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apropos 16

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The Conference continues tradition to bring together scientists involved in research focused on solid state physics and photonics.

The conference has started as a symposium entitled “Plasma and instabilities” held every three years in Vilnius since 1971. The event was initiated and hosted by the Semiconductor Physics Institute. After Lithuania regained its Independence in 1990, the Symposium was transformed into “International Symposium on Ultrafast Phenomena in Semiconductors (UFPS), Vilnius, Lithuania”.

In 2010 the Semiconductor Physics Institute became a part of the Center for Physical Sciences and Technology. The year of 2016 highlighted particular changes in the Center – the institution moved to a new building located in Saulėtekis (Sunrise) avenue. Modern technological and scientific laboratories opened novel facilities for science and innovations. Therefore, the conference also gained new scientific dimension and new name – “**Advanced Properties and Processes in Optoelectronic Materials and Systems**”, **APROPOS**.

APROPOS 16 manifests optoelectronics and nanotechnology – based scope covering topics of

- Semiconductor nanostructures and advanced photonics systems,
- Organic materials for optoelectronics,
- Ultrafast and terahertz phenomena,
- Laser technologies & light emitting diodes,
- Nano- and biophotonics.

Gintaras Valušis, chair of the APROPOS 16

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I1

Terahertz quantum cascade lasers – from devices to applications

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I2

Intense THz sources and Nonlinear THz Optics

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High-field carrier transport dynamics at terahertz (THz) frequencies in semiconductors can lead to numerous ultrafast phenomena, such as THz pulse self-phase modulation, intense THz field induced impact ionization, as well as dynamic Bloch oscillations driven by ultra-high THz frequencies [1-3]. In the nonresonant regime, carriers can be efficiently accelerated by the intense THz field, resulting in high ponderomotive energy that is proportional to the square of the peak field and inversely proportional to the square of the THz frequency [4]. In this work, we perform nonlinear THz-TDS measurement of InGaAs thin film using an intense THz source generated from an interdigitated ZnSe large-aperture photoconductive antenna (LAPCA), which can generate intense, asymmetric quasi-half-cycle THz pulses with low median frequency of approximately 0.2 THz [1]. With the same peak field, the ponderomotive potential is thus much higher than other higher frequency THz sources via, for example, optical rectification [1,5]. At high fields, we observe strong THz transmission bleaching, THz phase modulation as well as the generation of high frequency components (Fig. 1).

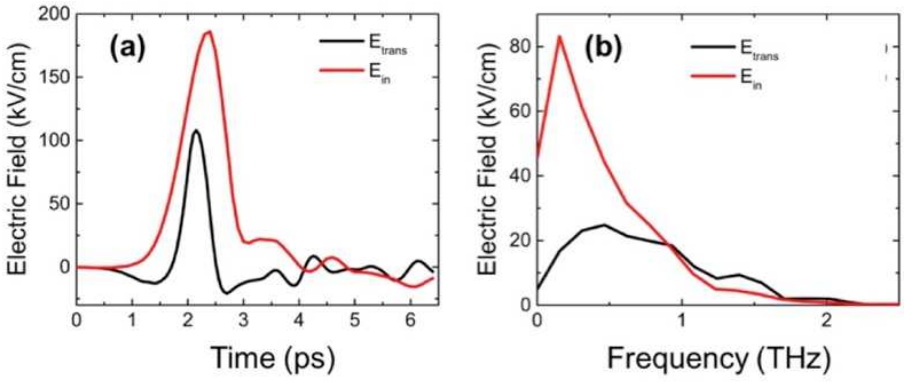

Fig. 1. (a). Incident and transmitted THz waveform through InGaAs, (b). corresponding spectra.

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O1

Stabilization of exotic atomic structures via wafer bonding.

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Wafer bonding is a ubiquitous technology utilized in diverse applications, starting from fabrication of lattice mismatched multijunction solar cells and grain boundary-based superconducting quantum interference devices, to packaging of microelectromechanical systems. In this study, we investigate atomic structures and their properties stabilized at the interface of bonded CdTe wafers.

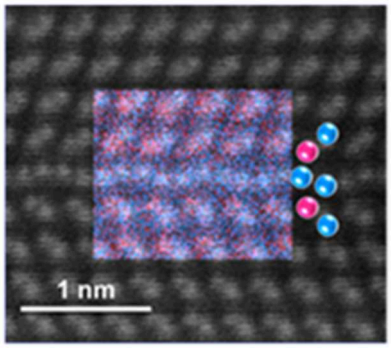

Fig. 1 Atomic-column resolved STEM X-ray image of interfacial tellurene stabilized by bonding of CdTe wafers [3].

Characterization and analysis of several wafer bonded interfaces will be presented, including arrays of dislocations created by low-angle miscut wafers, and structures created by bonding polar crystallographic planes [1,2]. We find that bonding same-polarity close-packed {111} CdTe planes leads to self-assembly of an interfacial monolayer tellurene. Electronic structure calculations and measurements show that the interface is metallic, exhibits Rashba-type spin-orbit band splitting and linear dispersion, as well as a pronounced plasmon-polariton response [3]. This suggests that crystal planes suitably chosen for bonding may act as a template to stabilize exotic and non-stoichiometric atomic structures, which would otherwise be challenging to synthesize using conventional growth techniques. Potential applications and effects of such interfacial structures on CdTe –based device performance will be discussed.

The atomic-scale structural and chemical characterization, as well as electron energy-loss spectroscopy of bonded interfaces, is performed using aberration-corrected cold-field emission scanning transmission electron microscopy. Electronic properties are investigated via first-principles DFT calculations, I-V characteristics, and 2-photon absorption time-resolved photoluminescence measurements.

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[3] In submission process.

I3

Spin relaxation dynamics in copper-doped CdSe nanocrystals

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Copper-doped colloidal semiconductor nanocrystals constitute a family of materials where the properties of a particular “charge transfer” (CT) exciton state can be investigated. This excited state is formed upon above band-gap photoexcitation and subsequent ultrafast capture of the hole by the copper ion. As a result, the energy of the recombining electron-hole pair is strongly redshifted with respect to the absorption edge and sensitive to the nanocrystal diameter. These properties make copper-doped nanostructures actively studied with a view of applications in imaging and display technologies, and in photovoltaics as spectral converters [1]. Importantly, the trapping of the hole changes the spin state of the copper ion from a nonmagnetic s = 0 singlet to a s=1/2 doublet. Consequently, the spin properties of the electron-ion state are governed by the total spin S=1 or 0. Thus, copper-doped nanocrystals offer a unique opportunity to study the spin properties of the CT exciton state composed of a delocalized electron and ion-bound hole [1]. Such states are usually unavailable in neither bulk nor organic semiconductors. Understanding the spin dynamics of the CT state is important for designing optoelectronic applications employing this degree of freedom.

In this work, we investigate the steady state and time-resolved photoluminescence (PL) of the copper-doped CdSe nanocrystals in a magnetic field. We address two specific issues. (i) We develop a detailed understanding of the circular polarization of the PL. (ii) We evaluate the spin relaxation time governing the relaxation among the Zeeman split CT states.

Application of a magnetic field results in a occupation imbalance among the Zeeman split CT states giving rise to a circular polarization of the PL. We find that this polarization is significantly stronger than for undoped CdSe nanocrystals, which we attribute to the particular spin structure of the CT state. To calculate the energies and the resulting occupations of the Zeeman split states, we develop a model that accounts for the electron-ion exchange interaction, the strain in the ion vicinity, and the averaging over the nanocrystal ensemble. The model reproduces the experimental findings and, in particular, explains the distinct nonlinearity of the polarization dependence on field observed by various authors [2-3]. We show that the effect arises as a result of different contributions to the PL polarization from nanocrystals with the quantization axis oriented parallel and perpendicular to the magnetic field.

We measure the spin relaxation time as the rise time of the PL polarization. We find that at magnetic fields below 1 T and at temperatures below 2 K, the relaxation is very slow and the relaxation time is on the order of microseconds. As the field or the temperature is increased, spin relaxation accelerates and at 8 T and 10 K, the relaxation time is on the order of 10 ns. These observations suggest a phonon-related mechanism. It is important to note that the spin relaxation of the CT exciton requires a flip of both the electron and the ion spin. Thus, we propose that the mechanism responsible for the observed dynamics is related to a two-phonon process. Importantly, the spin relaxation time is always shorter than the PL lifetime allowing the system to reach thermal equilibrium.

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O2

Charge carrier motion dynamics in semiconducting single-wall carbon nanotubes.

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Carbon nanotubes (CNTs) continue to attract interest and are considered as potentially promising materials for the development of devices based on new operating principles. Devices based on a single nanotube may be a good example paving a way towards a nanotechnology-based electronics. Due to strong and spectrally tunable absorption bands in visible and IR spectral regions and related photoconductivity, as well as high carrier mobility, CNTs are also promising for the development of materials with enhanced useful electronic properties for more conventional photoelectronic devices. Photoconductivity is one of the most important processes, however still not sufficiently clear.

\We combined several experimental techniques - time resolved electric field-induced second harmonic (TREFISH) generation, conventional transient photocurrent and time-delayed collection field – to directly track the carrier generation and motion processes in individual single wall CNTs (SWNTs) and their bundles. The investigated samples were prepared on combs of interdigitated electrodes as thin films of 6.5-SWNTs with different concentrations of fullerene derivative PCBM serving as electron acceptors. The samples were excited by IR light pulses to the first excitonic band and voltage applied to the interdigitated electrodes facilitated charge carrier generation.

Four photoinduced processes taking place on an ultrafast (ps to several ns) time scale in individual SWNTs were identified: first, electron transfer from photoexcited SWNT to PCBM or impurity creating CT state during less than 1 ps; second, CT state dissociation during 200-300 ps; third, a fast hole drift and fourth, recombination of a fraction of photohgenerated charge carriers on a ns time scale. Intertube hole motion in SWNT bundles is much slower taking several microsceonds.

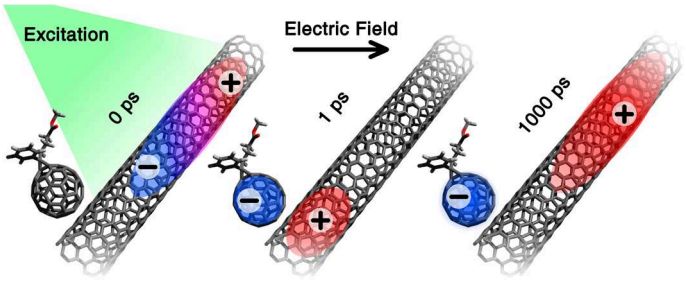

Fig. 1 Schematic illustration of ultrafast processes taking place in photoexcited SWNTs .

Direct tracking of electronic processes in photoexcited SWNTs give reference data necessary for clear understanding of the photoinduced processes in CNTs and development of CNT-based electronic devices.

O3

Nonlinear acoustoelectric effect in a superlattice: Bifurcations, current reversals, Bloch-like oscillations and amplification of THz electric fields.

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Coherent phonons can serve as a potent tool for enhancing optoelectronic and transport properties of nanostructured materials [1]. In particular, there has been increased interest in an amplification of acoustic phonons induced by their interaction with fast moving carriers in seminconductor superlattices (SLs) [2]. These experiments unfolded the importance of several superluminal concepts, such as ordinary and induced Čerenkov effects, for the acoustically driven miniband SLs, where semiclassical dynamics of electrons is intrinsically nonlinear. Recently, we theoretically discussed the related nonlinear electroacoustic effects in SL utilizing semiclassical nonperturbative methods [3]: Under the action of a strong acoustic wave, the drift velocity of electrons demonstrated abrupt changes of its magnitude and direction. The propagating deformation potential can also induce quasi-periodic Bloch oscillations of miniband electrons [4]. These transport effects are connected to global bifurcations (instabilities) developing with an increase of the wave amplitude, which serves as a control parameter [3]. An existence of the bifurcations clearly distinguishes the case of SL from the ordinary electroacoustic effect in bulk semiconductors with a quadratic band.

Here we discuss intriguing physical mechanisms behind the bifurcations, and also announce their potential application to a broadband amplification of THz electromagnetic waves. We show that the bifurcations caused by an emission of specific SL phonons by supersonic electrons, and their back action on the electrons. On the one hand, these phonons demonstrate features typical for the Smith-Purcell radiation (radiation of a fast charge particle that is propagating through a spatially periodic resonant structure). On the other hand, the underlining radiation mechanism is more complex than the familiar Čerenkov effect, and also includes electronic transitions in the potential well formed by the deformation potential (Ginzburg-Frank-Tamm superluminal effect). In summary, SLs could serve as a new playground for investigations of various superluminal physical effects in the presence of nonlinearity. Surprisingly, the accompanying deterministic instabilities able to provide promising applications in optoelectronics, including THz gain in unbiased configuration.

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O4

Effect of graphene quality on its high-frequency electromagnetic properties

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The CVD technique is the most promising approach for large-scale production of mono- or few-layer graphene. But typically CVD graphene films have a polycrystalline structure with high density of graphene/grain boundaries resulting to variable transport, thermal and electronic properties [1]. In this context, understanding the influence of the graphene microstructure is not only a fundamental problem but also technologically important for future development of various tunable graphene-based devices [2].

In this communication, the influence of the graphene microstructure on the total high-frequency electromagnetic response of graphene films has been investigated. In particular, the effect of grain size (from 10 μm up to 500 μm), boundary width and multilayer islands presented on the surface of the graphene sheet has been considered in details both, theoretically and experimentally. As it is shown, the distance traveled by an electron in graphene under high-frequency EM wave being small (~ 100 nm) compared with a typical grain size of CVD graphene (several tens μm), the latter hardly affects on the total electromagnetic response of graphene-based systems. From the experimental point of view, samples of CVD graphene with two-grain sizes (~20 μm and ~ 400 μm) were synthesized and experimental results obtained in the microwave and THz frequency ranges correlated well with theoretical simulation.

Based on the previous analysis, the efficiency of interface strain transfer between the PDMS elastomeric substrate with high Poisson ratio (0.5) and CVD graphene film as well as the effect of mechanical deformation on the total high-frequency electromagnetic response of CVD graphene have been analyzed. The weak sensitivity of CVD graphene high-frequency properties to large (more than 20%) mechanical deformation has been demonstrated. In the framework of this communication different ways for practical applications of such an effects will be presented.

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O5

Structure and properties of the graphene directly synthesized on Si and SiO_2

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2D nanomaterial graphene is at the top of the considerable interest due to the giant electron and hole mobility, charge carrier multiplication, flexibility, optical transparency, chemical inertness. One of the main limitations stopping the wider application of the graphene in semiconductor device technology, is a complex graphene transfer procedure. In this case graphene is synthesized on the catalytic Cu or Ni foils. Afterward, the long process of the graphene transfer onto the targeted semiconductor or dielectric substrates follow. During that process, graphene can be contaminated by different adsorbents. Transfer cause wrinkles or ripples to form on graphene. In such a case control of the graphene layer or graphene-semiconductor contact properties is complicated. Recently there were shown that direct synthesis of the graphene on semiconducting or dielectric substrates is possible. However, development of this technology is the very beginning.

In present research graphene layer were directly synthesized by microwave plasma enhanced chemical vapor deposition on the semiconducting monocrystalline Si(100) substrates and insulating SiO_2 films. Structure of the films was investigated by Raman scattering spectroscopy.

Effects of the deposition conditions on structure of the graphene layers were studied. There were revealed that control of the number of the defects in graphene (evaluated by calculating D/G Raman scattering peak intensity ratio) and graphene thickness can be achieved by changing deposition temperature, synthesis time, pressure, hydrogen and methane gas flow ratio as well as power.

Electrical properties of the graphene and graphene/Si contacts were investigated. Graphene/Si Schottky diodes were fabricated.

