalent circuit model were related to drift-diffusion parameters.

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Graphene-based liquid crystal display devices

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Recently, graphene demonstrates huge potential in modern technologies owing to its exceptional properties as very high conductivity, excellent transparency, thermal conductivity, mechanical strength, etc. Moreover, due to ultra-high carrier mobility and elasticity, graphene is regarded as an excellent candidate to replace the currently used indium tin oxide (ITO) in modern rigid and flexible displays, in photovoltaics, transparent electronics, light emitting diodes, smart windows, touch screens, etc. [1].

Our work is focused on graphene growth, characterizations and application in varieties of liquid crystal structures and display devices. Graphene was syntheses by Chemical Vapor Deposition (CVD) method which provides large scale and high quality production as well as precise control of the number of graphene layers. After transferring process, the graphene quality has been assessed by Scanning Electron Microscopy (SEM), Raman analysis, optical and electrical measurements and as well as bending ability tests on flexible substrates. Several graphene-based liquid crystal (LC) devices like tunable phase retarders, light valves and spatial light modulators on rigid and flexible substrates have been prepared, supported by video demonstrations [2]. The measured electro-optical properties as voltage-dependent transmittance, response time, phase modulation and bending ability will be summarized and compared to the same LC devices using ITO electrodes. Performed results open great potential of graphene integration into next generation ITO-free flexible and stretchable devices.

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Application of a simple low cost colorimetric probe for ground water quality analysis and evaluation

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Anthropogenic activities can lead to environmental contamination of groundwater, especially in agricultural areas. Groundwater monitoring is extremely important since chemical parameters that exceed the prescribed limits can degrade the ecological and chemical status of the surface water body associated with the underground aquatic medium [1].

Data from quality monitoring of groundwater collected from the agricultural area in the vicinity of Lake Zobnatica is of great importance since it is used for irrigation. Large quantities of pesticides and fertilizers that are used in agriculture can lead to pollution of the observed water body. Chemical parameters such as: orthophosphate, nitrate, nitrite, ammonium nitrogen, sulfate, chloride, fluoride, total chlorine, chromium (VI) and metal cations (nickel, iron, zinc and copper) were analyzed and evaluated.

Since the aforementioned parameters may have negative impact on ecological status of the environment, our previously developed fiber-optic systems [2-3] were adapted for monitoring of groundwater quality. As results of the measurements with the proposed probe system three parameters were obtained: Hue, Saturation and Value (from HSV color model). Based on these values, the concentration of the sample parameters was determined. Comparison of the results obtained with standard methods (UV-VIS spectrophotometer) and the colorimetric probe was carried out to confirm the possibility of using the sensor as a replacement for the expensive standard analytical equipment.

Given the sensor system has the capability of wireless communication via Bluetooth technology with a smartphone or a laptop computer, more precise measurements are performed outside the laboratory on samples whose concentration of chemicals of interest is rapidly changing after sampling.

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Colorimetric fiber-optic sensor based on reflectance spectrum estimation for determining color of printed samples

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In this paper, a new colorimetric method for determining the color of printed samples obtained using digital printing is presented. The method is based on estimation of the spectrum of electromagnetic radiation (in the visible range) by interpolation of previously known radiation values at certain wavelengths. Various types of interpolation algorithms were tested in order to make a better estimation of the spectrum. Since most of the commercially available colorimeters that offer high accuracy are extremely expensive, a new sensor based on the proposed colorimetric method was developed by upgrading our previous work [1].

Hardware implementation of the realized sensor consists of a transmitting block and a receiving block. In the transmitting block, there are six LED sources radiating at different wavelengths. Signals which drive LED sources are multiplexed combining Time Division Multiplexing and Frequency Division Multiplexing. The receiving block contains a broadband photo-detector with an integrated transimpedance amplifier and an operational amplifier for further amplification of the signal before processing.

Due to the multiplexing of the transmitted signals, it is also necessary to perform digital filtering of the signal collected from the photo-detector. Butterworth IIR filters of 8th order were implemented on a microcontroller. Further processing of the filtered signals requires additional averaging for greater stability of the system, as well as better repeatability of measurement. This can be achieved by calculating the arithmetic mean, which was initially applied here, but wasn't sufficiently efficient in terms of stability, and has also significantly slowed down the response. Thence, a more efficient solution had to be found, and it was done by implementing Kalman filter for estimation of the best measurement values [2].

The measurement probe contains transmitting and receiving optical fibers, which transmit light from the LED sources and to the photo-detector. In order to eliminate specular reflection, light sources are set at angles of 45° with respect to tested sample.

Based on the data gathered at three wavelengths (blue, green and red), interpolation was performed by inserting new points in order to approximate the configuration of the visible spectrum. One point is inserted at the beginning, one at the end of the visible spectrum, and one point between each pair of adjacent LED sources. A transformation from CIE XYZ [3] to sRGB color space was performed.

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Surface treatments of metal surfaces by new generation of high intensity laser sources

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Recent development in diode pumping solid-state lasers permitted achievement of new generation of high intensity lasers [1, 2]. Several laser systems with record parameters nowadays are operating in HiLASE center, located nearby Prague in Czech Republic. Besides development of lasers, the center is also focused on development of very demanding applications such as Laser Shock Peening (LSP) or efficient surface structuring of large objects.

The paper will firstly report on development of those two applications stations and related further laser development and optimization. A novel unstable resonator configuration for highly efficient cryogenically cooled Yb:YAG Q-switched laser operating at Joul level [3] has been recently demonstrated as new, small-size and affordable laser source which will enable LSP application even on less expensive components. As a demonstration of LSP capabilities, resistance of LSP treated samples to corrosion cavitation in the case of stainless steel 321 will be demonstrated.

Surface structuring of large surfaces for self-cleaning, anti-finger print, bactericidal effects, oil repellent properties or aesthetic application has been recognized as one of the most ambitious application. Despite demonstrated results on many materials, the processing efficiency and cost are not acceptable for real industrial application. High intensity ultra-short laser, with energy in the range of several mJ, in combination with multi-beam processing approach (usage of specially designed Diffractive Optics Elements (DOE) or Direct Laser Interference Pattering (DLIP)) may offer solution. Usage of this approach on PERLA B laser system (1-2 ps, 10 mJ, 1 kHz and $M^2 < 1.2$) will be also reported. Finally, the development of non-fluorinated super or ultrahydrophobic aerospace aluminum alloy (Al7075) surface by dual process of laser patterning by ps pulses and high pressure vacuum process will be presented as well [4].

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Broadband Multimode Emission of Quantum Cascade Lasers in Strong Magnetic Fields

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An external magnetic field applied to a quantum cascade laser (QCL) structure in the direction of the epitaxial growth splits all two-dimensional subbands in the upper and lower laser levels as well as the injector/collector bands into a discrete set of Landau sublevels and leads to quantization of the electron in-plane motion [1-5]. This feature offers a possibility to tailor the relaxation, scattering and diffusion rates on the active laser levels and thus to impact the QCL lasing dynamics, which is an especially handful tool for shaping the multimode self-pulsation or QCL frequency comb regimes. One well-known example is the lowering of the QCL lasing threshold in a magnetic field. Another case, which we studied here is the use of the magnetic field to favor the multimode Risken-Nummedal-Graham-Haken (RNGH) self-pulsations seen in the optical spectrum as two very broad modulations sidebands at the Rabi flopping frequency [6]. Our recent studies showed that the excitation threshold for the broadband multimode RNGH self-pulsations is mainly conditioned by the net relaxation rates of the carrier coherence and population gratings due to the inter-subband relaxation, scattering and diffusion of carriers [7, 8]. In this work, we show that the Landau quantization in an external magnetic field slows down the effective decoherence and diffusion rates. The pump current required to reach the broadband multimode RNGH self-pulsations (or a QCL frequency comb regime) is lowered with the magnetic field strength while the Rabi flopping frequency and the overall optical spectrum width remains practically unchanged. Our theoretical results indicate that an external magnetic field can be a valuable tool for achieving high-power broadband QCL frequency comb emission in practice.

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Ultrafast optical devices functioned by *in situ* synthesized nonlinear graphene

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Graphene has attracted huge attention from the society of ultrafast data management with its excellent electrical and optical properties. Many research groups have tried to demonstrate graphene-based ultrafast optical devices such as ultrafast pulsed lasers, high-speed optical modulators and optical switches convincing the nonlinear operation of graphene. However, conventional synthesis of graphene relies on high temperature process in vacuum condition, and mostly the synthesized graphene requires deleterious transfer steps onto targeted devices that degrade the graphene crystal quality, and the efficiency of nonlinear optical operation of the optical devices. Moreover, the transfer process limits the customized patterning especially for integrated devices.

We develop and demonstrate a novel process to synthesize graphene directly onto the designed substrate without the transfer process. [1-3] This approach guarantees the intact crystal structure of graphene that provides the expected optical nonlinearities. The synthesized graphene shows nonlinear saturable absorption in the fiber ring laser cavity to generate ultrafast optical pulses, thereby ensuring the passive mode-locking of the fiber laser operating in femtosecond scale at telecommunication band. With autocorrelator, the temporal pulse duration of femtosecond scale is confirmed. We also demonstrate ultrafast all-optical switching near 1550 nm using four-wave mixing (FWM) with the grown graphene that enhances the ultrafast nonlinear response especially for optical signal processing. The input signal channel is modulated at the speed up to 20 GHz, and this modulation information is successfully copied to the newly generated signals with the directly grown graphene. The directly synthesized graphene shows the extinction ratio improvement of > 50 % for the nonlinear switches.

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Test-Bed with EDFA Bi-Directional Amplifier for transmission of an ultra-stable coherent optical frequency

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A method to demonstrate the characterization of bidirectional optical amplifier used for very long distance transmissions of ultra-stable quantities as ultra-stable optical frequency or accurate time, eventually in the systems of the Wavelength Division Multiplexing (WDM) is presented. Optical fiber amplifiers make adequate preparation for in-line amplification of optical signals, effecting stimulated emission of photons by rare earth ions implanted in the core of the optical fiber. Amplifier is characterized for nominal ultra-stable coherent frequency input signal at -20dB level. We have developed an efficient technique using open-line system Czech Light™ [2] Erbium-Doped Frequency Bi-Directional Amplifier (CLA BiDi) for an ultra-stable coherent frequency transfer. The gain it achieves is relatively flat [1] so that such amplifiers can be cascaded for very long distance WDM transmissions [3].

The experimental lab test-bed, with laser pump current rates using Low-noise Integrated Tunable Laser Assembly (ITLA) provided by [4] is connected to CLA BiDi via 20dB attenuator. The usage of input power rates located in one frequency channel [5] leads to gain ultra-stable frequency transfer signal, the other designated channels carry noise traffic in WDM transmissions. Such BiDi Amplifiers are also utilized within CESNET2 network where frequency transmissions are running together with data traffic and other advanced services (sensing) and are currently utilized for e.g. precise measurements of nuclear power plant containment stability.

Also, project CLONETS [6] targets on pan-European optical network for ultra-stable frequency transmissions. The experiment carried out distinct spectral dependence of amplifier gain and noise figure using standard telecom ITLA pump with higher accuracy and firmware upgradation features solving the novel approach of getting an ultra-stable frequency signal gain rather than using conventional methods in current services.

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Analysis of the linewidth enhancement factor impact on the spectral and noise characteristics of the gain switched laser optical frequency combs

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Optical frequency combs are used in broad area of applications, ranging from high precision optical metrology [1] and spectroscopy [2] to radio frequency (RF) photonics, such as generation of microwave to terahertz signals [3], coherent wavelength division-multiplexed (WDM) optical communications [4], datacenter interconnects [5], etc. Different comb characteristics are being recognized as important with respect to the desired application such as spectral flatness, flexible and stable comb line spacing, high frequency comb bandwidth, tunable central wavelength, low implementation cost. The impact of the phase noise which is present on the individual comb lines plays an important role regardless of the desired comb application. It becomes especially important concern when considering coherent optical communication systems, in the first place those employing higher order modulation formats [6].

In this paper we theoretically analyze the impact of the linewidth enhancement factor on the spectral and noise characteristics of frequency combs generated by the gain switched semiconductor laser as an implementation simple and cost-effective method. We base our analysis on the detailed rate equations system of a semiconductor laser which describe the dynamics of the carriers inside the active region, photons and corresponding optical phase. We write the rate equation system in the form of stochastic differential equations which incorporate Langevin noise sources to account for the intensity and phase noise [7]. We show that the higher values of the linewidth enhancement factor can lead to higher number of pronounced comb lines, i.e. wider comb bandwidth even at low bias currents of the gain switched laser. By simulating the intensity and frequency fluctuations of the comb lines, we show that the linewidth enhancement factor has maximal impact on the intensity and phase noise of lines when the gain switching frequency is close to the relaxation frequency for the given bias current of the laser. Finally, for a fixed gain switching frequency, we show that this influence is minimal at lower bias currents. For this case we show that both higher and lower values of linewidth enhancement factor can lead to comparable noise characteristics, with higher values having a benefit of a wider comb bandwidth.

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Large-Signal Modulation of an RSOA Enhanced by Inductive Peaking

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Wavelength division multiplexed (WDM) passive optical networks (PON) are envisaged as a highly promising infrastructure which should enable seamless wireless/wired data traffic convergence and answer to the problem of the growing bandwidth demand together with the increased service diversity [1]. WDM PONs have been long relying on the self-seeded optical sources as are reflective semiconductor optical amplifiers (RSOAs) as one of their cornerstone technologies, due to RSOAs reliability, and the cost- and energy-efficiency. Additionally, RSOAs can enable network reconfiguration through dynamic wavelength allocation in optical network units (ONUs), owing to their broad optical bandwidth and self-tuning capability [2]. Nevertheless, the electro-optical (E/O) modulation performance of RSOA reported thus far can be considered poor [3], especially comparing to the semiconductor lasers of similar design [4].
It has been shown recently that the inductive peaking technique can significantly improve the RSOA's small-signal modulation response and its -3 dB bandwidth [5], emphasizing its inherent ability to support high speed signals. For employing RSOAs in digital transmission systems, a more indicative figure of merit is its large-signal modulation bandwidth, together with the back-to-back (B2B) bit error ratio (BER). Here, we present the study of the RSOA's large-signal modulation performance, proving the benefits of inductive peaking effect (IPE), through analysis of B2B Q-factor versus bitrate for RZ de-Bruijn signal sequence. We perform two-fold investigation of the Q-factor, (*i*) for various RZ modulation signals in terms of average bias current and extinction ratio for the fixed "0" bit levels, (*ii*) for various input signal's optical powers. We show that, in a wide range of operating conditions, IPE significantly improves Q factor for a given bitrate, implying that for a fixed Q-factor one can achieve higher modulation bandwidth with inductive peaking as opposed to parasitics-free RSOA. A trend of increase of Q-factor with the increase of RSOA's average bias current, as well as its extinction ratio, has been identified. Regarding the input optical power, Q factor is almost independent on it in the unsaturated regime, exhibiting higher values for RSOA enhanced by IPE than for parasitic-free one. In the weak and moderate saturation regime, Q factor increases with the input optical power, however, the rate of increase in IPE case is lower than in parasitics-free one. Nevertheless, inductive peaking in this regime still enhances the RSOA performance, boosting its Q-factor and opening the eye diagram more efficiently than parasitic-free RSOA. Finally, for strong saturation (>10 dBm), which is typically not used for RSOA operation, the inductive peaking becomes less effective in comparison with parasitic-free RSOA.

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Negative-Mode LDI-MS of corrosion products on the surface of Ag-Cu-X (X- Zn, Pd, In) alloys

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Copper-silver alloys have widely applied in many different areas such as information and communication technology, rail transportation, power transmission lines, microelectronics, machinery manufacturing, chemical processing industries, coinage, ornamental parts, etc [1, 2]. A group of ternary Ag-Cu alloys with different elements is used for binding different materials (brazing, fillers, and pastes). For example, Ag-Cu-Pd alloys are used in dentistry, as amalgams improvers or joint fillers for different dental materials [3]. Ternary AgCuIn alloy uses as a bonding metal layer; the use of AgCuIn as the bonding metal, greatly reduces the manufacturing costs of LED chip and helps to improve the life of the LED chip. Copper and its alloys belong to the group of semi-noble metals however they are not highly resistant to corrosion in some of the environments [4, 5]. Corrosion has particularly attracted attention due to the significant impact on the performance and reliability of this industrially important material group in their applications, as well as on the economy. Standard methods for characterization of corrosion films are: X-ray diffraction (XRD), Raman spectroscopy and scanning electron microscopy (SEM) with Energy Dispersive Spectroscopy (EDS) [6, 7]. The positive mode laser desorption ionization (LDI) mass spectrometry method can be successfully applied to analyze the composition of the corrosion film. In our previous work, it has been shown that the amount of sample required for the LDI method is much smaller than the sample quantity required for the methods mentioned above [8]. The purpose of this work was to study the possibilities of direct analysis of the corrosion films formed on $Ag_{60}Cu_{26}Zn_{14}$, $Ag_{58.5}Cu_{31.5}Pd_{10}$, and $Ag_{63}Cu_{27}In_{10}$ alloys using the negative mode laser desorption ionization (LDI) mass spectrometry method. The corrosion films of $Ag_{60}Cu_{26}Zn_{14}$, $Ag_{58.5}Cu_{31.5}Pd_{10}$, and $Ag_{63}Cu_{27}In_{10}$ alloys were obtained after anodic potentiostatic polarization treatment (at +0.25 V for 5 min in 3.5% wt. NaCl solution). Preliminary results show that the negative mode LDI mass spectra measured from the corrosion film of these alloys contains same ions$AgCl_2^-$, $AgCuCl_3^-$, $CuCl_2^-$, $Cu_2Cl_3^-$, $Cu_3Cl_4^-$. This result suggested that main reactions are the formation of CuCl layer on the surface of the Cu rich metallurgical phase and formation of AgCl film on the surface of Ag rich metallurgical phase**.**

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Ultrafast High-Field THz beamline at X-ray FEL

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THz sources at FLASH utilize spent electron beam from a soft X-ray FEL to generate very intense (up to 150μJ), tunable frequency (1-300THz) and ultrafast narrowband (~10%) THz pulses, which are naturally synchronized to soft X-ray pulses [1]. This unique combination allows for wide range of element specific pump-probe experiments in physics, material science and biology.

Here we discuss the unique features of the FLASH THz pulses and the accelerator source that bring along a set of challenges in the diagnostics of their key parameters: pulse energy, spectral, temporal and spatial profiles.

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Laser micromachining of sub-micron hole patterns and gratings for X-ray interferometry imaging

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Grating interferometry (GI) [1-3] is a cutting-edge imaging technique that has the potential to revolutionize medical imaging. The resulted rich contrast mechanisms provide additional information to improve diagnostic contents yet decreasing the dose deposited to the patients, which opens new opportunities for medical imaging. While GI method was extensively developed in the last decade, the bottleneck for implementation of the method into commercial equipment remains reliable production of gratings and their high cost. We aim to develop reliable gratings fabrication method with large area scalability and cost reduction perspectives.

We investigated fs green laser and ps UV laser with Gaussian and Bessel beam focusing to achieve a few micrometer pitch gratings with 100-200 μm depth and high quality edges (high aspect ratio lines).

In addition, we investigated the smallest feature that we could obtain with axicon lens. When the structure was produced with the axicon lens, the velocity of the axes was first defined in such a way that there was no overlap between the pulses. We produced very precise structured patterns of 0.9 micron diameter holes. However, the depth of those sub-micron holes is limited to approximately 1 micron.