I4

Optoelectronic properties of wide-bandgap hybrid organic-inorganic perovskite films

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Hybrid organic–inorganic perovskites have drawn tremendous research interest as the very promising semiconductors for next-generation photovoltaic technologies. Thin-film perovskite solar cells have already demonstrated outstanding performance with power conversion efficiency exceeding 22% which is comparable to traditional Si technologies. These materials possess excellent optical and electronic properties such as the bandgap tunable through perovskite chemical composition, high charge-carrier mobility and long carrier diffusion length, lightweight and mechanical flexibility. Another merit lies in the processing from solutions using such methods as spin coating or inkjet printing at room temperature; these processes potentially allow for a low-cost and low-temperature device fabrication well compatible with flexible plastic substrates.

Further improvement of the efficiency and stability of hybrid perovskite-based devices requires a deeper understanding of their intrinsic photophysical properties and nature of defects. In particular, an accurate picture of the density of states associated to traps and energetic disorder in such films is important as these have a direct influence on charge-carrier mobility, lifetime, and diffusion length. In this work we report on temperature-dependent photoexcitation dynamics and charge carrier trapping studied in several novel hybrid perovskite materials depending on perovskite film quality. Fabricated perovskite films were characterized by X-ray diffraction, time-resolved photoluminescence, and scanning electron microscopy techniques. Charge-carrier traps were identified in all investigated perovskite films and their energy distributions were characterized. Possible origins of observed traps are discussed. We found that perovskite chemical composition, annealing temperature and film crystallinity has a strong impact on the trap depth and trap concentration in films under investigations. We further demonstrate a clear correlation between optoelectronic device performance, crystallization dynamics in spin-coated perovskite films and trap densities in them. We also compare optoelectronic performance of 3D and 2D mixed-halide perovskite films and identify charge trapping centers in them. These results indicate that the charge trapping spectroscopy can provide valuable information about formation of crystal defects and the associated charge-carrier traps in hybrid perovskite semiconductors.

I5

Towards Terahertz Organic Electronics: Development of Solution Processed Terahertz Emitters and Detectors

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The most widely used pulsed THz emitters and detectors are based on crystalline semiconductors, e.g. GaAs and InAs. For the past few decades, many approaches were explored with the aim of increasing emission intensity and widen its spectral bandwidth. This led to the development of III-V multiple-quantum-well emitters, THz quantum cascade lasers, and non-linear crystals among others. However, improvement in the intensity of emission and limited tunability of detection remained a challenged that hindered this spectral region to be used for day-to-day applications. Furthermore, these devices are grown using intricate and cost-demanding molecular beam epitaxial techniques requiring heavy investment. In this talk, our efforts on developing THz emitters and detectors based on solution processed organic materials will be presented. THz emission from organo-metal halide perovskite-based materials and THz detector from celery plant will be discussed.

O6

Doped bifluorene crystals for organic laser applications

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Organic single crystals with long-range molecular order ensure superior carrier transport, enhanced photochemical and thermal stability as well as negligible light-scattering, what makes them attractive as an optical gain medium for electrically-pumped organic lasers [1]. Emission through dopant states enables approach where charge transport ensured by ordered closely packed molecules, while emission properties can be controlled by molecular design of the dopant.

Rational design of bifluorene-based compounds enabled control of intermolecular coupling realizing high radiative rates and high fluorescence quantum yield (ΦPL >0.8) in the sublimation-grown single crystals. Pronounced emission properties accompanied by excellent waveguiding properties, favorable orientation of transition dipole moments as well as non-overlapping excited-state absorption and the gain region enable to achieve extremely low amplified spontaneous emission (ASE) thresholds (down to 400 W/cm2) in the single crystals of bifluorene compounds [2,3]. Ultrafast spectroscopy studies of the crystals revealed an efficient exciton transfer to the highly radiative trap states. Doping of bifluorene crystal enabled control of energy transfer rate from the excitonic states to the trap states with the possibility of further reduction of triplet quenching.

Low values of ASE threshold encourage employment of organic crystals for lasing applications with separate optimization of charge transport and ASE properties.

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O7

Laser-Ablated Antireflective Structures and Focusing of Terahertz Radiation

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Recently demonstrated laser - ablated optical components for THz range, such as multilevel phase Fresnel lenses [1], provide excellent possibilities of their integration directly into semiconductor substrates. However, usual relatively high refractive indexes of common semiconductors lead to substantial losses due to reflections from surfaces when multiple such components are used in THz optical systems.

In this contribution, we will present our work on optimization and characterization of laser-ablated anti-reflective (AR) structures with the emphasis on their use for phase shifting applications. We applied numerical simulations based on finite-difference time-domain (FDTD) method to optimize the expected performance of AR structures with periodic arrays of pyramid-shaped structures taking into account the peculiarities of laser-based processing.

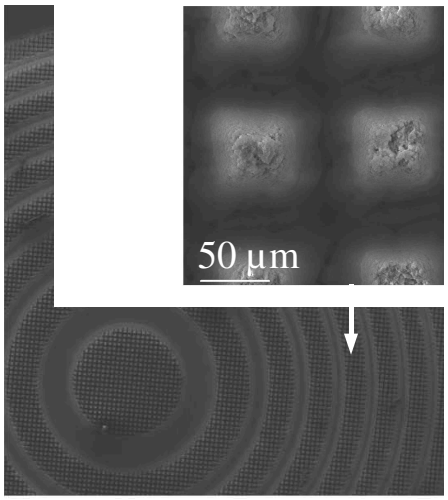

Fig. 1 SEM images of the produced zone plate and elements of AR structure (in inset).

Fundamental harmonics (1064 nm) of the picosecond high-repetition-rate laser and two beam delivery systems were employed to produce several AR structures on both doped and highly resistive silicon (HR - Si). In addition, binary zone plate employing phase shift differences induced by these AR structures was produced (Fig. 1). Teravil - Ekspla Terahertz Time - Domain Spectroscopy (THz - TDS) system was employed for measuring transmittance distributions of the samples. Consistent high transmittance of approximately 90 % was experimentally measured in 0.25 – 0.6 THz range for the HR-Si sample with both AR structured sides. Custom-made THz imaging system based on amplifier multiplier chain as THz source and 3D motorized stages was used to evaluate the focused beam profile in the focal plane of the produced zone plate and to reveal nearly diffraction limited performance of the zone plate.

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O8

Nano-composite electron emitters for terahertz radiation

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The *sine quo non* for implementation of terahertz (THz) electron beam devices is a high current density and long life thermionic cathode. The conventional thermionic cathode technology falls short of required current density by about an order of magnitude. Conventional dispenser cathodes currently used in microwave electron devices can generate zero field current densities of 10 A/cm^2 at 1,150°C, albeit with lifetimes of around 1,000 hours.

Scandate cathodes have attracted considerable attention due to their potential for high current-density emission at low operation temperatures. Several types of scandate cathodes have been developed during the last three decades, but the nano-composite scandate tungsten (NST) cathodes have been shown to solve the shortcomings of the previously investigated scandate cathodes: a uniform scandium oxide distribution in micro or nano scale tungsten pores assists with a high rate of electron resupply (low surface work function) and well distributed electron emission [1].

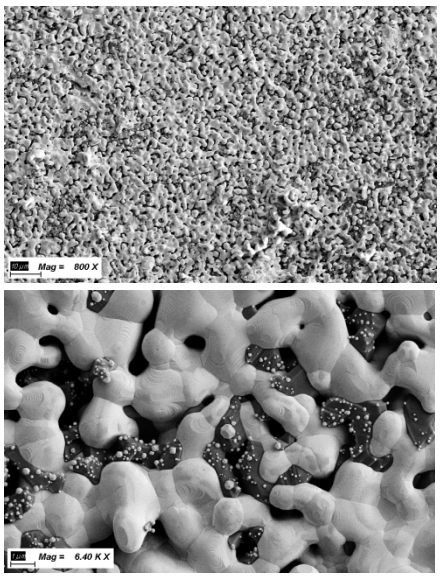

Fig. 1 Sintered matrix of the NST cathode (top), Scandium oxide distribution in tungsten pores (bottom).

NST cathodes offer 10 A/cm^2 emission density at 850°C promising lifetimes on the order of 100,000 hours; they also achieve over 100 A/cm^2 emission current density at 1,150°C without sacrifice in lifetime. NST cathodes are comprised of 1-2 µm tungsten particles sintered into a 25-28% porous tungsten matrix with well distributed 30-50 nm scandia particles (see Fig 1), the matrix is filled with a barium calcium aluminate emissive material. Sol-gel method is employed for manufacturing of the NST precursors so that uniform particle size and scandium oxide distribution is achieved to ensure uniform electron emission density distribution on the cathode surface.

High current density operation of the NST cathodes has been demonstrated to enable near THz radiation [2]. Research on material surface uniformity (flatness and roughness) as well as on uniform emissive material distribution and resupply is continuing to enable integration of NST cathodes into electron devices for production of intense THz radiation.

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O9

THz excitation spectroscopy for semiconductor band structure characterization

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Every accelerating charge radiates electromagnetic waves. As the semiconductor surface is illuminated with femtosecond laser pulses, photoexcited electrons starts to move and electromagnetic radiation in terahertz (THz) range appears [1, 2]. Because electron movement is largely influenced by electronic band structure, therefore by analyzing THz pulse one can get information about it.

By measuring THz amplitude dependence on excitation wavelength [3], we can probe the movement of electron with different excess energy. Inset in Figure 1 illustrates THz excitation spectrum of GaAs. At 1.75 eV and at 1.92 eV one can notice sharp decrease and a change of slope, which corresponds to electron scattering to X and L valleys respectively. By changing amount of Bi in GaAs1-xBix semiconductor we have determined how X and L valley energy depends on Bi concentration (Fig. 1).

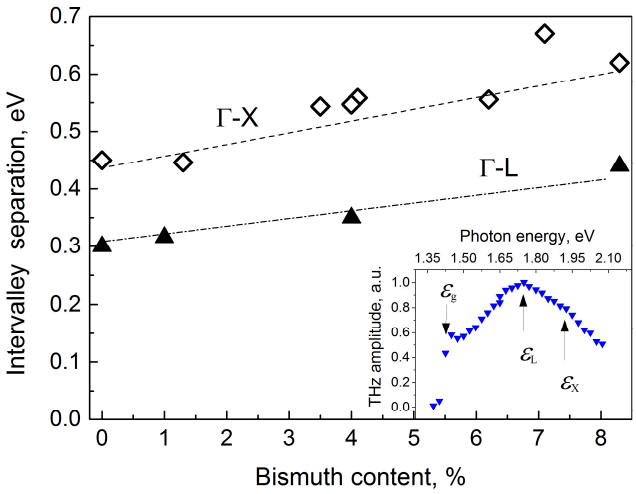

Fig. 1 Dependence of intervalley separation between Γ-L and Γ-X valleys in $GaAs_{1-x}Bi_x$ on bismuth concentration. Arrows in inset denote specific energies, which corresponds to band gap (ε_g), L valley (ε_L) and X valley (ε_X).

When junction between semiconductors with different band gaps is formed, conduction and valence band experience an offset. Here we will present a novel method which determines conduction band offset. We have applied this method for GaAsBi/GaAs heterojunction with different Bi concentration and have shown that theoretical offset calculations coincide with experimental data.

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O10

Terahertz emission enhancement by forming LIPS structures on the surface of GaAs.

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Surface structuring after laser irradiation of the solid material was first observed by Birmbaum [1] on various semiconductor surfaces. Since then, laser induced periodic surface structures (LIPSS) was formed on various materials and tested by many methods, but to our knowledge there are no attempts to investigate such structures using terahertz (THz) emission measurements. In this work, we report THz emission from LIPSS formed on three different substrates: n type (100) crystallographic orientation GaAs, semi-insulating (SI) GaAs (100) and SI GaAs (111). LIPSS were formed at various optical power and ablation speed using an industrial-grade diode pumped picosecond laser (Atlantic, Ekspla) with the wavelength of 335 nm. THz emission was induced by Ti:sapphire oscillator operating at 780 nm wavelength. THz electric field transient was detected with a GaAs THz detector (Teravil Ltd). We find out that LIPSS on GaAs substrate emit THz pulses and even enhance THz emission in comparison with a bulk GaAs (Fig. 1a). The strongest emission and the most predictable results were obtained from the highest periodicity structures that could be achieved using excitation fluence close to the ablation threshold (~ 1 J/cm^2 (in our case P = 0.02 W)). Moreover it was shown that depending on the LIPSS preparation conditions it is possible to enhance THz pulse amplitude up to 4 times. The bigger enhancement was observed in the transmission geometry (Fig. 1b). The enhancement of THz emission could be explained by the appearance of the parallel to the sample surface component of THz radiating electric dipole. This component has an azimuthal dependence and is responsible for enhancement of the THz pulse emission from GaAs surface.

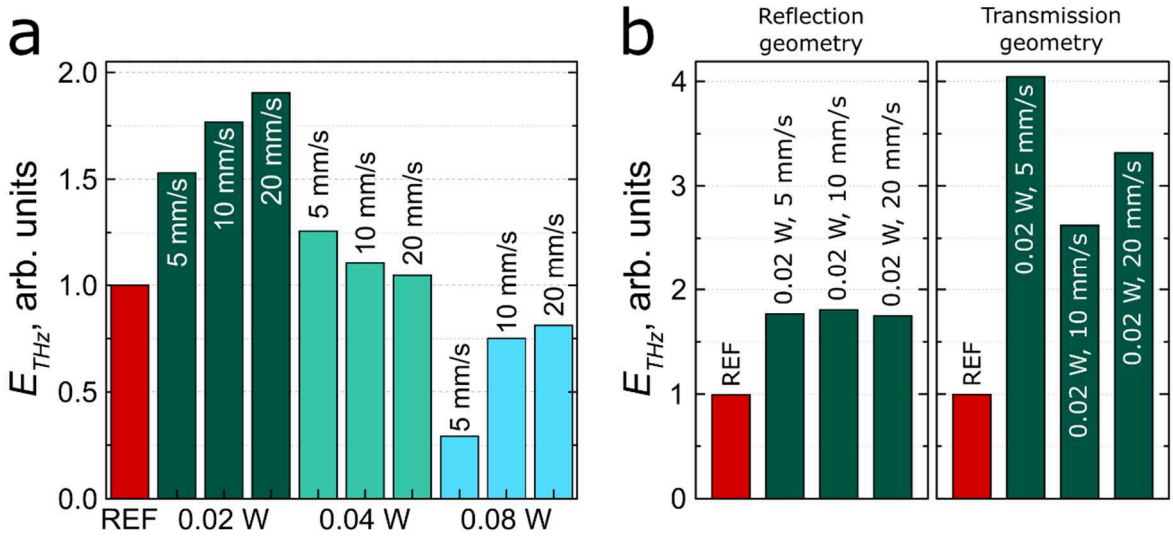

Fig. 1 Amplitudes of THz pulses emitted from n type GaAs (100) samples (a) and THz pulse amplitudes for SI GaAs (100) samples measured in reflection and transmission geometries (b).

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O11

Optimization of the terahertz modulation based on frequency-agile metasurface

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The optical modulator is a key component widely used for beam manipulation, imaging and optical communication in various parts of the electromagnetic spectrum. However, the technology of fast and efficient THz modulators is at its development stage. Modulation of THz transmission through a dynamically controlled metasurface is commonly used in the modulation scheme [1]. In this work, we consider principles of THz modulation when narrow-band radiation is modulated using a metasurface resonance frequency of which is dynamically tuned.

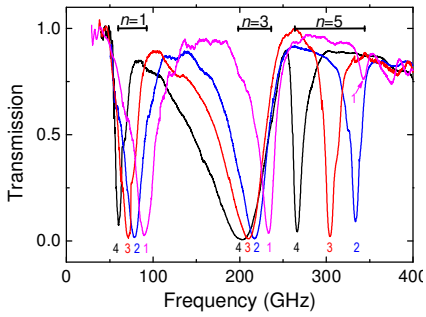

Fig. 1 Measured transmission of the split-ring resonator arrays 1, 2, 3 and 4 at lattice period 700 μm.