The advantages of Bessel beams compared to Gaussian beams are demonstrated for machining of rectangular profile gratings with sharp edges. However, the high-aspect ratio grating (10 microns wide and 200 microns deep) from tungsten foil could only be obtained with the Gaussian beam and focusing with an F-Theta type lens. Bessel beams contain most of the pulse energy in the side lobes. The limited amount of the pulse energy in the central, sub-micron peak of the beam, and material cloud formed deeper in the high-aspect ratio hole, prevented the Bessel beam deeper penetration with sufficient energy in the central peak, which limited the hole depth to 10-20 microns.

The significant advantage of the Bessel beam is that it could be formed with a diameter smaller than μm with a depth of focus of several millimeters [4]. This advantage of Bessel beam is used to create a precise structured pattern of sub-micron diameter holes in tungsten foil.

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Femtosecond laser surface engineering of biopolymer ceramic scaffolds coated with ZnO by low temperature ALD method

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Tissue engineering and regenerative medicine have become the standard field for replacing organ and tissue loss or failure resulting from injury and other types of damage which happen to be major human health problems. In fact, not quite long ago, the use of bone tissue or organ transplantation was severely limited by donor shortage. Current use of drug therapy, surgical reconstruction and medical devices are always available but they tend to exhibit problems, such as incapability of replacing all the functions of the damaged or lost bone tissue. Among the recent technologies in the multidisciplinary field of tissue engineering or regenerative medicine, use of various types of scaffolds is the key component. Scaffolds are the best materials for restoring, maintaining and improving tissue function. They play a unique role in repair and more importantly regeneration of bone tissues by providing a suitable platform, permitting essential supply of various factors associated with survival, adhesion, proliferation and differentiation of cells. Scaffolds can be made up of synthetic or absorbable, naturally occurring, biological, degradable or non-degradable polymeric and/or ceramic materials. These scaffolds act as a support structure for the cell attachment and growth into tissues and must have adequate mechanical and anti-inflammatory properties. Hydroxyapatite (HAp) is a mineral naturally found in bones and is used for fabrication of dense and porous bioceramics. Zirconia (ZrO_2) has excellent chemical and dimensional stability and mechanical strength. Chitosan (Ch) is a natural biopolymer with high biocompatibility, antimicrobial activity and superior affinity to proteins. It is recognized that the behavior of the cell adhesion, proliferation, and differentiation on materials depends largely on surface characteristics such as wettability, chemistry, charge, rigidity, and roughness. Femtosecond laser-assisted method for surface processing is a promising method since it is non-contact, with high degree of reproducibility, does not require chemical agents, it can create various nano- and micro-structures with increased roughness. Laser processing allows the fabrication of precise well-defined patterns. By employing femtosecond laser radiation, the mechanical properties remain unchanged after the laser treatment.

Atomic layer deposition (ALD) is a type of chemical vapor deposition, with precursor delivery in a sequential manner. Separation of precursors in time leads to only surface reactions which result in layer by layer deposition. That leads to conformal deposition on structures with complex 3D shape and accurate controlling thickness of the layer. Possibility to perform some synthesis processes at low temperatures allows to deposit on biomaterials without their degradation. Low temperature ALD with ZnO provides high antibacterial efficiency of the surface processed.

In this study both surface modification methods described above were applied on biopolymer ceramic composites based on Ch/Hap/ZrO_2, in order to monitor their complementary impact on the scaffolds properties for improving/ optimizing their application in bone tissue engineering. The microstructured scaffolds were investigated by SEM, EDX, XPS analyses. Such combined modification of bone tissue scaffolds can essentially improve bioactivity properties of hybrid organic-inorganic biomaterial.

Nanopatterning of silicon surfaces by ultrashort laser pulses

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Fabrication of ultrafine surface nanoripples by ultrashort (~0.1-10 ps) laser pulses has proved for a long time to be a "green", fast technology for large-scale surface nanopatterning in the form of regular arrays of surface 1D-nanowires or 0 D-nanodots, broadly used for nanophotonic and biomedical applications [1,2].

Large-scale surface nanopatterning of silicon wafer covered by a 5-mm thick liquid carbon disulfide layer, in the form of regular 1D-arrays of vertical nanosheets was performed by multiple focused 0.3- and 10-picosecond infrared (IR) laser pulses via excitation of deep sub-wavelength plasmons on the photoexcited silicon surface. Sub-micron thick silicon surface layers demonstrate the exposure-tunable near-IR– mid-IR optical density and related sulfur, carbon and oxygen contents. Transmission electron microscopy, electron diffraction and micro-Raman spectroscopy reveals the amorphous structure of the sulfur-hyperdoped nanosheets atop their slightly distorted crystalline basements. Their crystallographic structure and elemental distributions indicate their exposure-dependent growth via deposition of silicon and sulfur species from the interfacial vapor/plume bubbles, provided by Si ablative nanoplumes from the regular ablative trenches and carbon disulfide decomposition in the plumes/bubbles.

The fabricated nanocoatings demonstrate the remarkable anti-bacterial modality relative to Gram-positive bacteria (Staphylococcus aureus) [3].

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Inducing LIPSS on multilayer thin metal films by femtosecond laser beam of different orientations

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The occurrence of laser-induced periodic surface structures (LIPSS) has been known for a while [1]. Multilayer thin films, like Al/Ti, are suitable for LIPSS formation and attractive for applications – due to their wearing behavior and corrosion resistance; LIPSS generation may improve their properties as well [2, 3]. LIPSS properties depend not only on the material but also on the beam characteristics, like wavelength, polarization and scanning directions, etc. [4].

After exposing with NIR femtosecond pulses from Coherent Mira 900 laser system in several beam exposures, we have analyzed the samples of thin metal film systems with Tescan Mira3 SEM and NTegra AFM. The formation of LIPSS is most probably due to the generation of surface plasmon polariton, through the periodic distribution of energy in the interaction zone which lead to thermal processes in layers and interfaces. Two types of LIPSS were generated, which differ in shape, orientation and in ablation pronounced or not. For consecutive interactions in the same direction, LIPSS maintained its orientation, while for orthogonal passes LIPSS with mutually orthogonal orientation were generated. LIPSS period fluctuated between 320 and 380 nm and structures with pronounced ablation have significantly smaller width. Probable mechanism is that for greater accumulated energy pronounced ablation takes place giving LIPSS in the form of "trenches", while for less accumulated energy the buildup of the material – probably due to pronounced oxidation – lead to LIPSS in the form of "hills".

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Laser ablated ZnO and hybrid ZnO-Au nanoparticles

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This paper shows the production of colloidal solutions of zinc oxide nanoparticles and hybrid ZnO – Au nanoparticles using laser ablation of a zinc target in deionized water and an aqueous solution of chlorous acid ($HAuCl_4$), respectively. It is known that zinc oxide nanoparticles luminesce in the blue region of the visible spectrum [1]; therefore, zinc oxide nanoparticles can be used as a luminescent substance in environmental sensors. The creation of a metal shell on the surface of zinc oxide nanoparticles will increase the efficiency of luminescence.

Nanoparticles in the form of colloidal solutions were created by laser ablation of a solid target in a liquid. A laser system HTF MARK (Bulat) was used for laser ablation. This system consists of a fiber ytterbium laser and a scanning system, moving in three coordinates with control from a PC. The system has the parameters: wavelength - 1064 nm, pulse repetition rate - 20 kHz, pulse duration - 120 ns, and energy per pulse up - 1 mJ. Colloidal solutions were produced in deionized water and aqueous solution of chlorous acid at various scanning speeds.

Optical spectra in the range of 200-1100 nm of the obtained colloidal solutions of zinc oxide show a high absorption in the region of 250-350 nm. The sizes of nanoparticles have a wide range of values, but the average diameter of nanoparticles is a few ten nm. The image of nanoparticles planted on a silicon wafer, obtained on a scanning electron microscope, show that the nanoparticles have a cubic structure. It is also worth noting the rapid coagulation of nanoparticle solutions over time.

The creation of a metallic shell on the surface of zinc nanoparticles during laser ablation in chlorous acid is based on the reduction of gold under the action of laser radiation [2]. Optical spectra of nanoparticles obtained in gold chloride acid have an absorption peak in the region of the plasmon resonance of gold (about 550 nm) and sharp drops in the region of 250-300 nm. The model of a scanning electron microscope that was used to visualize nanoparticles has a prefix that performs elemental analysis. An elemental analysis of nanoparticles obtained in an aqueous solution of chlorous acid, detects the presence of gold on the surface of zinc oxide nanoparticles.

Thus, it was shown to obtain nanosized particles of zinc oxide without a shell and decorated by a metallic gold shell, which have a high absorption in the blue region of the spectrum.

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The use of nanoparticles to improve the analytical capabilities of LIBS for solution sample analysis

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Laser-induced breakdown spectroscopy (LIBS) is a diagnostic technique based on optical emission spectroscopy, suitable for rapid, in situ, and multi-element analysis of all sample types. LIBS has demonstrated its greatest potential in the analysis of solids, both conducting and non-conducting. However, when it comes to quantitative LIBS analysis of liquids, there are still some drawbacks that limit its applicability, such as poor repeatability and low sensitivity. To some extent LIBS performance may be improved if directly performing LIBS on the solution is avoided by converting the liquid into a solid phase. Another recently proposed method to resolve the difficulties in LIBS analysis of liquid samples is the application of Nanoparticle - Enhanced LIBS (NELIBS) [1,2]. The aim of the present work was to examine the effect of copper oxide nanoparticles (NPs) on the analytical capabilities of LIBS analysis of lead in aqueous solutions.

The apparatus for NELIBS experiments comprises a laser source, a spectrograph (F=850 mm, grating 1800 groves/mm, F/11) coupled with a CCD, and the focusing and collecting optics, i.e. the same as used in conventional LIBS. A double pulse Q-switched Nd:YAG laser at 1064 nm, pulse duration 10 ns, pulse energy 50 mJ, interpulse delay 1 μs was used. The spectra were registered in a time-integrated mode (integration time 1 ms). A glass plate was chosen as the substrate to ensure there is no interference between NPs and the substrate. The first type of samples was prepared by drying a droplet of a Pb solution (10 μl, concentration 100 ppm) on the glass substrate. The second type was prepared by drying a droplet of the copper oxide colloidal solution on the glass, prior to the deposition of the analyte solution.

Three sets of the LIBS spectra were acquired; spectra of glass with deposited CuO NPs, of glass with deposited sample solution of Pb, and of the glass with deposited NPs of CuO and the sample solution of Pb. The spectra were obtained in the 395-415 nm spectral range. Only in the third case, intense Pb lines appeared in the spectrum. Estimation of the limit of detection (LOD) for the resonance Pb line at 405.78 nm, without additional optimization of the measurement parameters, gave a value of 3.6 ppm. Regarding the fact that without the addition of the NPs layer no analyte signal was obtained, it can be concluded that the enhancement of the lead emission line intensity is caused by the presence of the NPs, i.e. by the lower plasma formation threshold and more efficient atomization of the analyte deposited on the NP layer.

The main benefits of using NELIBS for the analysis of solutions lie in its simplicity, speed, the small amount of solution needed (few microliters), and the ability to analyze very dense or slurry samples.

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Titanium target irradiation by picosecond laser in air and water – surface morphology and synthesis of nanoparticles

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Titanium target was irradiated by picosecond lasers with pulse length of 40 ps i.e. 150 ps in air and water environment. The goal was studying of the induced surface features in both ambiences, as well as synthesis of Ti-based nanoparticles in liquid. Morphologies of the target at both pulse lengths were studied by standard techniques, e.g. scanning electron microscope (SEM) and profilometry, while chemical analysis of the surface was done by energy-dispersive spectrometry (EDS). Interaction ps laser-Ti depends on a number of parameters – laser parameters, condition of the target surface, working ambience, etc. Irradiation conditions in this work were as follows: τ = 40/150 ps, wavelength 1064 nm, pulse frequency 10 Hz, pulse energy 2-20 mJ, pulse count 3000-9000, irradiation in focusing regime. Generally, induced features differ in air and water surrounding – damage is more diffuse in water, with characteristic wavy surface. In both media laser-induced periodic surface structures (LIPSS) are observed on the damage periphery, however they appear at lower pulse count in water. Irradiation of Ti in water led to creation of nanoparticles (NPs) in most cases as established by UV-Vis spectrophotometry, while their size distribution was determined by DLS (dynamic light scattering) analysis. These were, as expected, Ti-oxide NPs as laser ablation in water always leads to formation of oxide particles except in case of noble metals. The size and shape of NPs obtained using laser ablation in liquid (LAL) method depends strongly on the liquid medium used, as well as laser parameters. In our case NPs were spherical, sized from few tens to few hundreds of nanometers, with occurrence of smaller particles in case of 150 ps laser. With further optimization of conditions obtaining of smaller NPs can be expected.

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Low-cost plasmonic arrays of elliptic nanoholes

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Plasmon-supporting nanostructures such as nanohole (NH) arrays have various interesting characteristics when it comes to coupling with incident light [1]. On the other side, if the symmetry of this coupling is broken, chiral effects arise [2-7], meaning that left and right circularly polarized light (LCP and RCP, respectively) differently couple with the artificial material. One can therefore design nanomaterials that differently absorb LCP from RCP: effect known as circular dichroism (CD).

In this work we present an approach to induce the symmetry breaking in well-known plasmonic NH arrays with hexagonal unit cell. Arrays with circular NHs do not possess broken symmetry, but if the NH becomes elliptic, and tilted from the hexagonal symmetry lines, a lack of symmetry arises. The most precise technique for fabrication of such structures is electron beam lithography, but with a disadvantage of being expensive and time consuming. Instead of this, we use a much cheaper technique called nanosphere lithography [5, 8], with the symmetry breaking induced by specially tilted thermal evaporation of a 50nm metallic layer.

Firstly, we analytically examined NH in thin layers of three different metals (Au, Ag or Al). Here, transmittance and electric field confinement strongly depend on geometry and selection of metal. As expected, periodicity dictates the resonant wavelength by red-shifting the resonances with the periodicity increase, while the metal plasma frequency decides the range of application. Further, we compare the square and the hexagonal symmetries and show that the latter is better for our purpose. The distribution of the electric field shows strong confinement around the borders of the NH, and it is highly dependent on the angle of incidence and the polarization state of the light. We also examine how the periodicity affects CD in the elliptic NH arrays with tilted symmetry. Finally, we numerically investigate the fabricated sample with broken symmetry of NH array in Au. We show that the numerical results are in good agreement with extinction experiment, thus offering a way to design such nanosurfaces for the coupling with specific chiral molecules.

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Liquid crystal based tunable metasurfaces for beam steering at terahertz frequencies

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Metasurfaces are artificial, planar, and periodic electromagnetic structures consisting of subwavelength resonators which strongly enhance light-matter interaction. Therefore, metasurfaces are an excellent choice for making compact and fast tunable photonic devices in a broad window of the electromagnetic spectrum, including terahertz (THz) frequencies as well [1]. Gradient metasurfaces belong to a special class characterized by a spatially inhomogeneous phase response providing novel opportunities for beam steering and wavefront shaping [2]. Here we examine tunable metasurfaces with inhomogeneous phase profiles as efficient beam steering devices at THz frequencies. The considered structures are based on metal-insulator-metal (MIM) cavities, where the top layer consists of a metallic ribbon array separated from the bottom ground plane by a thin layer of a highly-birefringent nematic liquid crystal (LC) [3, 4], which serves as an electrically tunable element. The resulting change of the LC refractive index provides spectral shifting of the metasurface resonance and large phase shift of the reflected field at the desired frequency.

In order to achieve tunable beam steering, we designed metasurfaces based on periodic arrays of MIM cavities taken as building blocks, where the spatially varying phase profile, either binary or linear, is provided by spatially inhomogeneous and tunable LC refractive index. The metasurface with the binary phase profile consists of spatial zones with a phase shift either 0° or 180° and it operates as a beam splitter. The reflection angle of the first diffraction order is adjusted by changing the period of the supercell composed of individually-controlled MIM cavities, which provide the binary phase profile of the grating. At the same time, by suitably selecting the binary phase-shift values, the tunable grating enables the equal redistribution of the reflected power between the first diffraction order and the back-scattered zeroth order. Finally, we demonstrate that a gradient metasurface consisting of subunit cells with a discretized linear phase profile ranging from 0° to 270° behaves as a blazed grating. Tunable beam steering is then achieved by modifying the period of the linear phase spatial profile, which determines accordingly the reflection angle of the diffracted terahertz beam.

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MXene-based ultrathin metamaterial for enhanced wideband optical absorption

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In this contribution we propose, design and analyze a plasmonic metamaterial structure for enhanced optical absorption ("superabsorber"), based on titanium carbide MXene sheets.

MXenes [1] are a group of quasi-2D materials consisting of carbides, nitrides or carbonitrides (the "X" part) of transition metals – Ti, Cr, V, Zr, etc. (the "M" part). Discovered in 2011 [2], they can be delaminated into nm-thick quasi-2D sheets and have traits similar and in many cases superior to those of graphene. They are characterized by free-electron conductivity which makes them suitable for the use in plasmonics and optical metamaterials, are foldable and moldable. Some MXenes are more stable than graphene and have more advantageous photonic properties. Probably the most widely investigated MXene is titanium carbide.

We theoretically and numerically analyze a titanium carbide metamaterial absorber structure built as a sandwich with an MXene bottom layer, a lossless dielectric middle layer and an MXene mesh top layer, a geometry similar to that analyzed by Aydin et al [3], where silver-silica material pair has been used. The mesh consists of periodically repeating linear array of elongated trapezoidal titanium carbide segments crossed with an identical array rotated perpendicularly to the first one. As a result, a 2D mesh is obtained with varying width of the apertures along both axes. Such an approach ensures a bandwidth widening of thus obtained superabsorbers.

The described approach is quite general, since various alternative plasmonic materials can be utilized, including different MXenes, but other materials as well, such as graphene, metals and metal alloys, various semiconductors, etc. [4]. In this manner we extend the available toolbox for plasmonics and ensure a new degree of design freedom.

The proposed metamaterial structure could be applied, among others, for the enhancement of the operation of various types of photodetectors in a wide range of wavelengths, from solar cells to terahertz devices. Obviously, the applicability extends much wider and includes, among others, the transformation optics devices [5].

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Broadband enhancement of light harvesting and photocatalytic devices

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Stochastically roughened surfaces of plasmonic materials can provide field enhancement under irradiation by visible light due to the appearance of surface plasmon polaritons (SPP) [1, 2]. The stochastic surface profile acts as a superposition of diffraction gratings with different grating constants, which ensures a broadband coupling between propagating and surface modes [3]. There are various materials that can be used for the mentioned purpose, including noble metals such as gold or silver and, alternatively, doped transparent conductive oxides (TCO).

We considered the structure with a roughened metallic film on the bottom and a roughened TCO glass layer on the top, separated by a thin dielectric layer. We fabricated experimental structures and simulated them by the finite element method. Thus, we verified that the combined influence of two rough films significantly improves light trapping within the dielectric layer between them while plasmonic effects lead to concentration of electromagnetic field into volumes much smaller than a single wavelength. Consequently, the radiation intensities are proportionally increased, even for several orders of magnitude, compared to the incident beam. Another interesting property observed is that the structure continues to act as a diffractive light trap well into the UV region and simultaneously as a plasmonic superabsorber for IR light, turning the increase of TCO opaqueness with wavelength into a benefit since it significantly expands the useful spectral range. Tuning of dopant levels in TCO or using different metals or alloys together with varying coarseness of the films can further be used to tailor the electromagnetic response.