Metasurfaces consisting of periodically arranged resonators are usually made on parallel dielectric plates with finite thickness. Various methods are applied to eliminate the effects Fabry-Perot resonances (FPR) which strongly distort the metasurface transmission pattern. Our results indicate that FPR can significantly improve the performance of frequency-tunable metasurface used for amplitude modulation of a narrow-band THz source, for example, a quantum cascade THz laser. We demonstrate that the parameters of such a modulator can be optimized by the proper adjustment of the parameters of the dielectric substrate [2].

In planar arrays of resonators, the fundamental and third-order plasmonic modes are easily excited, but usually have poor quality factors. Although higher-order modes have the advantage of allowing to use a metasurface at higher frequencies, they receive much less attention. In this research, we show that the electric near-field coupling between the split-ring resonators (SRR) can be responsible for enhancement of the higher-order plasmonic modes in dense SRR arrays. In particular, we discuss the conditions that allow to achieve high Q factor, strong THz extinction and wide tunability of the fifth-order plasmonic mode (Fig. 1, *n=5*), thus making it a promising candidate for various practical applications such as narrowband filters, sensors and modulators. In Fig. 1, samples 1-4 represent arrays of square (side length is 500 μm) SRRs with different effective capacitance of the gap: $C_1<C_2<C_3<C_4$ [3].

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I6

High sensitivity biomarker detection from human samples with THz metamaterials

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THz bioanalytical techniques have proven to be a viable tool for the label-free detection of various biomolecular systems. Despite of this wideranging potential, significant improvements of THz sensing approaches are needed to reach application relevant sensitivity levels to sense biomarkers of medical relevance in real pathophysiological solutions from human samples. In this presentation, an overview of present developments toward high sensitivity THz sensing techniques is presented.

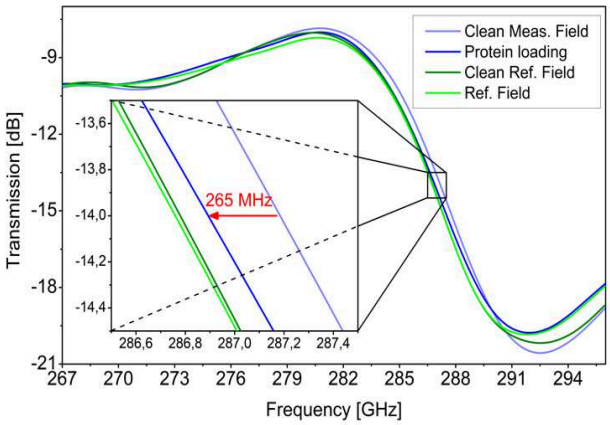

Fig. 1 Measured spectra of aDSR arrays. A frequency shift of 265 MHz is observed indicating the detection of the protein EGR2.

In a first part, direct, PCR-free detection of DNA sequences is presented. For this purpose asymmetric split ring resonators as proposed in [1] are adopted, using undercut areas below the split ring structures to provide areas with a with a selective covering with gold at the maximum field, i.e. maximum sensitivity, areas of the split ring resonator sensors. Selective chemical functionalization allows then to concentrate the analytes at such positions and thereby increase the sensitivity towards pathophysiological concentrations. Using this concept, PCR-free measurements from human samples are demonstrated for the first time.

Additionally, first results presenting the label-free THz sensing of the EGR2 protein as a human tumor markers are presented, using this highly sensitive metamaterial based THz biosensor. High affinity binding of the specific protein to DNA is utilized for localized functionalization to further enhance the detection sensitivity of such a tumor marker. First experiments of direct biomarker detection for melanoma are presented at sensitivities beyond recent demonstrations in microfluidic environments [2].

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I7

Detection and Manipulation of Methylation of Cancer DNA using Terahertz Radiation

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By canceration, there is a chemical change in DNA which is a rearrangement of 5-methylcytidine distribution called methylation. This chemical change of methylation is directly observed with terahertz time-domain spectroscopy, showing a resonance at 1.6 THz for various types of cancer. The resonance peak is reduced or controlled by illuminating high-intensity terahertz pulses and it is proved to be resonant process by applying a filter around the frequency.

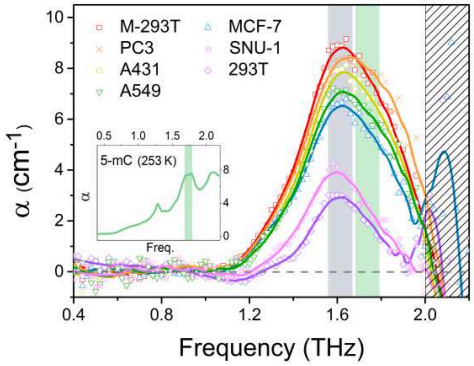

Fig. 1 Resonant peaks of normal and cancer DNAs [3].

Cancer is defined as a genetic and epigenetic disease involving the chemical and structural alteration of DNA. An epigenetic modification is the aberrant DNA methylation, which are a well-known carcinogenic mechanism [1, 2] and a common chemical and structural modification of DNA that does not change the DNA sequence. Terahertz electromagnetic waves can be utilized to observe such modification to DNA because the characteristic energies of biomolecules occur in the terahertz region. We have found resonance fingerprints of methylation in cancer DNA using improved terahertz spectroscopic methods [3]. The degree of resonance is also controlled and reduced by irradiating high-intensity terahertz electromagnetic waves at the resonant frequency.

The terahertz characteristics of methylated cytidine, a nucleoside, were a clue to observe the resonance fingerprints of DNA methylation (see the inset of Fig. 1). In aqueous solutions, we tracked and observed the molecular resonance of genomic DNA from two control (293T, M-293T) and five cancer (PC3; prostate cancer, A431; skin cancer, A549; lung cancer, MCF-7; breast cancer, SNU-1; gastric cancer) cell lines, using freezing technique and baseline correction, as shown in Fig. 1 [3]. The amplitudes of the resonance signals were dependent on the types of cancer cells the DNA had come from. These signals could be quantified to identify cancer cell types, and the results were similar to those of biological quantification method called ELISA-like reaction.

The resonance peak was reduced by irradiating high-intensity terahertz waves from a LiNbO3 crystal driven by 1-kHz regenerative amplifier with a filter around 1.6 THz.

The result demonstrates that the molecular resonance of cancer DNAs exists in the terahertz region. This can be utilized to diagnose early cancer at the molecular level and to provide a potential cancer biomarker. The degree of resonance is also controlled and reduced which could lead to the demethylation of cancer DNA.

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O12

Electrochemical shell-isolated nanoparticle-enhanced Raman spectroscopy: bonding, structure and function of monolayers at smooth gold electrode

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Shell-isolated nanoparticle-enhanced Raman spectroscopy (SHINERS) is based on enhancement of Raman signal by a strong electromagnetic field provided by gold (or silver) core nanoparticles surrounded by thin (2–3 nm) SiO_2 (or other dielectric) shell [1]. Such approach eliminates important SERS drawbacks associated with interaction of adsorbates and metal under investigation with nanoparticles. In this work we applied SHINERS method to in-situ probe the structure, bonding, and ion-pairing of the positive charge bearing pyridinium ring terminated self-assembled monolayer (MHP) at smooth gold substrate under controlled electrode potential [2].

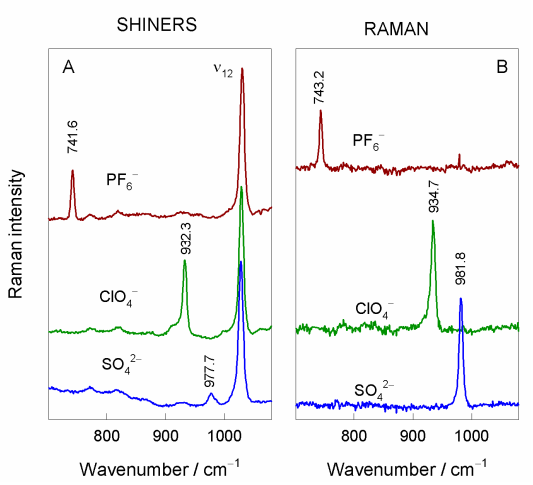

Fig. 1 Comparison of (A) SHINERS spectra of inorganic anions attracted at gold electrode modified with MHP monolayer at open circuit potential, and (B) Raman spectra of anions in aqueous solution at

Electrochemical SHINERS results show that the Au–S stretching frequency exhibits near linear blue shift as the electrode potential was tuned to more positive values. The frequency tuning rate was found to be as high as 18.6 ± 0.9 cm^{-1}/V. Spectroscopic analysis of ion-pairing at interface (Fig. 1) revealed correlation of amount of attracted anions and downshift in frequency of symmetric stretching vibrational mode with Gibbs hydration energy; higher hydration energy anions showed higher frequency shift and lower relative intensity in surface spectra. It was found that the intensity of SHINERS bands from surface anions decreases as potential shifts to more negative values. Such behavior was correlated with potential driven conformational changes in the structure of MHP. It was found that the negatively charged electrode surface attracts terminal positively charged pyridinium groups, resulting in loss of all-trans conformation in hydrocarbon chains of MHP and forces some methylene groups into the direct contact with the metal surface. In such conformation MHP molecules are not able to form ion-pairs with the solution anions.

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I8

From monitoring DNA polymerases *in vitro* to target search of CRISPR-Cas *in vivo*

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Single-molecule detection schemes offer powerful means to overcome static and dynamic heterogeneity inherent to complex samples. Probing interactions and reactions with high throughput and high spatiotemporal resolution, however, remains challenging.

In the first part, I will introduce DNA based FRET sensors that allow binding of DNA polymerases and even DNA synthesis to be monitored at the single-molecule level and in real time [1]. The sensors are further characterized in novel glass-made nanofluidic devices that confine the diffusional movement of the probes thereby enabling high throughput measurements and, in a mixing geometry, even the continuous observation of chemical reactions [2].

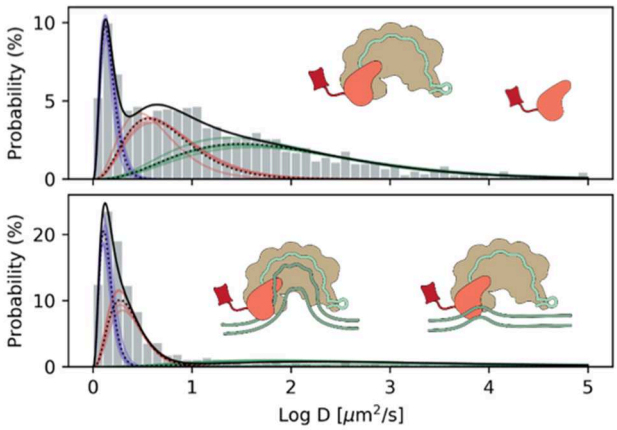

Fig. 1 Histogram of diffusion coefficients of the fluorescently tagged Cas8e subunit and its associated Cascade complexes in Escherichia coli. In presence of suitable DNA targets, the mobility significantly decreases.

In the second part, I will demonstrate how single-particle tracking can help to unravel details of a CRISPR-Cas system in its native bacterial host. CRISPR-Cas systems encode versatile machineries that have evolved to store, recognize and cleave specific DNA sequences in prokaryotic cells. Using fluorescent proteins as tags, we monitored a CRISPR-Cas system to understand how foreign DNA targets are found in a crowded, DNA-packed cellular environment. By tracking individual surveillance complexes in live cells, we show that these complexes interrogate potential binding sites much faster than reported before, enabling around 100 effector complexes to find a single invader DNA sequence within 20 minutes. We further observed mechanisms that prevent self-targeting of genomic DNA which otherwise would have a disastrous effect on the survival of the cell. Taken together, our results reveal new links between target search kinetics, host self-avoidance and CRISPR-Cas interference in its natural environment.

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O13

BN nanoparticles as spectroscopic marker and drug delivery system.

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The 2D-BN nanoparticles (NPs) application for biological purpose, namely for Raman spectroscopy (RS) and coherent-anti Stocks Raman (CARS) mapping of cell components, are reported. We used the 2D-BN particles as drug delivery systems for anti-cancer drug (DOX) in tumour cells and are going to study a modified squallene. We showed that 2D-BN NPs penetrated through cell membrane during incubation for 1 hour. As a result, we registered a drastic changes in Infrared and Raman spectra of the cell membrane. After incubation for longer time (2 and 10 hours) the 2D-BN nanoparticles reached other cell components (cytoplasm, mitochondria, nucleus) that was visualized by the vibrational spectra and confocal microscopy. A luminescent emission from this system on gold supports was found to be significantly enhanced. It is suggested that the 2D-BN nanoparticles, due to their high refractive index act as a “mirror” for laser beam while mapping a position of cell component.

New approach for cancer treatment based on squallene-type drugs loaded on BN nanoparticles was proposed with abovemention paradigma. Quantum-chemical calculation, vibrational spectroscopy and optical microscopy was applied for probing the cell components, especially, cell membrane under impact the squallene drug- BN delivery system. The preliminary data on squallene interaction with BN nanoparticles and imaging of modified squallene loaded on BN nanoparticles passing through membrane are discussed.

ACKNOLEDGMENT

We thank to Ukrainian- Lithuanian Project (2018-2020), the H2020-MSCA-RISE-2015 690853 — assymcurv and NATO SPS 985291 projects.

O14

Temperature effect on molecular rotors.

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Fluorescent viscosity sensors - molecular rotors – provide one of the most convenient ways for measuring viscosity in aerosols, model membranes and living cells [1]. However, despite the increasing usage of molecular rotors, their photophysical properties are not well studied and their cross-sensitivity to other parameters, such as temperature, is not well examined.

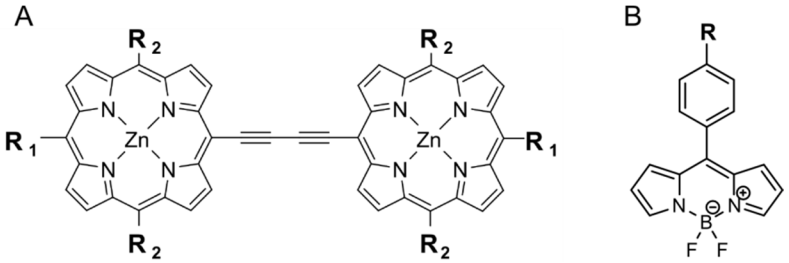

Figure 2. The molecular structures of two classes of molecular rotors examined: porphyrin dimers (A) and BODIPY molecular rotors (B).

We have studied how two important classes of molecular rotors are affected by temperature. The first group is porphyrin dimers (Figure 1A): deep-red fluorophores capable of sensing viscosity in two ways. Our results show that some dimers are insensitive to temperature and act as pure viscosity sensors while others can be used for simultaneous viscosity-temperature measurements [2,3]. Additionally, we have examined a series of BODIPY-based molecular rotors (Figure 1B) including one of the most widely used molecular rotor to date [1]. We have shown that the rotors exhibit complex sensitivity to viscosity, temperature and solvent polarity, which can be altered by modifying their molecular structure [4]. In conclusion, these works provide complex yet exciting picture of fluorescent sensors' sensitivity to their environment.

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O15

Determination of time-dependent diffusion coefficient of excited species from time-resolved absorption spectra.

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Exact determination of time dependence of the kinetics of photoexcited species in nanostructures provides important information towards construction of efficient optoelectronics devices.

It turned out by the analysis of transient absorption spectra in organic systems that kinetics of photoexcited species provides a power-law decay for polarons [1] and inter-chain polaron pairs [2] in P3HT, or singlets and triplets in metallo-supramolecular polymers with ditopic thiophene-bridged terpyridine ligands [3], which cannot be explained rigorously by the diffusion controlled collision processes with the time-independent diffusion coefficient.

Therefore, we elaborated a novel approach with **time-dependent diffusion coefficient** and provided a method of its determination from transient absorption spectra of decay kinetics of photoexcited species by the collision controlled processes [4].