The proposed structure can be utilized for a vast majority of photocatalytic systems, for the enhancement of light harvesting devices regardless of their type as well as for ultrasensitive chemical sensing [4-6]. The small distance between the two metal films ensures that practically the whole region between metal and TCO is the area of enhanced evanescent field allowing for ultrathin devices. This is particularly beneficial for light harvesting devices as it increases their sensitivity while reducing the materials consumption and thus the device cost while at the same time it utilizes one transparent (TCO) and one opaque (metal) electrode of the kind already present in a majority of solar cells. Similar conclusions on materials consumption can be drawn for photocatalytic devices, only instead of the active region there is a microreactor channel.

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Detection of Glucose by Chitosan Coated Nanogold array on Optical Sensor Platform

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Biosensor studies have gained significant importance recently in terms of its usage in many areas such as in medicine, health monitoring and disease detection. However, most of biosensors still needs continuous improvement due to some of the disadvantages. For example, they are time-consuming, expensive and bulk instruments. Therefore, a fast, real time, sensitive and portable biosensors must be developed [1]. Metal nanoparticles bearing significant characteristic called Localized Surface Plasmon Resonance (LSPR) are new generation materials used to overcome these challenges. LSPR occurs when incident light interacts with the conduction band electrons of the metal nanoparticles. This interaction causes localized coherent oscillation of electrons, leading to the formation of a surface plasmon wave around the nanoparticles. Any change in refractive index in the environment of the nanoparticles causes an important change in their LSPR signal [2]. Therefore, we want to observe medium weight chitosan and glucose solution interactions through Localized surface plasmon resonance. When spherical gold nanoparticles are replaced with anisotropic analogues, like gold nanorods, the optical properties become much size dependent since single SPR in this case splits into two different modes; a transverse surface plasmon resonance (T-SPR), corresponding to the light absorption and scattering along the short axis of the particle, and a longitudinal surface plasmon resonance (L-SPR), corresponding to light absorption and scattering along the long axis of the particles making gold nanorods. Such enhancement in optical characteristics makes gold nanorods more desirable structures than isotropic morphologies due to increased sensitivity. In the literature, optical fiber probe sensor coated with gold nanoparticles for the glucose sensing had a significant improvement in terms of the sensitivity of its glucose solution measurement [3]. In this study, U-shaped fiber optic biosensor was developed. Fiber probe was covered with gold nanorods and spherical shape gold nanoparticles to form LSPR signal Different concentrations of glucose solution were used from %10 to %50. Output power values and optical properties were compared. The present study introduces a new platform for sensitive detection of glucose for potential applications.

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Thin layers of phase change materials for optical control of metamaterials in the infrared

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Phase change materials (PCMs) have been widely applied to tune the nanophotonic components: thin layers which switch between stable phases upon heat stimuli can drastically change amplitude or phase of the optical wave at the nanoscale. If a specific application requires two states which are non-volatile, reversible, and stable at the room temperature, the best choice are chalcogenide PCMs such as $Ge_2Sb_2Te_5$ (GST) and GeTe, which possess at least two different stable phases (crystalline and amorphous) that dramatically differ in optical and electric properties. For example, in [1, 2] we showed that these PCMs can be combined with Si-based all-dielectric metamaterials to switch the sharp transmission peaks at 1.55 μm, providing high modulation depth and contrast ratio. More recently, we experimentally showed that GeTe-Si-based metamaterial, conventionally produced in Silicon-on-Insulator technology, provides high reflection contrast at 1.55 μm between the crystalline and the amorphous GeTe state [3].

Another promising PCM is surely vanadium dioxide (VO_2), which undergoes semiconductor-to-metal phase transition at about 68°C [4, 5]. We recently investigated emission control of Er^{3+} ions sandwiched between a thin VO_2 and an upper metamaterial structure [6], for tunable emission at 1.54 μm. Metamaterial dimensions can be adjusted to provide the almost unitary absorption in the desired spectral range, which can be switched to zero absorption by changing the VO_2 phase. In this work we focus on the infrared spectrum, where the VO_2 layer lies between the ground Au layer, and the upper metamaterial made of Au nanoresonators. When VO_2 is cold, hence semiconductor, the whole structure provides metal-insulator-metal resonance that leads to high absorption (thus infrared emission). Heating of the VO_2 to the transition temperature makes the whole surface metallic, with high reflection and low absorption. We further propose the optical switching of a large number of unitary cells by means of a visible laser. For given wavelength and power of the laser, one can adjust the spot-size to ensure the metamaterial response of the surface. Moreover, higher order nanoresonator resonances can be used to increase the laser absorption and decrease the power needed for the phase transition. We believe that this approach can lead to optically controlled high contrast absorption tuning in the infrared range.

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Surface plasmon polariton launching by light scattering on grooves in metal films

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Surface plasmon polaritons (SPPs) are electromagnetic surface waves which propagate at a metal-dielectric interface. The optical properties of SPPs such as subwavelength field confinement, field enhancement and high sensitivity to the composition and structure of the surface have been exploited for numerous applications ranging from sensors to optical integrated circuits [1]. Many of the numerous applications of the SPPs require efficient and controllable methods for conversion of the free-space light to SPPs [2]. In order to achieve SPP launching in such a way, the transverse momentum of the free-space light has to be matched to that of a SPP. The momentum matching is traditionally done by using a prism or a metallic grating. However, these bulky elements are not convenient for applications demanding high density of integration, as it is the case with the SPP based integrated optics. As an alternative to prisms and metallic gratings, structures such as nano-sized slits and grooves perforated in metal films have been proposed recently as promising candidates for novel compact SPP based devices [3].

In the process of light scattering on a groove in a metal film only a fraction of the incident wave is converted to SPPs. Here we investigate the SPP launching efficiency in the 600 nm - 900 nm wavelength range, using finite element based numerical simulations under the assumption that a plane wave is incident on the groove. We study the influence of the groove shape, incident angle, angle between the plane of incidence and the groove axis (the azimuth angle) and the polarization of the incident wave on the launching efficiency and the character of the launched SPPs. We find that the SPP launching efficiency exhibits minima (maxima) whenever the scattering into SPPs is in destructive (constructive) interference with the scattering arising via the groove mode excitation. The spectral position of these extremal points strongly depends on the groove shape and the azimuth angle, while it is virtually independent on the incident angle. We show that the rotation of the plane of incidence modifies the SPP wavevector resulting in an offset between their amplitude and phase fronts. The former becomes slanted with respect to the Poynting vector, while the latter remains perpendicular to it.

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Multiple Defect Modes in One-Dimensional Quasiperiodic Photonic Crystal

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The experimental and theoretical investigation of quasiperiodic porous silica photonic crystals (PCs) with artificially introduced cavity modes is presented. Narrow peaks caused by edge modes and cavity modes were observed in each band gap.

A plenty of linear and nonlinear optical effects can be enhanced by the light localization near the photonic band gap (PBG) edges. A wide class of nonlinear effects, such as sum frequency generation and coherent anti-Stokes Raman scattering, involves interaction of two or more waves with different frequencies. The enhancement of these effects can be improved by the photonic crystal with two or more band gaps located in effect-specific spectral ranges. It can be achieved by using quasiperiodic photonic crystals (QPPCs) [1] which have multiple photonic band gaps and the position of each PBG can be varied independently of each other. Microcavities, the PCs with defect layer of $\sim\lambda/2$ thickness, can be used to concentrate light of a narrow spectral range. However, the production of QPPC-based microcavity is not trivial: the cavity mode depends on the thickness of the cavity layer. In case of two different PCs with defect layer embedded between them such modes are also called optical Tamm states [2]. In this paper we propose the QPPC with narrow spectral dips based on cavity modes. The cavity modes are localized at the defect layer and decay into both QPPCs with slightly different reciprocal lattice vectors. Hence two QPPCs have pairwise partially overlapping band gaps.

The QPPC structures composed of two QPPCs with two spatial periods each were produced by electrochemical etching of silicon [3]. The reflectance spectra were calculated by the transfer-matrix method. Two wide bandgaps in ranges of 435-500 nm and 730-870 nm can be observed. Each bandgap has a narrow dip in the reflectance spectrum corresponding to cavity mode at the defect layer between the QPPCs. The dip in the bandgap near 800 nm consists of two close modes corresponding to edge mode of one of QPPCs and cavity mode. This two-fold structure was not observed in the reflectance spectrum of the QPPC structure without the cavity layer.

The quasiperiodic photonic crystal structure with multiple photonic band gaps and narrow cavity modes in each PBG is experimentally demonstrated. The spectral position of each PBG and cavity mode can be tuned independently. The presented structure can be used for the enhancement of nonlinear interaction of two or more different waves or as the selective multiband interference filter.

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Confinement of light through realistic 3D cavity superlattices

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We investigate theoretically the confinement of light in a three-dimensional (3D) superlattice of cavities that is embedded in a 3D photonic band gap crystal. Such a superlattice serves to trap photons and manipulate their behavior, which is relevant in applications like photovoltaic absorption enhancement, Anderson localization of light [1], or photonic computing [2].

As a host of the 3D superlattice we choose the so-called inverse woodpile structure that consists of two perpendicular sets of pores in a high-refractive-index backbone. Inverse woodpile crystals made from silicon, as realized in our group, have a broad 3D photonic band gap [3], ideal for cavity confinement. Cavities are defined in the inverse woodpile structure by introducing two proximate defect pores to have smaller radius than the other pores [4]. Near the intersection of the defect pores, excess silicon traps light. Indeed, band structure calculations reveal flat defect bands in the band gap, typical of cavity resonances. For the optimal pore size for the band gap, the single-cavity resonances are identified to have quadrupolar symmetry [5]. When the band gap cavities are weakly coupled in a superlattice, light effectively hops from cavity to cavity, along main Cartesian (x,y,z) directions, hence the name “Cartesian light” [6].

It seems that resonances (and the band gap) are strong functions of the crystal pore radius and the defect pore radius. But this behavior has to date not been mapped, whereas such a map is crucial to interpret ongoing experiments, where real crystals have pore radii that differ from the design, or pore radii that depend on the location where the crystal is probed. Here, we set out to obtain such a map, and study whether the resonances remain quadrupolar. We use the plane-wave expansion with supercells to assess the open questions. In certain parts of parameter space, the number of resonances changes drastically compared to the known behavior: there are sometimes just a few (perhaps displaying dipolar behavior) and in other ranges 11 to 13 resonances that are attributed to higher order multipoles. At the same time our results show good agreement with available experimental data and offer new insights into the physics of light confinement and propagation through 3D nanostructures.

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Plasmonic defect states in metallodielectric superlattices

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The recent progress in depositing high-quality ultrathin metal layers, with thickness well below the light penetration depth [1], has allowed the fabrication of metallodielectric superlattices with properties very similar to hyperbolic homogeneous media [2]. The latter are characterized by a very large photonic density of states (PDOS) [3] and thus considered promising for the development of novel light sources [4].

In a boundless metallodielectric superlattice, the PDOS consists exclusively of bulk-like plasmonic states, formed through a strong hybridization of surface plasmon polaritons of many individual metal-dielectric interfaces comprising the superlattice [5]. So far, however, semi-infinite superlattices have been more relevant in practice as quantum emitters have typically been deposited on top of metallodielectric layers [6]. The superlattice-homogeneous medium interface introduces two additional types of states into which photons may be emitted: far-field and Tamm plasmon modes [7], which causes a strong spatial variation of the PDOS composition [8].

Here the problem of a single-defect in an otherwise boundless metallodielectric superlattice is considered. It is relevant for emitters embedded into the superlattice, which has been suggested [4] as a measure for further increasing PDOS. The considered defects take the form of a slightly different layer thickness or a local permittivity deviation, so that the system may be regarded as a combination of two semi-infinite superlattices interacting through a common capping layer. We investigate the conditions leading to the formation of transversally localized plasmonic defect states, study their dispersion and field distribution and evaluate their contribution to the total PDOS. The results we obtained show that the total PDOS is significantly increased in comparison to a defect-free case, which is of great interest for quantum well-based light-emitting devices and infrared detectors.

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Refractive index change due to bianalyte adsorption in plasmonic sensors

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Detection of chemical and biological analytes and characterization of biomolecular interactions by adsorption-based surface plasmon resonance (SPR) sensors relies on the change of the refractive index of the medium adjacent to the sensing surface. This change is caused by binding of analyte particles (gas atoms or molecules, viruses, bacteria, proteins, DNA fragments, etc.) to the surface adsorption sites [1, 2]. SPR sensors are nowadays widely used as important analytical tools. However, the problem of selectivity still exists in the case of samples that contain other analytes apart from the target analyte. Therefore, there is a need for the analytical models that consider the influence of multicomponent adsorption on the sensor temporal response, and enable a correct interpretation of the measurement results. The need for such models also exists because one of the directions of the future SPR sensors development is simultaneous multianalyte detection by a single sensing surface, which increases the experimental throughput, while reducing material consumption [3]. The mathematical model of the time response of adsorption-based sensors, commonly used for the analysis of measurement results in the case of multianalyte binding, is based on the linear model of reversible adsorption [3]. The model assumes the adsorption and desorption rates to be linear functions of the numbers of adsorbed particles of all adsorbing species. A more complete non-linear model, applicable for microfluidic SPR sensors, takes into account the influence of mass transfer process of the particles of all analytes on the sensor response [4]. Although these models cover many practical applications of adsorption-based sensors, in the case of sensors with a closed reaction chamber there is a need for a model of multicomponent reversible adsorption that takes into account the depletion of the sample due to the adsorption of analyte particles. A marked influence of the depletion on the sensor response exists in cases of ultralow analyte concentrations, which was shown by the analysis performed using the non-linear model in the case of single analyte adsorption [5]. In this work we perform the analysis of the temporal response of an SPR biosensor (and generally a plasmonic sensor) in which the effective refractive index change is caused by adsorption of two analytes. The analysis is based on the non-linear model of two-component adsorption, which takes into account the depletion of the particles of both analytes from the sample. The results in terms of the refractive index change, obtained for different combinations of parameter values (analyte concentrations, adsorption rate constants, number of adsorption sites on the sensing surface) are compared to those in the case of single analyte adsorption. In this way, the conclusions are obtained about the influence of adsorption of the second analyte on the sensor response. Both the presented model and the analysis are useful for the prediction of the influence of unwanted adsorption of the second substance on the target analyte detection, as well as for using the response of a single sensor to simultaneously obtain information about multiple analytes. This is especially important for the new generation of plasmonic sensors that can detect ultralow analyte concentrations, where the use of the non-linear model becomes necessary.

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Deep learning based classification of high intensity light patterns in photorefractive crystals

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Extreme events (EE) continue to challenge researches in diverse fields of natural and social sciences [1]. The traces of different dynamics of huge intensity light events recently observed experimentally on the output facets of a SBN photorefractive crystal were challenge of this kind for us. We investigate the statistical properties of high intensity events by adopting the standard methods of the EEs detection and classification [2]. It was shown that these events were inevitable in our experiment for a large set of parameters, which was confirmed by a simple theoretical model based on the two-dimensional Schrödinger equation with saturable nonlinearity. We distinguished two main EE regimes, one with speckles pattern and another one with soliton-like structures.

In order to classify different EEs regimes we used the achievements of the deep learning methods applied in various fields of science and implemented them in the EE framework [3]. We applied the convolution neural network (CNN) architecture consisting of the 3-stage feature extractor and a fully connected multi-layer perceptron to classify different high light intensity profiles. These profiles were formed in the experiment and in the corresponding numerical simulations of the light propagation through the SBN crystal [2]. Each feature learning stage incorporated the convolution, ReLU nonlinear activation and max-pooling. Three high intensity profiles: caustic-, soliton- and speckling-like were confronted to the linear dispersion one (i. e. no RW regime). The train and test sets of data were formed from the light intensity profiles. The network architecture and optimal hyperparameters were selected using 10 fold cross-validation. The model performances were evaluated on the blindfolded test set after the model was trained on the whole training set. When the combination of theoretical and experimental data were considered, the overall accuracy of selecting the soliton and speckling regimes, which can be associated with different types of extreme events was above 97%. The caustic regime which can be considered as a nucleus of high intensity events was extracted correctly from the other regimes, too with the accuracy of 97.51 %. Satisfying performances of the CNN based detector and classifier of the high intensity events were an encouraging outcome for continuing the study. We are interested in going towards the prediction of the system preferences for the formation of high intensity events using the deep learning strategy, since these events usually have a devastating effect in the systems.

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Automated design and global optimization of projection lenses for lithography based on global search algorithms

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Global optimization strategies in lens design are radically enhanced by novel features and implemented algorithms over the last six decades. Available computer power boosted the interest in development of new tools for global optimization strategies that can overcome the barriers of merit function around the local minimum. Nevertheless, as the number of variables grows, even the local optimization begins to be extremely time-consuming process, and it becomes challenging task to apply such a tool in lens design.

We describe the method based on global search algorithm that can be successfully used in design of complex systems, such as lithographic objectives with more than 20 lenses. The well-known grouping method is splitting the complex optical system, into more subsystems with moderate complexity [1]. We explored a few approaches which allow that a smaller number of variables distributed on two subsystems simplify design of complex lithographic lens and increase the applicability of global search algorithm.
A shortcoming of developed method is that we first generate two starting points of photo-objectives in the UV spectrum with maximum of 15 lenses. More in detail, we build macros in Synopsys OSD lens design software and run global search of two separate modules [2].
The most challenging parameters of macro input to be adjusted and determined in macro are: the field of view, a number of lenses, length of objective and glass material. Developed method consist of few steps and stages which should formalize the writing of macro input.
In Step 1, we calculate the characteristics of both parts at object side, field of view and semi-aperture. This is the easier part of adjusting input parameters of macro by assuming a point where the two parts to be connected.
In Step 2, we run a series of simulations that sweep through the possibilities of starting designs adjusting the number of lenses and total length of optical module. Ideally, these simulations by Design Search should determine a set of input parameters where the transversal aberrations, over entire field, will be less than 0,005 mm. In Step 3. we combine the separate parts in one optical scheme obtaining the starting point of lithographic objective for further global optimization which tends to provide adequate quality, while maintaining moderate system length and size.

While the traditional design methods lead to designs with very complex theoretical analysis of separate modules which is not inevitable, our modified grouping design method relay on effectiveness of global search algorithm [3]. The final key advantage of proposed design approach is that we generate significantly more starting points of microlithographic objective, that can be analyzed with further optimization leading to the best solution, in less time-consuming process.

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Computationally intelligent characterization of a photoacoustic detector

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Artificial neural networks as machine learning techniques have proven to be suitable tools for intelligent decision making. This paper presents the application of artificial neural networks for fast and precise characterization of electret microphones by photoacoustic measurements based on optical generation of sound. The transfer function of this type of devices is usually not determined precisely enough by the producers, especially phase transfer function, because such detectors are not widely applied in scientific experiments but are rather used in audio techniques where amplitude transfer function is more important. The distorted photoacoustic experimental signal, influenced by the measurement set-up in a non-linear manner, represents the input of our model, while the outputs are the detector characteristics.

The model consists of two neural networks: the first one for the classification of the detector type and the second one for the determination of the detector parameters, related to its electronic and geometric features.

Based on this approach and the theoretical model, relying on the acoustics of small volumes, the parameters and transfer characteristics for several microphones are obtained and compared to the characteristics provided by their producers. It has been shown that the suggested method results in much better detector characterization than the one provided in the official specifications. This could be significant not only for scientific applications of microphones but also for their design and applications in audio techniques.