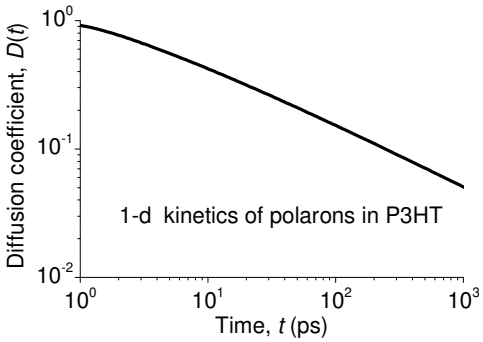

Fig. 1 Time-dependent diffusion coefficient of polarons in 1-d P3HT systems obtained from transient absorption spectra of bi-molecular collision controlled polaron decay kinetics

In our presentation we show the basic principles of the methodological concept of this novel approach for single-molecular or bi-molecular collisions in 1d and 3d systems. The theoretical approach will be also applied for experimental data of transient absorption spectra in organic nanostructures utilized for optoelectronics.

Acknowledgement
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O16

DNA curtains – nanoscale platform for studying of DNA-protein interactions at the single-molecule level.

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During last 20 years, since the first applications, single-molecule (SM) fluorescence microscopy methods have evolved and widely spread allowing answering many biological problems that have been inaccessible using ensemble type of measurements. Currently, SM fluorescence methods employing Forster Resonance Energy Transfer (FRET) and other principles enables monitoring various dynamic interactions between nucleic acids and proteins and to study conformational dynamics of proteins, to track movements of individual biomolecules and other nanoscale objects and also to reveal rotational movements [1, 2]. Here I will present SM fluorescence microscopy methods and nanotechnology tools that we recently started to employ in our laboratory to create a nanoscale platform for protein – DNA interaction studies at the SM level – DNA curtains (Fig. 1). DNA curtains is a well-working concept, which relies on stretching of long DNA molecule along the buffer flow on the surface [3]. We apply new and hopefully widely applicable strategy to create such a platform. Biotinylated DNA molecule is immobilized on the nanoscale lines, composed of Streptavidin protein, formed on the surface of silanized and PEGylated glass (contains biotin-PEG). These immobilized DNA molecules can be fluorescently labeled and also stretched along the surface using buffer flow. The movement and interaction of fluorescently labeled protein can be monitored in the other fluorescence channel.

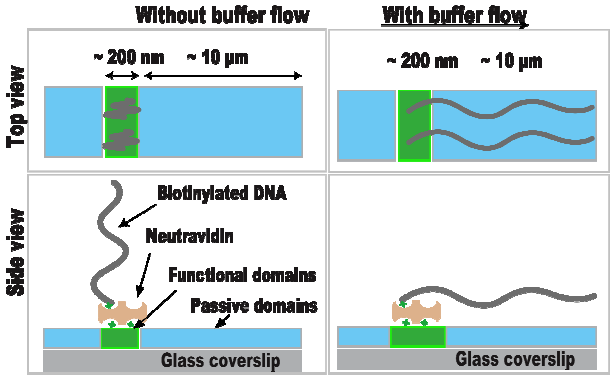

Fig 1: Schematic representation of the DNA curtains platform for DNA-protein interaction studies.

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I9

Field Effect Transistors Based Terahertz Detectors Based on Transistors: From Basic Science to Real World Applications

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An overview of main results concerning THz detection related to plasma nonlinearities in nanometer field effect transistors will be presented. In particular, the physical limits of the responsivity, speed and the dynamic range of these detectors will be discussed. We will also present applications of the FET THz detectors for construction of focal plane arrays and based on them nondestructive quality control and security screening scanners. Finally, possible future developments will be discussed.

In the beginning of 90-ties Dyakonov and Shur proposed field effect transistors (FETs) as potential candidates for THz detectors and emitters. In their pioneering works the operation principle has been explained using physical models of plasma-waves propagating (or overdamped) in the channel of the transistors- for review see references [1,2]. Later some specific cases (room temperature overdamped plasma oscillations) has also been described as a distributed self-mixing resistive mixer [3,4] and by a lumped element approach [5]. A complete analytical expression valid in all regions of operation of the FET, including sub-threshold, linear and saturation as well as the loading effect has been proposed in references [6,7]. The theoretical predictions have been confirmed by many experimental results and the matrixes of FETs detectors were reported- for review see reference [8]. The real interest in FET based THz detection and imaging was triggered by a breakthrough discovery that standard Si-MOSFET transistors, in spite their low carrier mobility, can be very efficient detectors [9,10]. Later it has been shown that wide band – up to 4THz single pixel and focal plane arrays operating at sub-THz atmospheric windows can be achieved in Si -Technology [11,12]. Wireless communication applications with Si-CMOS based THz receivers operating at sub-THz bands have been also demonstrated [13].

We present an overview of results concerning THz detection related to plasma nonlinearities in nanometer field effect transistor. The subjects were selected in a way to show physics related limitations and advantages rather than purely technological or engineering improvements of FETs Terahertz detectors. We address the basic physics related problems like temperature dependence of the response [14], helicity sensitive detection [15] and nonlinear/saturation response at high incident power [16]. We present also the first results on new THz detectors based on GaN/AlGaN edge gate transistors and Si junction-less FETs [17,18] showing that the signal-versus gate voltage has unusual behavior and the results cannot be interpreted using standard models. A new theoretical approach is presented. All the recent results will be discussed in view of the physical and technical limitations of FET THz detectors and their application for quality control and postal security and nondestructive quality control linear scanners [19].

Finally, we will discuss possible future direction for FET-THz detectors improvements and applications.

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I10

THz wave concentrators: Carbon based photonic crystals and perfect absorbers

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Humankind uses practically all parts of the electromagnetic spectrum. However, there is a range of frequencies which is still overlooked. This is so-called terahertz (THz) range and the associated problem is called the terahertz gap. The recent growing interest in terahertz science and technology is due to its many important applications in physics, astronomy, chemistry, biology, and medicine, including THz imaging, spectroscopy, tomography, medical diagnosis, health monitoring, environmental control, chemical and biological identification, and in 5G and future communication networks. According to the recently published "The 2017 terahertz science and technology roadmap" among the most important challenges are passive components, i.e., filters, polarizers, collimators, lenses and concentratorsHaving a precise control of the structure and geometry of the 3D template, we will come to regular conductive cellular structure with pre-defined electromagnetic response.

The modern 3D-printing technology with high spatial resolution offers many promising opportunities for creating of complex 3 dimensional periodic polymer structures. In contrast to classical photonic crystals [1], it is interesting to estimate electromagnetic properties of lossy periodic structures with carbon-containing skeleton with finite conductivity.

Two classes of carbon-based periodic structures made by 3D-printing that could possess high absorption ability of electromagnetic radiation and resonance behavior in microwave-THz frequency ranges are discussed:

(i) Carbon based reticulated photonic crystals made by 3D-printed techniques (see e.g. [2]).

(ii) 3D printed sandwiches [3] and other 3D structures of sophisticated geometries made from a nanocarbon polymer composite fiber.

The peculiarities of EM response of both carbon-based materials are investigated; the advantages of each type of carbon structures along with CVD graphene/polymer sandwiches [4] and metasurfaces depending on particular application are emphasized.

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O17

Silicon based diffractive optics for imaging applications at sub-THz frequencies

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Practical potential of terahertz (THz) imaging at sub-THz range for nondestructive testing [1] and biomedical research [2] encourage a search for compact and practically convenient solutions. One of the important issue is assumed to the development of compact THz diffractive optic components which let to replace bulky parabolic mirrors into much more attractive thin optics elements [3, 4].

In this communication, multilevel phase Fresnel lens (MPFL) designs for 300 GHz and 600 GHz (Fig.1) are presented. The design of MPFLs starts from two-phase quantization levels P and extends up to kinoform shape.

MPFLs were designed by using three-dimensional finite-difference time-domain (3D FDTD) method. High resistivity silicon wafer of 0.46 mm thickness was served as high refractive index stable material for the MPFL fabrication using industrial-scale-compatible LDA system [5]. All samples were fabricated of 17.5 mm in diameter with the focal distances of 10 mm and 5 mm.

The focusing was investigated by measuring Gaussian beam intensity distribution in the focal plane and along the optical axis at 0.3 THz and 0.6 THz frequency. The focusing efficiency was evaluated by varying phase quantization number. Finally, THz imaging with close to wavelength limited resolution is achieved using MPFLs.

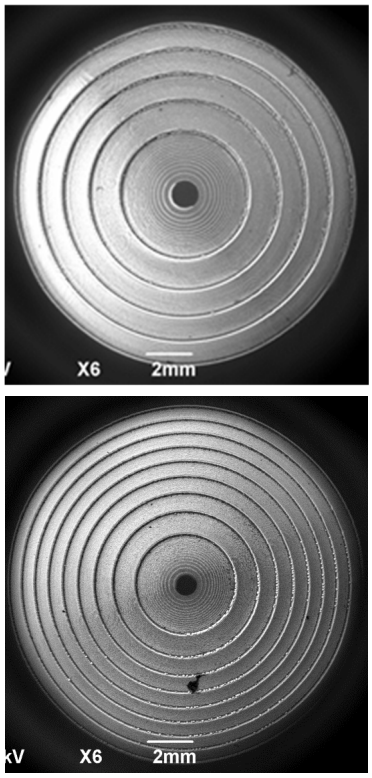

Fig. 1 SEM images of 5 mm focal length and 16 phase quantization levels MPFLs for 300 GHz (top) and 600 GHz (bottom).

Acknowledgement: this work was supported by the Research Council of Lithuania (LAT 04/2016).

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I11

Surface plasmon-polaritons studied by scattering-type SNOM

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Scattering-type Scanning Near-Field Optical Microscopy (s-SNOM) allows for spectroscopic studies with a spatial resolution on the order of 20 nm irrespective of the wavelength of the electromagnetic radiation used. Here, we employ the technique for the investigation of surface plasmon polaritons (SPP) both in the visible/near-infrared spectral regime and at THz frequencies. In the first case, we study SPP on patterned and unpatterned gold films. The focus of the investigation of the unpatterned films (see s-SNOM image in the top panel of Fig. 1) is the identification of excitation channels for the surface waves [1]. One excitation pathway is by illumination of the edges of the films, another involves the metallic tip of the cantilever itself which otherwise serves as the scatterer transforming guided waves into the radiated fields to be detected. In the case of the patterned Au films, the focus is on anisotropic meta-surfaces, where we study SPP modes which are difficult to excite and identify with prism or grating couplers [2]. These SPP waves are launched with the help of a silicon nano-sphere antenna placed onto the meta-surface (see sketch in the lower panel of Fig. 1) and allowing to couple into various surface modes by virtue of the relaxation of the momentum selection rules for their excitation. Another focus of these studies lies on the exploration of novel technologies explored for the challenging fabrication of meta-surfaces for possible applications in the VIS/near-IR spectral regime.

The last topic to be discussed is the observation and characterization of SPP on gated graphene excited with THz radiation.

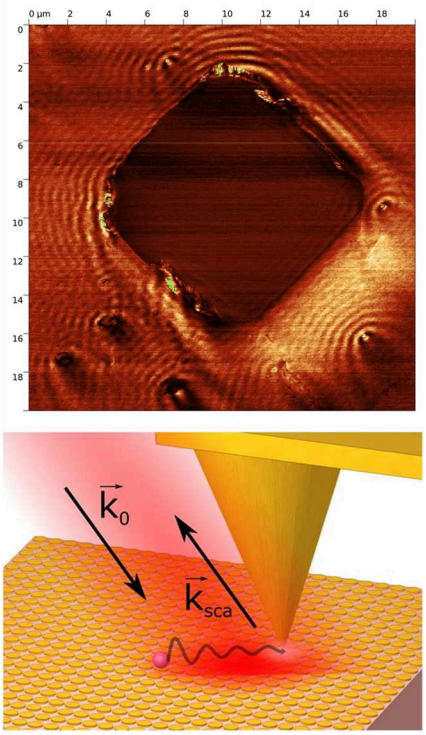

Fig. 1. Top: Image showing SPP interference patterns measured on a gold surface. The SPP are excited at the edges of the window in the Au film (dark region) and at contaminations on the film. **Bottom:** Schematic of an s-SNOM measurement on an anisotropic meta-surface with a laser-illuminated spherical nano-antenna as emitter of SPP.

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I12

Decrease the photovoltage losses in organic solar cells

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The open-circuit voltage (VOC) of organic solar cells (OSCs) is usually lower than the values achieved by inorganic or perovskite photovoltaic devices with comparable band gaps. Energy losses during charge separation at the donor (D): acceptor (A) interface and non-radiative recombination are among the main causes of such voltage losses. We present a range of existing and new D:A systems which combine efficient photocurrent generation with electroluminescence yield up to 0.03%, leading to non-radiative voltage losses as small as 0.21 V. We provide a rationale to explain and further improve the performance of recently demonstrated high-VOC OSCs.

I13

Performance and emission dynamics of multi-section passively mode-locked semiconductor lasers

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Passively mode-locked semiconductor lasers are inexpensive sources of short optical pulses with high repetition rates. They find applications in high-capacity optical interconnects and high-precision metrology, where stable pulse trains with small amplitude and timing jitter are required. Optimizing the design of monolithic mode-locked semiconductor lasers for such demands has therefore become of major interest.

Combining a traveling-wave model for the electric field propagation with microscopically based quantum-dot (QD) charge-carrier rate equations, we investigate the performance and dynamics of multi-section QD mode-locked lasers. Two devices will be in the focus of our investigations, i.e. a three section passively mode-locked device with a long tapered gain section at the pulse emission facet as well as a v-shaped cavity where gain and absorber are separated by an external cavity. Our simulations enable us to vary the device geometries and investigate different positions for the saturable absorber and the gain chip. We analyze the effects these changes have on the dynamics and the emission properties of the mode-locked lasers and perform a bifurcation analysis to characterize the different dynamics that can occur: fundamental mode locking, higher harmonic mode-locking, quasiperiodic pulse trains, and irregular emission. As a result we are able to predict specific device geometries for stable operation with short and high power pulses with low timing jitter.

I14

Reduction of graphite oxide to graphene using intense laser radiation

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Graphene is proven as valuable material for the medical, electronics, sensors, energy storage, environmental and other applications. One branch of graphene production methods exploits laser-induced graphene (LIG) formation. Operating with a tightly focused laser beam, the formation of complex graphene microstructures is also feasible. We review our recent results on modification of carbonaceous materials by lasers.

Graphene oxide (GO) is a low-cost material synthesised from graphite; it retains a layered structure but, at the same time, it is characterised by the loss of electronic conjugation caused by the oxy groups at the graphene sheet edges or plane defects. Graphene formation was implemented utilising laser irradiation for GO reduction [1]. Graphene phase formation in reduced GO was confirmed by Raman spectroscopy (Fig. 1). Our recent experiments show that nanosecond laser irradiation can form high-quality LIG from pinewood in a nitrogen atmosphere (Fig. 1). The minimal electrical sheet resistance of LIG in wood was 35 Ω/sq.

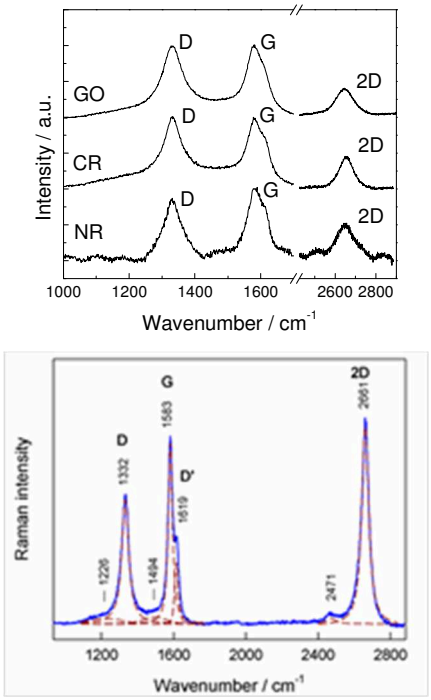

Fig. 1 Raman spectra after laser reduction of GO and GO-dye composites (top), LIG in wood (bottom)

In our previous works, we noticed the role of additives to the stability and repeatability of GO reduction process by laser irradiation. It was shown, that adding of certain dyes can improve the level of GO reduction [1]. Adding Congo red (CR) dye or Neutral red (NR) molecules can lead to the formation of larger rGO nanoplatelets during the reduction process. Reduced GO surfaces fabricated using a laser with adjustable hydrophobic properties are applicable to the production of membranes, self-cleaning surfaces, biosensors, and other graphene-based electronic devices [2]. LIG in wood can be used for biodegradable electronics or super-capacitor applications.

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I15

Structural change of macromolecules by intense THz radiation

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O18

Simulation of charge separation in disordered molecular systems – coherent effects

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Spectroscopy studies of molecular assemblies indicate that optically induced quantum coherences in these systems survive much longer than predicted from secular rate equations. These findings sparked numerous debates whether the coherent system dynamics are related to the efficiency the excitation energy transfer and possibly of charge separation in molecular systems in general. The problem could be addressed by studying coherent excitation dynamics and its relaxation based on rigorous theoretical approaches where the system-bath models are treated beyond simple rate equations.

Stochastic wavefunction approaches allow accessing detailed microscopic picture in a scale of a single wavepacket dynamics. Stochastic equations have been derived for an arbitrary spectral density of the “wet and noisy” environment. The stochastic wave functions allowed to define excitation coherent dynamics, polaron formation dynamics and energy relaxation [1]. Simulations of the energy transport in a model solar cell charge separation center shows that charge separation efficiency may be facilitated by inter-site coherence of electronic wavefunction.

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O19

Optical properties of boron vacancy-related defects in hexagonal boron nitride

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Recently hexagonal boron nitride (h-BN) has attracted a lot of attention because of discovery of single-photon emitters (SPEs) in monolayer, multi-layer and bulk [1-4]. Single photon emission exhibits linear optical polarization and has been attributed to point defects. Despite active investigations, the nature of these emitters has so far remain unresolved [5-6].

Optical properties of boron vacancy-related defects in bulk h-BN are studied from first-principles theory using hybrid density functionals. The set of defects include the bare boron vacancy, as well as complexes with oxygen and hydrogen. We have considered all internal and free-to-bound transitions in these defects. Excitation energies of internal transitions have been obtained via the ΔSCF method.

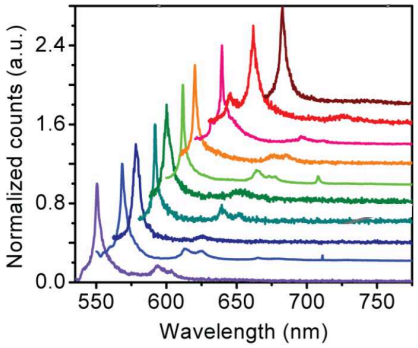

Fig. 1 Luminescence signals of single-photon emitters with various zero-phonon line

By calculating configuration coordinate diagrams and by performing group theory analysis for all processes we have classified them into (i) predominantly non-radiative transitions, (ii) dipole-allowed optical transitions, and (iii) weak dipole-forbidden optical transitions. For dipole-allowed transitions we have calculated Huang-Rhys factors and luminescence lineshapes. We have found that internal transitions are mostly non-radiative, while dipole-allowed free-to-bound optical transitions result in large (>5) Huang-Rhys factors and thus rather broad luminescence lines.

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O20

Density dependence of the microwave conductivity of carbon nanotube based composites

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Carbon nanotubes (CNT) are very elongated and conductive nanoparticles. They found a large number of applications including nanocomposite area. Electromagnetic response of CNT-based composite materials has been actively studied for two decades. Currently, there is no clear understanding of the physical mechanisms of electromagnetic wave interaction with disordered array of CNTs. The variety of the experimental data is still not systemized. A few papers reported broadband spectra of the permittivity and conductivity of CNT-based composite [1,2]. The influence of the density on the frequency dependence of the conductivity was recently shown in [3].

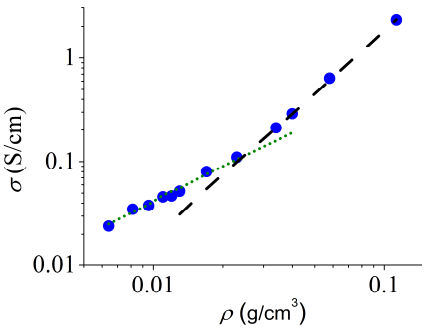

Fig. 1 Microwave conductivity versus CNT density at 30 GHz for CNT-based composite.

Here we report an experimental study of electromagnetic parameters of the composites at different density of single-walled CNTs. Two regimes, before and after percolation threshold, are demonstrated. The volume fraction of CNT varies in wide range from 0.05 to 5%, and frequency interval is from microwave to terahertz range. To obtain density dependence of the conductivity, we prepare a sponge like composite material - the mixture of the cotton-wool and single-walled carbon nanotube flakes. Initial density of the tubes is 7 mg/cm^3. Compression of the composite leads to the CNT density variation thus providing the possibility to measure the effective conductivity of the composite at different tube density. Results are presented in Fig. 1. Density dependence can be approximated by two power-laws with exponents 1.1 (at low density) and 2 (at high density). The exponent can be varied in the range between 1 and 2 by variation of the amount of cotton wool. The polymer composites at different density of individual single-walled CNTs have been produced and their conductivity is measured and analyzed in the microwave and terahertz ranges. The influence of the tube density on the exponent in the power-law was demonstrated.

Obtained results show a possibility to control the density and frequency dependence of the conductivity of CNT-based composites.

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O21

Noise temperature spectrum in a GaN quantum-well channel

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Noise temperature serves as a good source of information on ultrafast processes in semiconductor nanostructures. In the present abstract, a deterministic model for calculation of electron noise temperature spectrum in a GaN quantum-well channel is proposed.

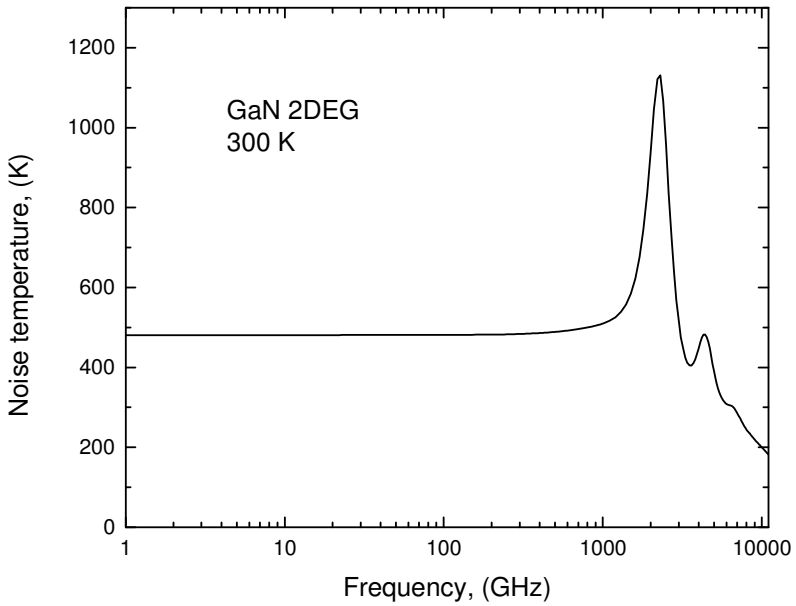

Fig. 1 Noise temperature spectrum of electrons confined in infinite square quantum well at 10 kV/cm electric field.

The electron transport and fluctuations are considered in the framework of the semiclassical Boltzmann transport equation [1]. The electron distribution functions and the kinetic equation are expanded in Fourier-type harmonics. Numerical algebraic methods are used for solving the resultant system of equations. The Langevin approach is applied for the treatment of fluctuations in the two dimensional electron gas channel [2]. The spectral intensity of the electron drift velocity fluctuations and the small signal conductivity are calculated after the Green's functions of the corresponding kinetic equations. The calculated spectra of the electron noise temperature, for the electrons confined in a 6 nm infinite quantum well is present in Fig.1. High quality resonance peaks are resolved in the terahertz frequency range.

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O22

Silicon Field Effect Transistors for Nonlinear Terahertz Autocorellators

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Experimental optical setups with short-pulsed sources require techniques for the monitoring of the temporal characteristics of the pulses. This monitoring is often performed using non-linear interferometric autocorrelation technique [1]. In the THz frequency domain, one option is quantum-engineered devices, exploiting, for example, intersubband transitions, but such detectors require cryogenic cooling [2]. Recently, we showed that for certain conditions, the field-effect transistor (FET) could be used as alternative candidate with the advantage that it can be operated at room temperature [3]. The proposal relies on the super-linear behavior of FET response to large THz signals in the sub-threshold bias regime.

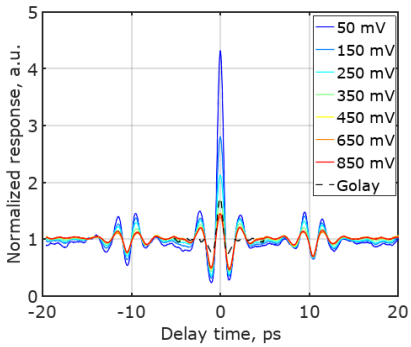

Fig. 1 Autocorrelation traces of CMOS TeraFET response at different gate-voltages. The sub-threshold bias regimes are below 250 mV.

Here we present a successful exploitation of antenna-coupled field-effect-transistor-based terahertz (THz) detectors (TeraFETs) in nonlinear autocorrelation experiments performed with THz pulses generated by a femtosecond-scale pulsed laser radiation. The detector was fabricated employing the 90 nm CMOS technology, has a transistor with gate length of 100 nm and width of 1 µm and exhibits ~100 V/W optical (referred to the power in the beam) responsivity and a minimum optical noise equivalent power (NEP) of 67 pW/√Hz at 0.6 THz. It has a flat small-signal responsivity spectrum spanning from 400 GHz to 2 THz.

When the detector is biased with sub-threshold gate voltage and for high THz peak powers, it can be driven into a super-linear regime. The measured intensity autocorrelation trace exhibits a 4.5:1 ratio due to the strong nonlinear response (Fig. 1). For standard quadratic detection, the ratio between the signals measured for zero time delay and for temporally separated pulses is 1.5:1. All response regimes allow for interferometric autocorrelation measurements, however, the modulation depth is by far the largest in the super-linear regime. Observed higher-order nonlinear phenomenon could be used as a convenient tool for monitoring of the temporal characteristics of THz pulses.

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O23

Optical properties of $GaAs_{1-x}Bi_x$ compounds

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Bismide-based structures are suitable for a variety of potential longer wavelength optoelectronic applications, such as infrared light-emitting diodes, photodetectors, solar cells, terahertz, and spintronic devices [1]. Though, to design and optimize such GaAsBi-based devices it is essential to know their optical properties and electronic structure.

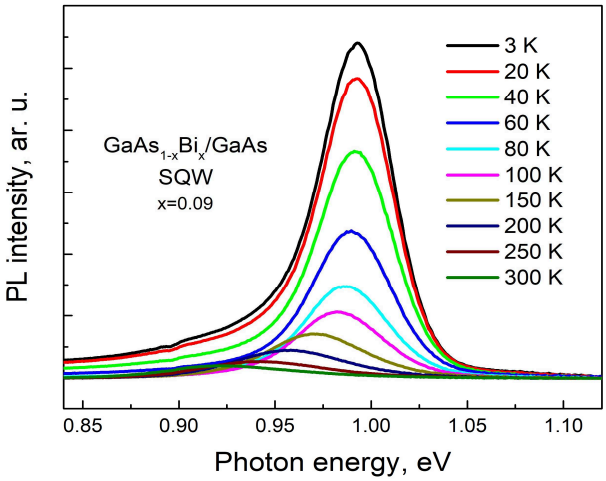

Fig. 1 Temperature-dependent photoluminescence spectra of GaAsBi/GaAs single quantum well (SQW).

This work presents a comparative spectroscopic study of GaAsBi-based structures (bulk GaAsBi, GaAsBi/GaAs and GaAsBi/AlAs quantum wells (QWs) with different Bi contents) grown by molecular beam epitaxy (MBE) and migration enhanced epitaxy (MEE). Temperature- and excitation-dependent photoluminescence (PL) and photoreflectance (PR) spectroscopic techniques were used to explore optical interband transitions at temperature from 3 K to 300 K.

Temperature-dependent PL and PR spectra reveled a variety of interband transitions, which were interpreted by numerical calculations. As further matter, energy of optical transitions variation with temperature was analyzed using Varshni expression [2]. Also, temperature-dependent PL data (Fig. 1) allowed to derive electron activation energies and, thereby, provided insight into thermal quenching processes. Additionally, in this work, it is shown that thermal annealing of GaAsBi structures at higher than 600 °C temperatures leads to substantial changes in the material structure – Bi quantum dots (QDs) formation [3]. Simple theoretical model is presented to explain bismuth QDs related PL signal.

ACKNOWLEDGMENTS

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Poster presentations

P1

Charge carrier spatial trapping limits all-polymer solar cell performance

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Extraction of photogenerated charge carriers from organic bulk heterojunction (BHJ) solar cells is one of the most important processes determining device performance. Slow carrier extraction causes their accumulation in the active layer and, as a consequence, an increased bimolecular recombination, which reduces the short-circuit current and particularly the fill factor. It is commonly assumed that the optimal morphology for efficient BHJ solar cells is one where photogenerated electrons and holes avoid recombination by moving via spatially separated percolating domains consisting (predominantly) of electron accepting material in one phase and donating material in the other. However, such strongly phase separated morphologies are prone to cause extraction problems due to the formation of dead ends and/or isolated domains.

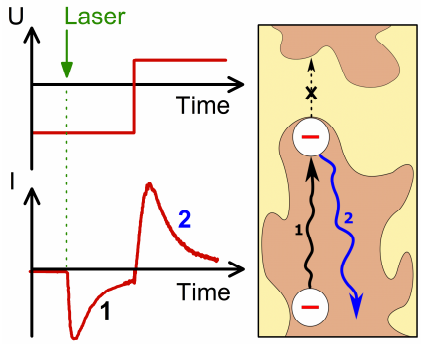

Fig. 1 Charge carrier spatial trapping contributes strongly to photocurrent decrease (1), reversing electric field polarity results in increased photocurrent due to carrier detrapping (2)

We have investigated charge carrier motion in an archetypical all-polymer organic solar cell by a combination of carrier extraction experiments and numerical modeling. We find that in the as-cast active layer, the bulk heterojunction morphology contains a significant concentration of spatial traps that we tentatively associate with individual polymer chain ends. The presence of these spatial traps manifests in a suppressed yield of free charge generation due to one of the charges in the splitting CT pair 'getting stuck' close to its countercharge, leading to enhanced geminate recombination. While these findings highlight a morphological problem that seems most likely to arise in all-polymer BHJ (in BHJ based on the same polymer donor with a small molecule (PCBM) acceptor spatial trapping is much weaker) they also show that the number of spatial traps can, at least in the present case, be drastically reduced by thermal annealing.

P2

Ultrafast recombination and diffusion processes in lead free $MASnI_3$ perovskites

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Lead-halide perovskites are attractive materials for wet-cast photonic applications, but their toxicity raises serious environmental and health concerns. Therefore, the lead-free perovskites are extensively studied as a possible nontoxic substitution of similar or even superior performance.

Here, we investigate the ultrafast processes of carrier thermalization, recombination, and diffusion in a set of $MASnI_3$ layers, grown from solution by using different precursors [1]. We employ a unique light-induced transient grating technique together with the photoluminescence and differential transmission measurements.