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Machine Learning in Ca signaling via fluorescence probes for diagnostics of Neuroinflammatory Diseases

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Automated Quantitative Live Cell Fluorescence Microscopy utilizes high throughput screening and analysis of large cell numbers which is expectedly hampered by demanding processes of cell selection and classification of their responses. In a series of previous studies, we demonstrated the effect of purified immunoglobulins G from patients of amyotrophic lateral sclerosis (ALS IgGs) on Ca homeostasis in rat astrocytes in culture. In order to develop automated diagnostic screening of the effects of these IgGs as compared to healthy IgGs, the raw data for the analysis came from the primary rat cortical astrocytes recorded for calcium imaging. We will present various approaches with Unsupervised Machine Learning algorithms in order to: (1) characterize traces and extract significant features, (2) cluster the traces and (3) if any groups could be found, train a classifier to reliably predict a class for any given test trace. Clustering with Decision Trees along with Block Bootstrapping for time series to model the traces, as well as k-Nearest Neighbors classification, gave us satisfactory preliminary results for applying Majority-Voting classification and comparison with the performance of Convolutional Neural Networks. The overarching goal would be to adapt a method of sparse dictionary learning framework for time series imaging by successively adding constraints based on the hierarchical architecture of the decision tree group representations. Thus, populations of traces characteristics for specific patient subgroups could be individuated and proven different from the control signals.

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Generation of zeroth- and first-order long range nondiffracting Gauss-Bessel beams by annihilating multiple-charged optical vortices

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One of the main necessities when working with laser beams is keeping their parameters stable in time and space. Focusing a laser beam in order to achieve high intensity and/or spatial resolution belongs to the most abundant processes in optics. However, due to diffraction the focal length is finite, i.e. the intensity of the light drops after the focus. Tighter focus corresponds to faster intensity decrease with increasing the propagation distances. Because of this, other beam profiles than Gaussian are analyzed theoretically and created experimentally. The so-called Bessel beams offer a solution, at least in theory, since they belong to a special class of non-diffracting, self-healing optical beams [1]. Bessel beam is a field of electromagnetic radiation whose amplitude is described by a Bessel function and is an exact solution of the Helmholtz equation. Unfortunately, ideal Bessel beams are infinitely wide and carry infinite power therefore, it is not possible to be exactly generated in practice. Reasonably good approximation to Bessel beams is made with Gauss-Bessel beams [2, 3]. Here we will demonstrate a novel approach to generate Gauss-Bessel beams with unprecedented extended foci. The idea originates in mathematics, namely in the Fourier transformation of bright ring-shaped beam. It is shown both theoretically and experimentally that the topological charge (TC) of an optical vortex (OV) could be set to zero [4]. As a result, a well-formed Gaussian beam is observed in the Fourier plane. However, if the TC of the OV is higher than 10 (e.g. of the order of 30 – 50) and is subsequently erased, the obtained profile of the beam in the far-field is close to a Bessel function, more precisely – to a Gauss-Bessel function. Based on the study in [5], we developed an analytical model in which a relation between the radius of the vortex ring and the width of the ring arc is shown. If the radius of the ring is much larger than the ring width, then with setting the vortex TC equal to zero, one can expect a Gauss-Bessel beam to be formed in the focus of a lens (artificial far-field). These initial analytical studies were confirmed by series of experimental measurements. The results showed that highly-charged optical vortices (with a TC>10) generated by spatial light modulator (SLM) and then reflected from a second SLM encoded with spiral phase profile of a suitable topological charge, can produce zero-order and first-order non-diffracting Gauss-Bessel optical beams with an extremely extended focal range. Using this approach we will report detailed results of measurements obtained by varying the TCs of the OVs on the two SLMs from 10 to 50.

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The apokamp discharge – transient luminous event in physical laboratory

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In 2016 the group of experimentalists led by Eduard Sosnin (Institute of High Current Electronics, Tomsk, Russia) has been discovered a new phenomenon in low-temperature plasma physics: an extended plasma jet developing perpendicular to the bending point of the pulsed arc discharge channel between two electrodes [1]. This phenomenon occurs if the discharge ignites between two electrodes: first one must be under the high pulse-periodic potential, and the other have to be floating potential, i.e. connected via a capacitor to "ground". The discharge has been entitled an "apokamp" (from Greek απο - "off" and καμπν - "bend"). As it was found that apokamp represents a single needle or a conical jet of 6–7 cm length being attached to the bending point of the current channel. This new unusual type of discharge phenomenon is observed at high (atmospheric) and medium pressures in gas mixtures usually containing a small portion of electronegative admixture, e.g. oxygen or chlorine. It was shown experimentally that apokamp does not exist in highly purificated non-electronegative gases (argon, krypton, nitrogen). It should be also noted that depending on voltage pulse parameters, the apokamp can turn into more than one plasma jets also directed almost perpendicularly to the current channel [2]. In [3], it was shown that the apokamp in low-pressure air represents an exact tiny analogue of large-scale stratospheric transient luminous events, e.g. "blue jets" or "sprites" depending on the operating pressure. Here we give first theoretical backgrounds for the apokamp phenomenon in terms of deterministic DC-discharge theory. We use the "two-moment model" [4] of a multicomponent discharge plasma to describe a self-sustained periodic discharge in pure oxygen both in the inter-electrode gap and in the surrounding space above the electrodes. To simplify the consideration of a physical situation the 2D-model is used instead of 3D, so the discharge between two plane electrodes with similar to experimental physical conditions has been considered. In simulations, the high-voltage potential is connected to the pulse voltage source through the 10 kΩ ballast load. The floating potential electrode is connected to the ground through the 10 pF capacitance. We also consider a simplified plasma-chemical reactions and species sets for oxygen [5]. Our reduced formulation includes only electrons, neutral molecules O and O_2, positive O_2^+ and negative O_2^- single charged ions. The reactions numbers are restricted to four most important: electron impact ionization, impact dissociation, electron attachment and ion-ion recombination. We also used non-uniform initial conditions for quasi-neutral plasma density and temperature distribution in the inter-electrode space to perform the simulations in the pre-conditioned medium.

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Anisotropic nanostructures for broadband achromatic polarization-insensitive meta-lenses

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Metasurfaces have attracted widespread attention due to an increasing demand of compact and wearable optical devices [1-7]. For many applications, polarization-insensitive metasurfaces are highly desirable, and appear to limit the choice of their constituent elements to isotropic nanostructures [8]. This greatly restricts the number of geometric parameters available in design. Here, we demonstrate a polarization-insensitive metalens using otherwise anisotropic nanofins which offer additional control over the dispersion and phase of the output light. As a result, we can render a metalens achromatic and polarization-insensitive across nearly the entire visible spectrum from wavelength $\lambda = 460$ nm to 700 nm, while maintaining diffraction-limited performance. The meta-lens is comprised of just a single layer of $TiO2$ nanofins and has a numerical aperture of 0.2 with a diameter of 26.4 μm. The generality of our polarization-insensitive design allows it to be implemented in a plethora of other metasurface devices with applications ranging from imaging to virtual/augmented reality. In addition, we also explore and present an alternative approach to design and select nanostructures using machine learning which is in contrast to the conventional numerical methods deployed by simulation software such as Lumerical.

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Effect of nitrogen presence during the deposition on structural and optical properties of Ge quantum dot lattices in alumina matrix

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Effect of nitrogen presence during magnetron sputtering deposition of Ge quantum dot lattices embedded in alumina matrix [1, 2] was studied. Three series of samples were deposited by varying substrate temperature, nitrogen flow rate and germanium content. The aim was to examine the effects of these parameters on structural and optical properties of the material and the self-assembled growth regime. It was shown that the presence of nitrogen affects the size of Ge QDs, their oxidation and optical properties. Furthermore, it was shown that nitrogen also influences the ordering quality of Ge QDs and that second order of Bragg spots are narrower and better visible for the film with 2% of nitrogen. Increase in the deposition temperature results in larger Ge QDs. Especially grows lateral radius of Ge QDs, Rl. It increases from 11.9 nm to 20.8 nm when the temperature changes from 300ºC to 500ºC. Germanium oxidation was studied using x-ray photoelectron spectroscopy and it was shown that germanium oxidation strongly influences optical properties of our thin film material. Combination of the mentioned parameters presents a powerful tool for control of the properties of the materials that are important for the optoelectronic applications.

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Inner-shell spectroscopy of titanium (IV) iso-propoxide

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The quality and properties of synthesized nano structure strongly depend on several factors, like the choice of substrate and the appropriate precursors as well as the optimal conditions for substrate-precursor reaction. For deposits such as TiO_2 these factors become particularly important because directly affect properties such as magnetism and conductivity [1].

In the view of the intense activity related to synthesis of nanomaterials based on TiO_2, we investigated inner-shell ionization and excitation in the titanium (IV) iso-propoxide $Ti[OCH(CH_3)_2]_4$ molecule, which, due to its structure and chemical characteristics is considered as an efficient precursor for deposition of TiO_2 thin films. Complementary experimental techniques (XPS, NEXAFS, mass spectrometry) as well as extensive molecular dynamics (MD) simulations have been used to investigate the photo induced fragmentation of $Ti[OCH(CH_3)_2]_4$. The experiments have been performed at the Gas Phase photoemission beamline of the Elettra synchrotron radiation source (Trieste, Italy) [2, 3].

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Understanding trends in lithium binding at two-dimensional materials

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Layered structure and peculiar electronic properties of two-dimensional (2D) materials foster the concept of utilizing them as main components of lithium-ion batteries. Understanding basic physical mechanisms governing the interaction of Li with 2D crystals is of key importance to succeeding in a rational design of cathode and anode materials with superior functionalities. Study of Li atoms adsorbed at graphene clearly shows that Li atoms, featuring a long-ranged electrostatic repulsion, are individually dispersed across the surface [1]. This was a motivation for the further investigation of Li adsorption at a number of different 2D materials. In this study density functional theory was applied to reveal the microscopic picture of Li interaction with 15 2D crystals, including several transition metal oxides and dichalcogenides, carbides of Group XIV elements, functionalized graphene, silicene, and germanene, as well as black phosphorus and Ti_2C MXene [2]. We found that the general trend in Li binding can be estimated from positions of conduction band minima of 2D materials since the energy of the lowest empty electronic states shows a nice correlation with the strength of Li adsorption. At variance to the majority of studied surfaces where the electron transferred from Li is spread across the substrate, in monolayers of carbides of Group XIV elements the interaction with Li and the charge transfer are well localized. This gives rise to their capability to accommodate Li structures with a nearly constant binding energy of alkaline atoms over Li coverages ranging from well-separated adatoms to a full monolayer.