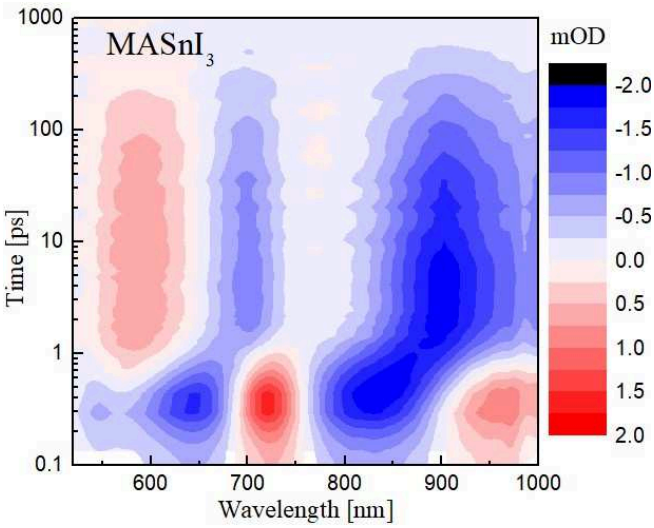

Figure Time-resolved differential transmission spectrum in $MASnI_3$ layer under pulsed 200 fs excitation at 515 nm

We demonstrate that highly excited Sn perovskite layers exhibit very promising electrical properties: the measured carrier diffusion coefficient and lifetime reach 0.5 – 1.6 cm^2/s and 100 – 140 ps, respectively, resulting in the diffusion length of 100-150 nm. These values are comparable to those of vapour-deposited lead-halide perovskites [2]. We observe the fast (within 2 – 4 ps) carrier thermalization in the layers. We show that amplified stimulated emission (ASE) can be readily obtained in Sn perovskites, but the ASE threshold strongly depends on layer quality; in our case it varied in the 5 - 70 $\mu J/cm^2$ range. We note that the lowest ASE threshold value of 5.4 $\mu J/cm^2$ is considerably lower than that reported in $MAPbI_3$ samples with additives [3]. These results suggest that Sn perovskites can be an effective active material for photonic devices like lasers and high power LEDs.

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P3

Recombination and diffusion processes in electronic grade 4H silicon carbide

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There has been considerable interest in characterizing the lifetimes of carriers within epitaxial layers of 4H-SiC [1] as lifetime is a key parameter for SiC bipolar devices. However, wide variations in measured lifetimes stem from differences in experimental conditions, such as injection level, temperature, as well on growth conditions. Typically in n-type 4H-SiC main recombination mechanism is attributed to deep $Z_{1/2}$ traps [2], providing an increase of lifetime with excitation and temperature. In case of low defect concentration, the surface recombination was indicated as the main recombination mechanism.

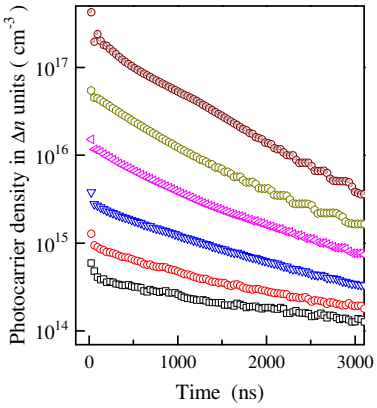

Fig. 1 The time dependences of photocarrier density evaluated from the MPC decays in 60 μm 4H-SiC.

Therefore we performed detailed analysis of photoexcited charge carrier dynamics in 10^{14} - 10^{18} cm^{-3} density range in 4H-SiC by using complementary optical free carrier absorption, photoluminescence, light-induced transient grating, and microwave photoconductivity (MPC) techniques. 4H-SiC epilayers of 35, 60, and 120 μm thickness and 10^{15} cm^{-3} doping were investigated. In Fig. 1 we present a set of kinetics of excess carrier density (Δn), measured in 4H-SiC by using MPC method [3]. The sample excitation was performed by ps-duration laser pulses at 355 nm. Varying layer thickness allowed to distinguish impact of surface and bulk recombination. Surface recombination rate increase with excitation was explained by surface potential screening. An unusual bulk lifetime decrease with excitation from 4 μs to 460 ns was observed in the thickest n-type 4H SiC layer. This feature we attributed to shallow electron traps as evidenced by photoluminescence spectra. Modeling of excitation-dependent electron capture by these traps and subsequent hole capture provided the trap position at E_C – 0.19 eV, their density, and electron-hole lifetimes at high excitation conditions.

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P4

Influence of the temperature and the excitation power on the optical properties of InGaAs quantum rods

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Semiconductor self-assembling quantum dots (QDs) allow to achieve the intriguing atomic-like quantum confinement. To enable light polarization control, quantum rods (QRs) were proposed [1]. InGaAs QRs were synthesized by molecular beam epytaxy, depositing a short period InAs-GaAs superlattice (SL) on top of a "seed" InAs QDs layer. Thereby, InGaAs QRs are immersed in a shallower InGaAs/GaAs quantum well (QW).

In this work, we investigate the effects of As source (As_2 / As_4) on the optical and the electronic properties of different aspect ratio (0.25–4.1) InGaAs QRs. To get the insight into physical properties of the QR structures, complementary spectroscopic techniques of photoluminescence (PL), PL excitation (PLE) and photoreflectance (PR) were used and supported by numerical calculations within 8-band **kp** model.

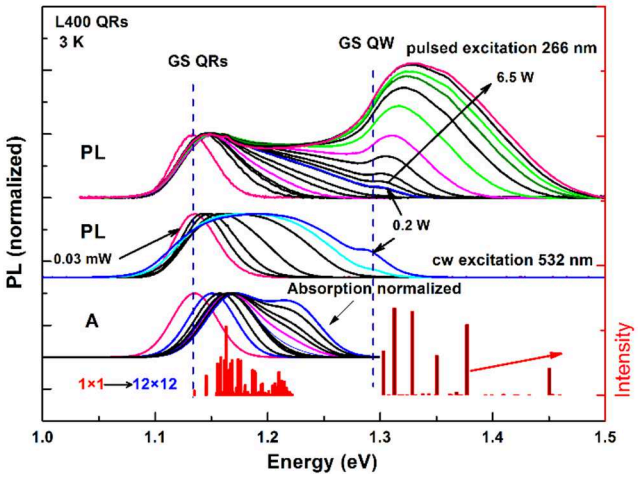

Fig. 1 PL spectra measured with different lasers and normalized intensity of calculated optical transitions at 3 K temperature (A), gradually including electronic states from 1×1 to 12×12. The low (high) energy bars indicate QR (QW) optical transition energies and intensities calculated within strain-dependent 8-band **kp** model (envelope function approximation).

Temperature and excitation power dependent variation of interband optical transitions within In-rich InGaAs QRs and the surrounding InGaAs QW are revealed and discussed. In particular, PR technique has been used to determine the band structure of QR/QW complex system, while PL spectra show a QR height-dependent blue-shift with increasing excitation power [2]. According to calculations of optical transitions (see Fig.1), the observed blue-shift of QR ground-state (GS) transition is discussed in terms of the phase-space filling effects in the QRs. Furthermore, possible channels of carrier transfer were established from PLE measurements, performed at different temperatures.

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P5

Investigation of reflectivity spectrum of GaN with periodic apertures on the surface

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Periodical structures, processed on the surface of polar semiconductors have been widely investigated in order to achieve light manipulation in subwavelength regime as well as to modify the optical features of the fabricated devices [1,2,3].

In this work Reflectivity spectra of doped GaN were investigated theoretically and experimentally. Work was carried out in order to engineer surface phonon polariton modes in order to modify the optical response spectrum of the sample. Numerical light diffraction from periodic micro structures etched in GaN wafer surface was carried out using Rigorous Coupled Wave Analysis method [4] modified accordingly to account the optical response of infrared active LO and TO phonon modes [3]. EM field distribution plots were also studied in order to understand light confinement and different surface phonon polariton modes interaction phenomena.

A semicunductor GaN crystal was investigated providing two dimensional, semi-infinite rectangular apertures of different period and height varied in the range 1 to 30 um. Samples were doped with electrons in the experimentally available range 1E17- 5E19 cm^{-3}. Reflectivity spectra were obtained by FTIR spectroscopy in the region between 10 cm^{-1} and 2000 cm^{-1} uisng TM and TE polarization.

Theoretical modeling showed a reflection minimum at the TO phonon frequency of GaN, which gets narrower with the increase of the doping density up to 5E19 cm^{-3}. A region of high reflectivity defined by the Resthrahlen band (560-740 cm^{-1}) is observed in the undoped sample, which strongly broadens with the increase of doping concentration. Introduction of the periodic aperture grating on the surface of the sample introduced surface phonon polariton modes in the optical response of the sample. The modes are seen as narrow reflectivity minima in the reflectivity spectrum. Mode position in the spectrum and the broadering can be changed by varying the geometrical parameters of the periodic apertures and the doping density, respectively.

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P6

Growth and characterization of a few monolayers MoS_2 based optical properties in practical devices

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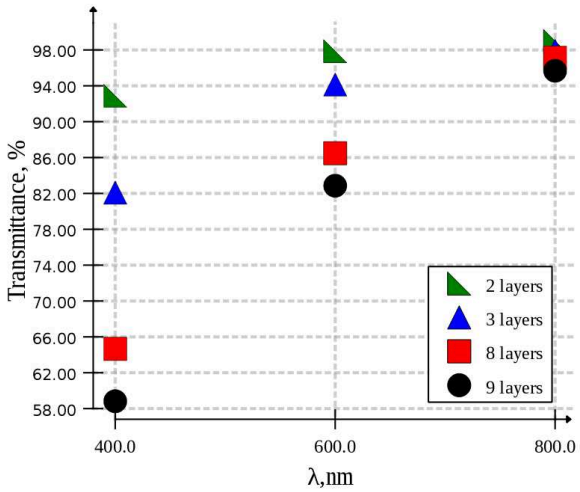
Transition metal dichalcogenides (TMD) have attracted a lot of attention due to their unique optical properties for the wide range of novel approaches in development of optoelectronic devices. The TMDs like MoS_2 films were proved being highly useful due to possibility to control the properties of the films by changing the number of the atomic-thick layers. Until now, the models of the devices are typically manufactured by mechanical exfoliation of MoS_2 sheets though the chemical vapor deposition (CVD) grown MoS_2 films are much more acceptable for the development of the intentionally controlled large area device systems.

Fig. 1



Few layer MoS_2 film on quartz transmittance dependence on layer number for 400, 600 and

In this work, we present a study of the properties in the CVD large area MoS_2 films that were grown using an intentionally controlled metallic Mo precursor film. The MoS_2 thin films were grown by thermal sulfurization of the precursor films in an atmospheric pressure CVD furnace. The diverse substrates were used aiming to reveal a dependence of the film properties on the substrate (Si/SiO_2 wafers, quartz, sputtered Au on Si/SiO_2) and the growth parameters. The MoS_2 films were characterized by the parameters obtained from the Raman spectroscopy and AFM topography experiments for the films on various substrates. The primary objective of the work was to describe a dependence of the optical properties of the films on growth parameters and the number of atomic-thin layer of the MoS_2 flakes obtained on diverse substrates. Typical results for the optical transmittance are shown in the Fig.1. The optical parameters were investigated and discussed in the terms of the photonic processes in the structures.

P7

HRTEM characterization of Bi quantum dots in annealed GaAsBi/AlAs structure

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High Resolution Transmission Electron Microscopy (HRTEM) is the premier tool for understanding the internal microstructure of materials at the nanometer level. It allows one to obtain real-space images of materials with resolutions on the order of a few tenths to a few nanometers, depending on the imaging conditions, and simultaneously obtain diffraction information from specific regions in the images (e.g., nanoparticles).

In this work, MBE grown InGaAsBi and GaAsBi/AlAs quantum well structures were analyzed. In-depth analysis of QW's and Bi-nanoparticles orientation and strain distribution was performed using HRTEM and Geometric Phase Analysis while elemental analysis was done using EDX mapping and STEM HAADF techniques. EDX mapping was standardized by using different layers of the same sample, and the results were compared with HRXRD and PL results [1].

Analysis revealed that Bi-containing phase during annealing partially decomposes forming GaAsBi phase with reduced Bi content and metallic Bi nanodroplets, while AlAs layer acts as barrier for Bi out-diffusion, as total Bi quantity in layer does not change during annealing. Furthermore, GaAsBi layer remains strained, while Bi quantum dots are fully relaxed and distributed randomly.

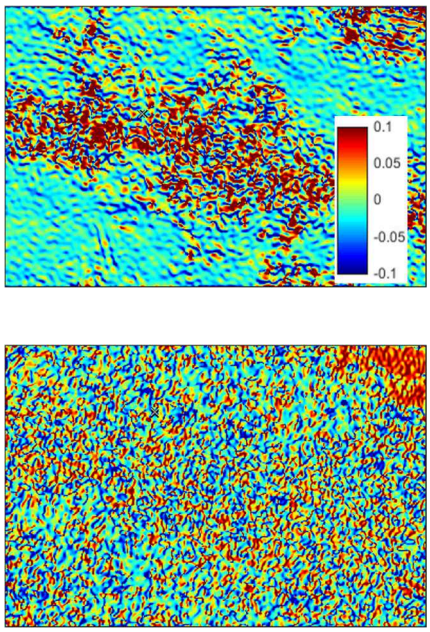

Fig. 1. ε_{yy} (top) and ε_{xx} (bottom) strain maps of GaAsBi/AlAs structure. It is clearly visible that GaAsBi is strained in respect to AlAs.

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P8

Rapid thermal annealing of epitaxial layers grown by MBE

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GaInAs system lattice-matched to InP for a long time is used in optoelectronics for telecommunications and near-infrared applications (up to ~1.7 μm). For longer wavelengths GaInAsBi compound could be used. Theoretically, it is possible to grow lattice-matched GaInAsBi/InP systems working up to 6 μm [1].

GaInAsBi epitaxial layers were grown on semi-insulating (100)-oriented InP:Fe substrates with GaInAs buffer layer by molecular beam epitaxy (MBE). For structural analysis ω-2θ rocking curves of 004 reflex and reciprocal space mappings (RSM) of 115 reflex were measured. Incorporation of Bi up to 3.6% in quaternary compound was calculated from rocking curves and lattice parameters were calculated from RSM measurements. The latter demonstrated that both the buffer and the bismide layers are fully strained even when their total thickness is of the order of 1 μm (Fig. 1). Layers were annealed for 180 s at temperatures ranging from 450 °C to 750 °C. Optical absorption, photomodulated reflectance, photoluminescence (PL) experiments and carrier lifetimes measurements of both annealed and as-grown GaInAsBi layers showed an improvement of optical characteristics, also Bi concentration changes correlated with HR-XRD results.

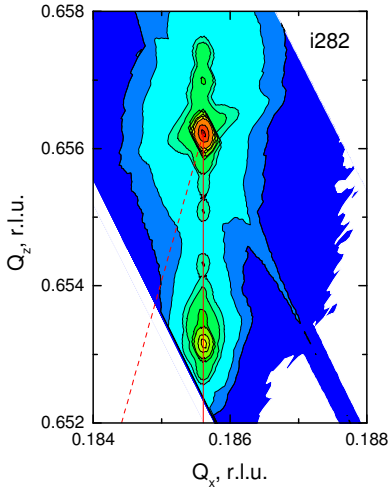

Fig. 1. Reciprocal space map measured for the GaInAsBi layer (115) reflex with 3,6% Bi

Structural and optical analysis of GaInAsBi quaternary compound proved that this could be prospective for IR optoelectronic applications. Rapid thermal annealing for the annealing temperatures in the range of 650-700°C improves photoluminescence intensity, extends carrier lifetime and enhances electron mobility.

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P9

Fast damage of thin II-type superconductor films by cumulated magnetic flux

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Opto-electronic switch operating on the basis of transition from superconducting state to normal state (S-N switching) is prominent for its fast switching time which is less than 10^{-8} s. Generation of power pulses requires films having large values of critical current. However, for II-type superconductors, the problem of damage current still exists [1]. The aim of this work is to clarify the process of fast local damage of high quality thin II-type superconductor films by current pulses slightly exceeding the critical current.

Different YBaCuO films of 200 nm to 400 nm thickness and having wide range of critical current values (10^4 – 10^6 A/cm^2) were fabricated by laser ablation and by chemical vapour deposition methods. Nanosecond electrical pulses were used to determine the value of critical current, and the pulse voltage magnitude was risen further until the film was damaged. SEM images revealed cracked areas of the damaged films different from the ones presented in [1] and showing traces of vortexes driven by the Lorenz force from the edge to the film center.

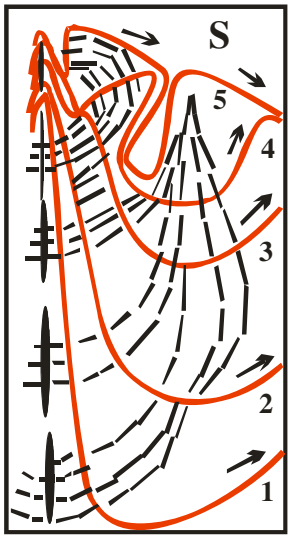

Fig. 1 Dynamics of cracks (dashed black lines) and S-N border (red lines); arrows indicate current direction. The image dimensions are 18x32 μm^2.

The cracks open perpendicularly to the current flow and contain information about S-N border propagation. Fig. 1 restores schematically the dynamics of this process at the right side of the main crack which is seen as black outstretched spots. Different time moments ($t_1<t_2<t_3<t_4<t_5$) disclose cumulative manner of magnetic flux flow and formation of the main crack by the coherent jet. In high quality films additional edge barrier is formed by bending of transport current [2]. Our investigation revealed that vortexes do not overcome the barrier. Instead, the cumulated magnetic flux sharply bends S-N border (t_1) and penetrates into the center of the film with following alignment of the border (t_5). Under these conditions, high speed of coherent jet and high current concentration at the top of the jet cause the S-N switching as well as fast local damage of the films.

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P10

Hot carrier impact on photovoltage formation in semiconductor p-n junctions

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To make the photovoltaic energy more cost-effective, one needs either to reduce the price of solar cells or to increase their conversion efficiency fundamentally constrained by the Shockley-Queisser limit by refining and developing new technologies and materials.

We demonstrate additional influence of hot carriers on the efficiency which is usually assumed only through their thermalization. In case of light-illuminated semiconductor p-n junction, photoresponse is composed, in general, of three components:

$$U_{response} = U_{ph} + U_{hc} + U_T. \qquad (1)$$

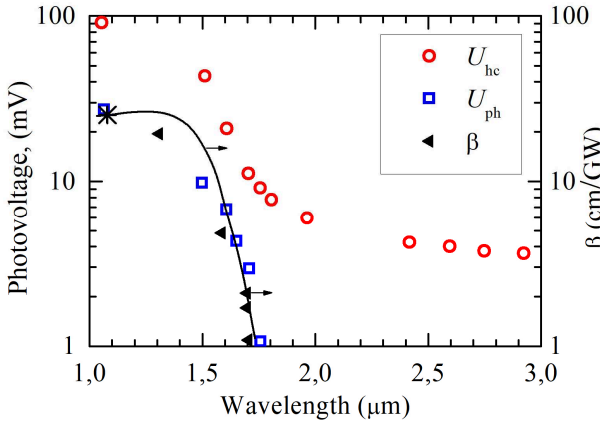

Fig. 1 Hot carrier photovoltage and classical photovoltage across GaAs p-n junction versus light wavelength. Two-photon absorption coefficient β values are taken from Ref. [1].

Here U_{ph} is the classical photovoltage resulting from electron-hole pair generation, U_{hc} is the hot carrier photovoltage, and U_T stands for the thermoelectric voltage caused by the junction heating. Domination of each component depends on light intensity and wavelength, temperature, semiconductor junction parameters.

The latters two have polarity opposite to the classical's one. The speed of U_{hc} is basically limited by electron energy relaxation time (~10^{-12} s), and it impacts on the net photoresponse previous to thermalization. Fig. 1 evidences the fact that the carriers are heated and thereby the hot carrier photovoltage is induced not only by the direct intraband free carrier light absorption ($\lambda > 1.75$ μm) but also by the residual photon energy left over during the electron-hole pair generation ($\lambda < 1.75$ μm).

The presented findings can influence and considerably facilitate the design of high efficiency solar cells.

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P11

Charge drift nonlinearity in organic semiconductors– harmonic generation as a probe of charge transport properties.

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Transport of the electrical charge in organic semiconductors is an entangled process. Mobility of the charge carriers depends on the intensity of the electric field and, also, experiences temporal relaxation. These features is the result of intrinsic disorder in this class of materials. Charge transport governs operation of organic electronic devices. Thus, experimentally determined charge mobility is the key information for the design of devices, such as organic light emitting diodes, solar cells, field effect transistors etc. There are numerous techniques for the measurement of charge mobility in organic electronic devices. Charge extraction by linearly increasing voltage (CELIV) is one of the most widely used method due to its versatility [1]. However, the field dependence is lost in the CELIV measurement as the voltage is continuously changed and the result of the measurement is the average value obtained for the certain range of the bias voltage.

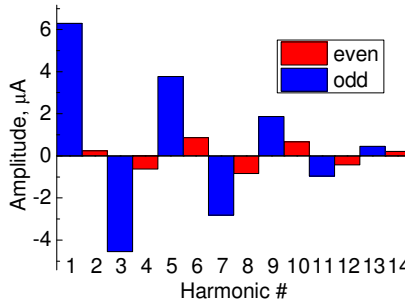

Fig. 1 Current spectrum of the perovskite-based light detector under illumination, fundamental frequency 100kHz.

We propose the method for the measurement of field-dependence of the charge carrier drift, which relies on harmonic analysis of the sample's response to sine input voltage. The charge drift non-linear dependence on the applied field causes higher harmonic components in the flowing current. The amplitudes of these components are used for the reconstruction of the charge drift speed dependence on the applied field. The experiment is implemented by applying the sine voltage to the sample from the function generator. The current is monitored and recorded by the oscilloscope. Further, Fourier transform is performed on the time trace of the current. This gives amplitudes of higher harmonics in the frequency spectrum (Fig. 1), which allow determination of the coefficients in the expression of the charge drift speed:

$$v(E) = \frac{v'(0)}{1!}E + \frac{v'''(0)}{3!}E^3 + \frac{v'''''(0)}{5!}E^5 + \cdots (1),$$

where *E* is the electric field.

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P12

Enhancing of spontaneous emission rate of small organic molecule material by using Tamm plasmon structures and periodic metal-dielectric structures

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We have investigated ability of Tamm plasmon (TP) structure [1] and periodic metal-dielectric structures to control spontaneous emission rate of CBP (N,N-Dicarbazolyl- 4,4-biphenyl) organic emitting material. Recent researches demonstrated modification of spontaneous emission rate by usibg TP structure [2]. Considered TP structure is based on SiO2/TiO2 5 pairs distributed Bragg reflector (DBR), with 26 nm CBP and 50nm silver layers on the top. Two periodic silver-organic structures were fabricated by using thermal evaporation technique with different CBP thickness (30nm and 15 nm). Structures properties was analyzed by both theoretical (using S-quantization approach) and experimental methods. The rate of fluorescence intensity decay of TP (fig.1(a)) and periodic structures was experimentally measured in near ultraviolet region.

We show that decay time of CBP fluorescence intensity in TP structure and periodic metal-organic structures decreases several times (3 for TP structure and 10 in metal-organic structure case).

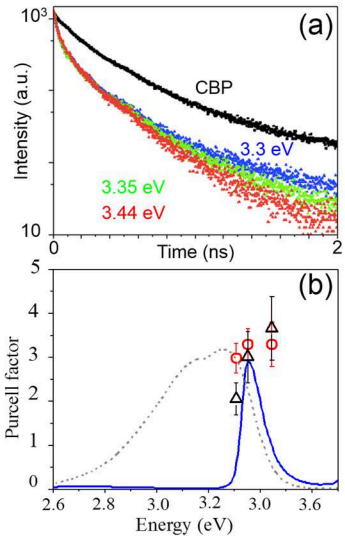

Fig. 1 (a) Measured PL decay time of bare CBP and in TP structure. (b) Comparison of calculated Purcell factor with experimental in TP structure case.

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P13

Excited state dynamics of photochromic dimethyldihydropyrene derivatives in solutions

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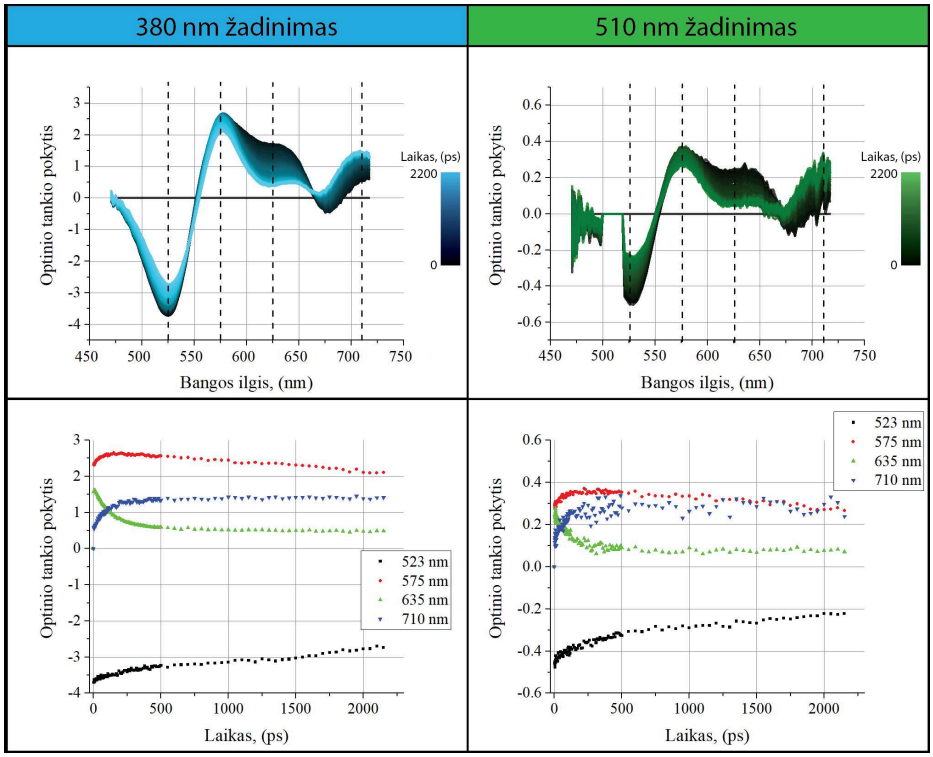
Molecular switches can be commonly applied to control different functions and properties of materials which can be used in organic electronics (as for example in new memory elements based on single molecule) or in biology to manipulate the biological systems. Photochromism of dimethyldihydropyrene derivatives is a reversible transformation under UV and visible light irradiation between two, open-ring hexatriene and closed-ring cyclohexadiene, isomers with different spectroscopic properties. Usually, the optical-active derivatives of diarylethene were fluorescent in the open-ring state and non-fluorescent in the closed-ring form.

New dimethyldihydropyrene derivatives were synthesized, and their optical properties as well as excited state dynamics were investigated in the solutions. We focus on the emissive properties of dimethyldihydropyrene derivatives with the possibility to switch them between fluorescent and non-fluorescent states. During the first 100-300 ps after excitation under visible light the closed-ring cyclohexadiene isomer were opened. Reverse transformation took place through intermediate stage during several picoseconds.



P14

Terahertz Excitation Spectra of InP Single Crystals

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Terahertz (THz) electromagnetic waves generated from semiconductor surface using femtosecond laser pulses was introduced by Auston [1]. Due to THz emission dependence on semiconductor properties, THz emission spectroscopy emerged [2]. In this work InP single crystals with different doping and crystallographic structure were investigated.

In order to determine energy separation between the main and subsidiary conduction band valleys, THz pulse amplitude dependences on photoexcitation photon energy (in a range of 1,3 – 3 eV) were measured (Fig 1 a). These dependences had a clear maximum at ~2,3 eV, which corresponds to 0.75 eV intervalley energy separation in the conduction band of InP (Fig 1 b). Moreover, THz generation mechanisms in InP surface were investigated It has been shown that the main physical mechanism of the surface THz emission is spatial separation of photoexcited electrons and holes, when using photon energy >1,6 eV. Photocurrent surge in the surface electric field can also contribute to the THz emission from a semi-insulating crystal illuminated by optical pulses with wavelengths close to the absorption edge. By additionally analysing the azimuthal angle dependences of the emitted THz signal amplitude and power. Non linear photocurrent effect with similar symmetry to second order optical non linearity was determined.

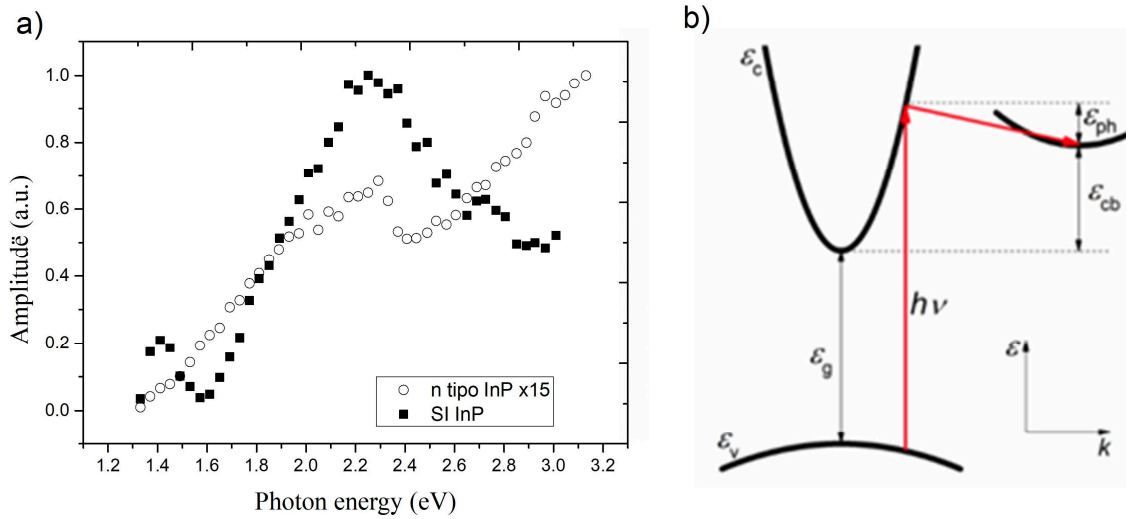

Fig. 1 a) THz excitation spectra of SI and n type InP, THz signal amplitudes are normalized to the number of photons incident to the sample's surface. b) Shows band structure of InP with ε_g = 1.34 eV, ε_{cb} = 0.75 eV and ε_{ph} = 43 meV. Red arrows show electron transitions: excitation by a

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P15

Uncertainties of Terahertz Wave Attenuation Due to Rain in Wireless Communications

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World mobile data traffic is growing nearly exponentially, and the delay-sensitive traffic is one of the major contributors to this data stream today. The limited bandwidth would restrict the future growth of wireless communications unless new frequency ranges are exploited. The unallocated bandwidth in sub-terahertz (sub-THz) and terahertz (THz) ranges would be perfect candidates [1], however the rain attenuation is one of the most serious obstacles to overcome.

Statistical evaluation of terahertz (THz) wave attenuation in heavy rain conditions is presented taking into account expected extreme densification of the infrastructure and application of highly directional beams of 5th generation (5G) and beyond 5G (B5G) wireless networks. Weibull raindrop-size distribution [2] was used, since it best describes the rain attenuation above 30 GHz. It was demonstrated that deviations might be comparable with the average value of the absorbance once the total beam-rain interaction volume is reduced to $V \approx 1$ m^3, as might be expected in 5G/B5G networks. Deviations might exceed the average value by an order of magnitude in case of heavy rain when estimated for narrow, several cm diameter beam in several meters distance of laboratory-based setup described in [3]. Nevertheless, numerically simulated deviations for an extreme rain are much smaller than the experimentally observed [4]. Thus, new application of laboratory-based rain attenuation experiments could be envisioned - they can be a valuable tool for estimating the upper limit of the rain induced noise in THz communication channels.