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Luminescent PMMA films and SiO_2 nanoparticles functionalized with Ln^{3+} complexes for highly sensitive ratiometric optical temperature sensors in the physiological range

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Optical thermometry based on luminescence is an expanding field of research because non-contact temperature sensing can have different applications, such as for bioimaging in the physiological temperature region, in the cryogenic temperature region for space and aeronautics applications, or in industry where it is necessary to have good sensing properties in precisely defined temperature ranges [1]. Lanthanide β-diketonate complexes have been extensively investigated in the past, as they are cheap, easy to synthesize and they tend to form highly stable complexes with lanthanide ions. Lanthanide β-diketonate complexes have been used as NMR shift reagents, also they are good precursors for further synthesis in some more complex matrixes (such as sol-gels, polymers, etc.), used as OLEDs and as temperature probes because of their distinct luminescence properties [2].

Here, we report novel structures of different homonuclear complexes (Ln^{3+} = Eu^{3+}, Tb^{3+} and Sm^{3+}) with two different β-diketonate ligands and one neutral ligand. The β-diketonate ligands (L) used for the synthesis of the complexes are 4,4,4-trifluoro-1-phenyl-1,3-butadione (bfa) and 4,4,4-trifluoro-1-(4-chlorophenyl)-1,3-butadione (Clbfa) and the neutral monodentate ligand triphenylphosphine oxide (tphpo). The complexes show distinct luminescence properties such as color purity and high quantum yield, which gave us the idea to process these complexes in different matrixes and try to make functional thermometers for use in the physiological temperature range. The complexes were doped into poly(methyl-methacrylate) (PMMA) at different ratios to obtain PMMA thin films that could be used as luminescent thermometers. We have two series of PMMA films, first with $Ln(bfa)_3(tphpo)_2$ complexes and second with $Ln(Clbfa)_3(tphpo)_2$ complexes. In the series we have two different subseries: one with Tb^{3+}-Eu^{3+} ions and another with Tb^{3+}-Sm^{3+}. We have obtained a series of Eu-Tb and Sm-Tb thermometers with different ratio between the lanthanide complexes. The best performing sample from the Eu-Tb series shows a maximal value of Sr = 4.38% K^{-1} at 303 K in the 253-353 K region, as for best performing sample for the Sm-Tb series shows a maximal value of Sr = 3.85% K^{-1} at 313 K in the 253-343 K region. The best PMMA films were coated on SiO_2 nanoparticles and were studied in water in the 5-50 °C temperature range. The Eu-Tb sample shows a maximal value of Sr = 4.14 % C^{-1} at 20 °C and for the Sm-Tb sample a maximal Sr = 3.81 % C^{-1} at 20 °C.

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Inverted field interferometer for measuring the topological charge of optical vortices

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We present a novel technique for measuring both the magnitude and sign of the topological charge (TC) of optical vortex beams. The method itself relays on well aligned collinear inverted field interferometer (IFI) setup. IFI differs from usual interferometers in the number of reflections in their arms prior to the final overlap of the beams [1]. Then, as a result of an additional reflection in one of the arms, the two interfering beams propagate collinearly with one of the beams being flipped with respect to the second one. Letting a vortex beam with an unknown TC to pass through it, one can observe/record an interference pattern resembling the so called "necklace beam" [2, 3] profile. As a first step, the modulus of the TC can be determined by counting the number of observed pattern peaks, which corresponds to the double of the absolute value of input beam TC. As a second step, the time delay in the interferometer can be changed causing rotation of the interference peaks. When using calibrated IFI, the direction of this rotation determines the sign of the TC of the OV. Simulations, based on analytical model, and experimental evidences for the interference signal obtainable at the output of IFI are in an excellent agreement. These results are valid for both continuous wave and femtosecond optical vortex beams and pulses with an eventual pulse front tilt [1, 4]. An IFI also appears to be a valuable tool for calibrating a built-in variable delay line and for estimating an eventual pulse front tilt of the input ultrashort laser pulses without any realignment.

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Ideal Efficiency of Resonant Cavity Perovskite Solar Cells

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Perovskite solar cells (PSCs) attracted high attention in recent years due to the rapid increase in device efficiency (over 22% since 2018), ease of fabrication, and the potential to produce low cost photovoltaic modules [1].

In this work we determine the ideal efficiency of PSCs with the p-i-n device structure, where p is the hole transport layer (HTL), i is the perovskite absorber layer, and n is the electron transport layer (ETL). The absorption of incident light occurs in a thin perovskite layer (800-1000 nm). In cases when the incident light wavelength is comparable with the thickness of the absorption layer, it is necessary to take into account interference effects. Contact junctions are made of transparent indium-tin-oxide (ITO) on the p side, and gold on the back side. In the optical sense, we represent the HTL and ETL layers with the corresponding complex reflection coefficients R_1 and R_2. In that way the PSC structure is represented by a Fabry-Perot resonator. By using the method described in [2, 3], the optical flux $I(x,\lambda)$ within the absorbing perovskite layer is calculated as a function of the spatial coordinate x, for a certain wavelength λ, at the normal incident light. The power quantum efficiency is calculated assuming that the incident light source is a black body at the temperature of the Sun, by using the definition given in [4]. The results obtained by using the derived expressions that take into account the interference effects are compared with those obtained by neglecting these effects.

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Ultrafast Dynamics of Quantum Cascade Laser: Modelling and Optical Properties

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Quantum Cascade Lasers (QCLs) are powerful semiconductor sources of coherent radiation in the mid-infrared (MIR) and Terahertz (THz) band with potential applications in free-space communications, medical diagnostics, and chemical sensing [1]. These devices use sequential tunneling and usually comprise a large number of semiconductor heterostructure periods (typically GaAs/AlGaAs for THz QCLs).

QCL modeling can be usually classified into semi-classical rate equation approaches and quantum approaches such as density matrix (DM) models and non-equilibrium green function models [2]. The most common applications of QCL models consider systems with few states, which usually yield analytic expressions. We present a density matrix model [3] capable of treating a structure of arbitrary number of states while retaining low numerical complexity when compared to the more extensive models.

The model couples *10N²* equations (where *N* is number of states in one QCL period) that result from the DM Liouville equation, with Maxwell wave equation under slow-varying approximation:

$$\frac{d\rho}{dt} = L_{10N^2}(E)\rho$$

$$\frac{\partial \mathrm{E}}{\partial \mathrm{t}} = -\frac{\gamma_n}{2}E - j\frac{w}{2\varepsilon_0 n^2}P(\rho)$$

Where L_{10N^2} is the Liouvillian superoperator that is formulated from the corresponding Hamiltoninan and transport mechanisms, γ_n is optical conductivity and directly linked to optical loss, w is lasing frequency, n is the refractive index and P is the polarization that is calculated through DM formalism.

The resulting system may be solved numerically with assistance of various dynamical ODE tools providing an insight into dynamical properties of QCL. In this work, we apply the model on exemplary structure and simulate single mode dynamics. The model presents powerful simulation tool and in future work we will be able to investigate various dynamic effects with QCL, such as multimode operation, self-mixing interferometry and frequency comb generation.

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Electron quantum transport in InGaAs/GaAsSb double barrier resonant tunneling structures

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Some of the most interesting optoelectronic unipolar devices are intersubband (quantum-cascade) lasers and quantum well infrared photodetectors. These devices exploit electron quantum tunnelling, and are usually composed of a large number of semiconductor quantum well and barrier layers. These devices are mainly based on III–V semiconductor compounds. High temperature performance of mid-infrared and far-infrared unipolar lasers has been demonstrated in InGaAs/AlGaAs lattices, matched to InP and GaAs/AlGaAs based systems. In addition, the usage of InGaAs/AlGaAs and InAs/AlSb systems has been recently demonstrated in quantum-cascade lasers, whilst GaN/AlGaN systems become promising for near-infrared unipolar lasers and photodetectors [1]. However, the aforementioned materials usually contain a significant fraction of aluminium in the quantum barrier material, resulting in large electron effective masses. Therefore, the search for an aluminium-free material system, that would result in lighter electron effective masses in the barrier layers, becomes a hot topic. Higher optical gain and improved device performance would be the benefits of such a material system with lighter electron effective masses barrier electrons. Recently, optoelectronic devices based on intersubband transitions were demonstrated in an Al-free III-V antimonide-based material system, where $In_{0.53}Ga_{0.47}As$ was used as the quantum well for electrons and $GaAs_{0.51}Sb_{0.49}$ acted as the barriers [2]. In order to optimise these devices to a particular application, an understanding of the physics of quantum-mechanical carrier transport throughout these complex heterostructures is needed.

On the other hand, the resonant tunnelling diodes (RTDs) [3] have been widely studied from the beginning of the 1990s. They provide a considerable amount of information about the quantum mechanical aspects of electron transport in these semiconductor structures. The understanding of the physical properties of such a simple structure and refined experimental techniques allows for the development of numerical models to describe electron tunnelling transport in the novel material systems. Such models could be used to investigate InGaAs/GaAsSb RTDs [4] and in the optimisation of more complex devices like quantum-cascade lasers or quantum well infrared photodetectors.

In this work, the transport properties of the double-barrier InGaAs/GaAsSb structure were numerically modelled as an RTD. Based on the Tsu & Esaki formula for the tunnelling current, the current-density-voltage characteristic of a novel $In_{0.53}Ga_{0.47}As/GaAs_{0.51}Sb_{0.49}$ structure — with different quantum well width at cryogenic and elevated temperatures — was calculated. The tunnelling coefficient was calculated in the framework of effective mass approximation with non-parabolicity using the transfer matrix method. A very good agreement of the position of resonant current peaks with the experimental analysis by de Sousa et al. [4] was achieved. We calculated InGaAs/GaAsSb RTD peak to value tunneling current ratio to be ~1.8 at cryogenic temperatures.

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