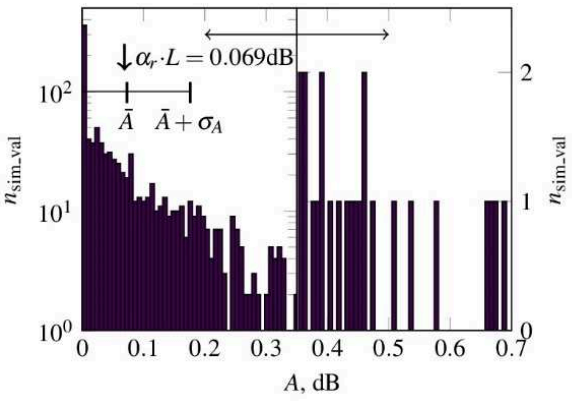

Fig. 1 Distribution of 1000 simulated absorbance A values at $R = 40$ mm/h rain rate, $f = 0.3$ THz frequency and Weibull distribution of drop sizes [4]. Graph is split in the middle to reveal better lower numbers of $n_{\text{sim\_val}}$ with high absorbances. Bar width equals 0.007 dB.

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P16

Efficient THz emission from AlGaAs/GaAs parabolic quantum wells with Bi quantum dots

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To □nabl□ advantag□s of t□rah□rtz (THz) sp□ctroscopy and imaging to oth□r t□chniq□□s and to □xt□nd application fi□ld, a compact and low-cost sp□ctroscopy and imaging syst□ms ar□ r□q□ir□d. As s□nsing cam□ras r□ach□d q□it□ high val□□s in s□nsitivity [1], an □ffici□nt incoh□r□nt THz □mitt□r in partic□lar is d□sirabl□.

In this comm□nication, n□w approach for incoh□r□nt THz □mission from AlGaAs/GaAs parabolic q□ant□m w□lls (PQWs) is pr□s□nt□d and disc□ss□d. Th□ PQW with □q□idistant q□ant□m □n□rgy l□v□ls (QELs) is mod□l□d solving stationary Schröding□r □q□ation [2]. Th□ p□rformanc□ of th□ d□vic□ is mod□l□d □sing rat□ □q□ations taking into acco□nt diff□r□nt transition tim□ constants for scatt□ring m□chanisms [3]. Th□ p□mping of th□ d□vic□ is r□aliz□d by radiativ□ □xcitation of carri□rs from val□nc□ to cond□ction band. Th□ carri□rs ar□ □mitting THz q□anta by int□rs□bband transitions down to th□ low□st QEL, s□□ Fig. 1. Th□ introd□c□d Bi q□ant□m dot insid□ th□ PQW s□rv□s as th□ □ff□ctiv□ scatt□ring chann□l for carri□rs with optical phonons.

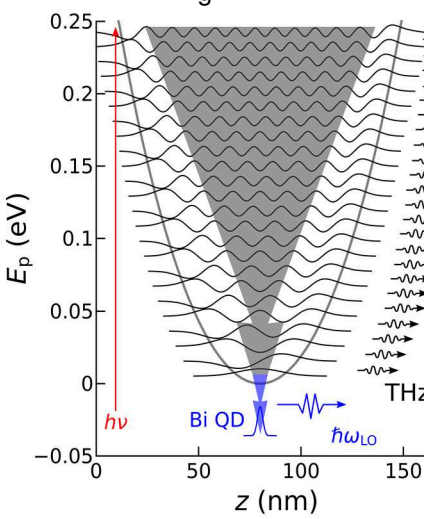

Fig. 1.
PQW for 2.5 THz incoherent THz

Th□r□for□, th□ fast d□pop□lation of th□ low□st QEL of PQW l□ads to THz □mission □nhanc□m□nt. It cr□at□s conditions to constr□ct incoh□r□nt AlGaAs/GaAs PQW THz so□rc□ – THz torch – for THz □mission at 2.5 THz (Fig. 1) and 7 THz fr□q□□nci□s.

ACKNOWLEDGEMENT

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P17
Investigation of charge carrier transport in MID-IR laser diodes through the low-frequency noise spectroscopy

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While 1.9 μm – 3 μm wavelength GaSb-based laser diodes (LDs) are widely used in medicine, defense, gas sensing, etc. [1], investigation of physical processes related to the charge carrier transport through the active layer of the LD and through the leakage channels are still of high importance and technological changes differently affect this.

It is well known that low-frequency noise investigation reveals important information about material and devices defectiveness, however analysis of cross-correlation coefficient between the electrical and optical fluctuations helps to identify location of noise sources in the LD structure and to evaluate their impact to charge carrier transport [2].

LDs with different quantum wells structure, emission wavelength and growth conditions have been investigated using the low-frequency noise spectroscopy in order to find out the physical processes which affect the charge carrier transport.

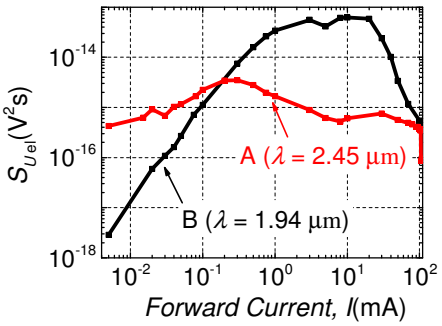

Fig. 1 Voltage fluctuation spectral density dependencies on forward current at 1 kHz frequency in the subthreshold region with different level of observed noise maximum for A and B samples.

The obtained results demonstrate that observed maximum in the voltage fluctuations spectral density dependence on forward current in the subthreshold region (Fig. 1) is characteristic for the presence of generation-recombination noise component and is related to the leakage channel existence in the LD structure. The formation of this channel is very sensitive to the different growth conditions and the surface defectiveness. What is more, this leakage channel has influence to the lasing characteristics of LDs. For such samples the cross-correlation coefficient between the electrical and optical fluctuations becomes negative just after 700 h of ageing. The negative correlation [3] indicates presence of the current redistribution between the active and the neighbour layers due to the potential height of the barrier modulation caused by defects and non-radiative recombination centers. Thus, low-frequency noise spectroscopy in the subthreshold region enables prediction of charge carrier transport mechanisms in LDs.

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P18

The first 1 TW-class laser system is under development in FTMC to study the intense laser-matter interaction

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Great efforts have been made in Lithuania [1] and all over the world [2] to create TW-class laser systems, which take up a lot of space, while development and maintenance costs limit their use. Therefore, such systems are usually shared by many scientists with limited access time. For the wide distribution of high peak power lasers, it is vitally important to pay special attention to reducing the size and cost.

We demonstrate the development of the first in our institute 1 TW-class Optical Parametric Chirped Pulse Amplifier (OPCPA), seeded and pumped by a two-stage double-pass Yb:YAG Chirped Pulse Amplifier (CPA) and a pulse compressor. Reducing the repetition rate to 100 Hz allows us to use the simple, compact and cost-effective design of the OPCPA pumping source based on conventional Yb:YAG rods with low doping level.

Amplified in CPA pulses with a total gain of ~ 2900, an output energy of ~ 20 mJ (Fig. 1 – top), an energy stability of StDev ± 0.75 % and beam quality of M2 ~ 1.1 (Fig. 1 – middle) were compressed to ~ 1.15 ps (Fig. 1 – bottom) with an overall efficiency of > 91 %. By combining up to 19 pumping diodes the output energy can be scaled up to 60 mJ providing a peak power of ~ 50 GW. These output pulses are used both to generate supercontinuum in a YAG crystal, and to pump parametric amplifiers after frequency doubling in LBO, thus automatically synchronizing the signal and the pump for 1 TW-class OPCPA.

This work has been funded by Research Council of Lithuania under contract LAT-10/2016.

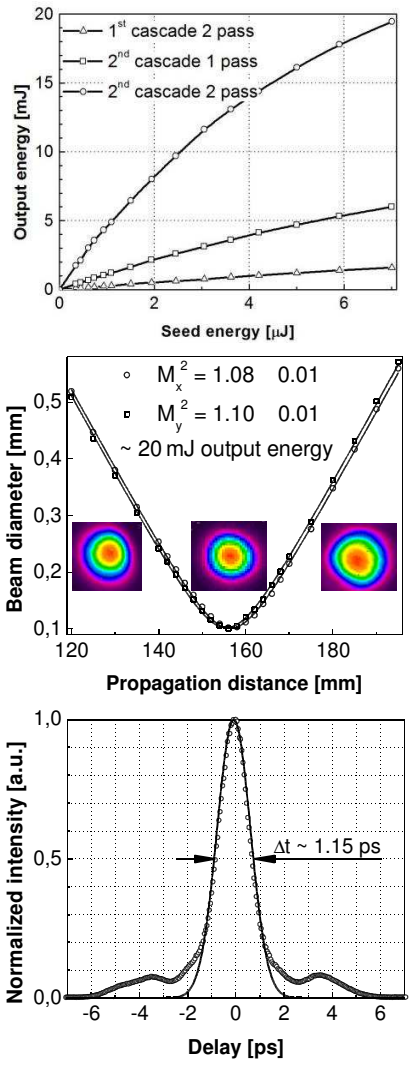

Fig. 1 The output vs seed energy, beam quality and autocorrelation trace of compressed pulses.

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P19

Impact of angular deviation of optical axis on the contrast ratio of beta barium borate crystal

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The Q-switching technique is used for the high and medium power laser pulse width modulation [1]. Key element for such technique is an electro-optic modulator also known as a Pockels cell. Contrast ratio is one of the main parameters of the Pockels cell [2]. In order to achieve high contrast ratio values of the Pockels cell crystal, optical axis of the crystal have to be aligned in parallel with the laser beam.

There are cases in the high peak power laser systems when laser beam has to be focused or cannot be collimated before traveling though the Pockels cell crystal [3], [4]. In such a situation just the small amount of the beam energy travels in parallel with the crystals optical axis. As a consequence, the contrast ratio of the Pockels cell crystal decreases.

The novelty of this work is that the quantitative relation between the beta barium borate crystals contrast ratio and the angle of the optical axis was obtained (Fig. 1).

The investigation results show that the contrast ratio decreases more than two times if angular deviation from the center of the crystals optical axis is more than 5 arcmin. The obtained quantitative results are important because they allow us to use the Pockels cells based on the beta barium borate crystals for high and medium power lasers more effectively.

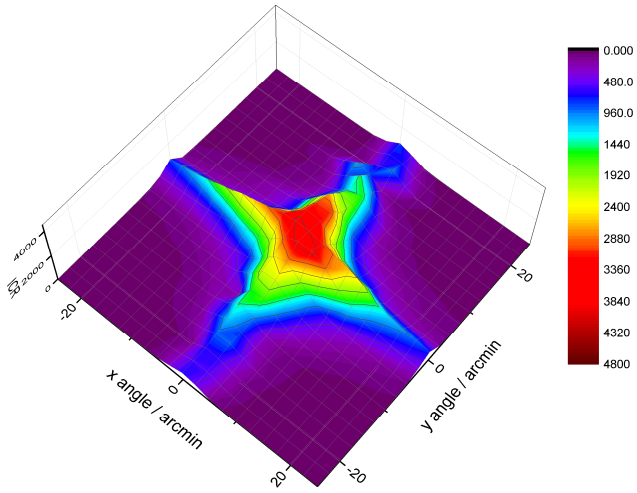

Fig. 1 Contrast ratio dependence on the angular deviation when no external electrical field is applied

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P20

Growth and Characterization of GaAsBi MQW Structures for NIR Lasers

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The bandgap engineering of novel semiconductor materials allows control of lasers emission wavelength. It was demonstrated previously, that incorporation of 1% of Bi to the GaAs lattice reduces bandgap of GaAsBi by 88 meV [1]. Moreover, dilute bismide alloys exhibit low temperature bandgap coefficient [2], therefore bismide based sources could operate without additional cooling. These properties force an investigation of GaAsBi as an active region for IR lasers.

The aim of this research is to find optimal technological parameters for GaAsBi multiple quantum well (MQW) structures deposition and to grow under these conditions MQWs laser diode exhibiting strong photoluminescence (PL) signal for the 1.17 μm peak wavelength. The effect of number of QW, thickness of the well, barrier layer composition and thickness as well as content of Bi on PL intensity was studied.

GaAsBi MQW structures were grown by molecular beam epitaxy on semi-insulating GaAs (100) substrates. High Resolution X-Ray Diffraction (HR-XRD) was employed to evaluate crystalline structure and content of bismuth. PL measurements were performed to investigate optical properties. PL spectrum (Fig. 1) demonstrates the characteristic emission at 1.044 eV (corresponds to 1.19 μm) of a sample containing 3 GaAsBi QWs.

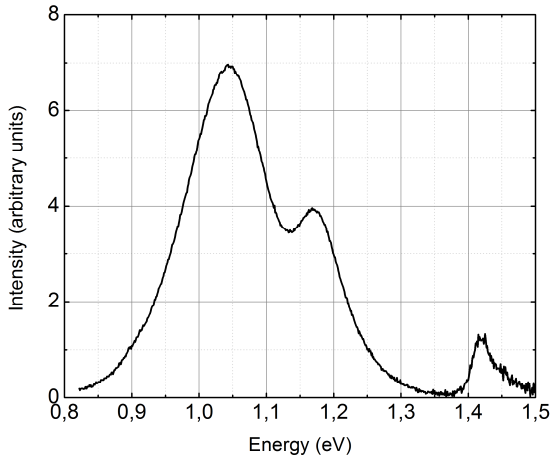

Fig. 1. Photoluminescence spectrum of 3 GaAsBi QWs grown on GaAs substrate

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P21

Thick epitaxial GaAsBi layers for infrared components

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GaAsBi structures have potential for application in novel devices operating in infrared region at room temperature. Due to unique bismide properties, such as, energy bandgap reduction from 70 to 90 meV with introduction of 1% Bi and lower thermal sensitivity of Eg [1, 2], GaAsBi layers and structures are successfully used in photoconductive THz components [3], telecom wavelength laser diodes [4], light emitting diodes [5]. Although dilute bismides have been successfully applied, to obtain high Bi incorporations and high crystal quality is still very challenging.

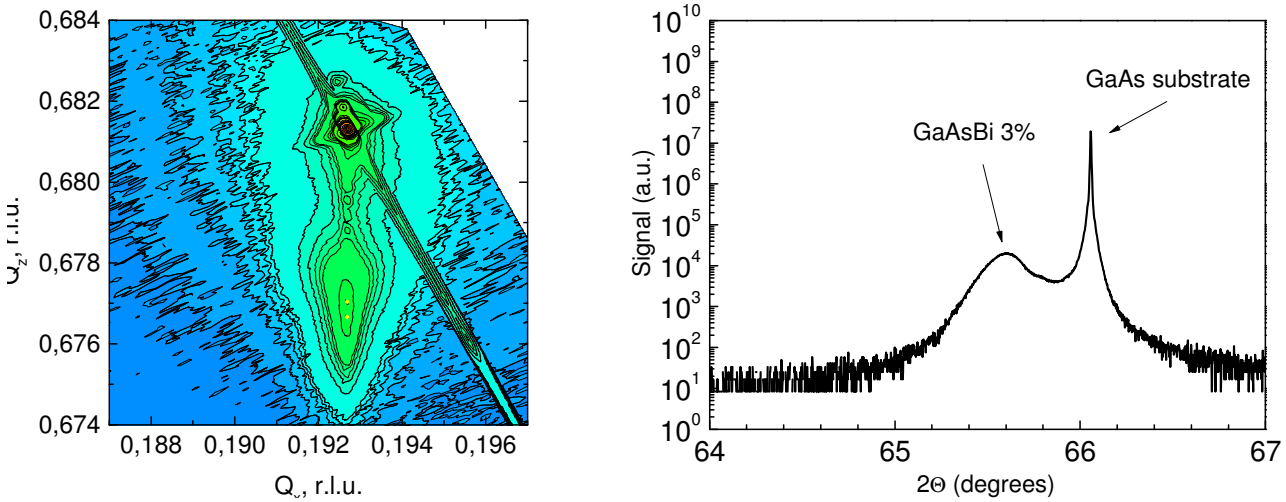

Fig. 1 Reciprocal space map (on left) of GaAsBi; XRD diffraction patterns (on right) from (400) lattice plane measured of ternary GaAsBi.

In this work 100 nm thick epitaxial GaAsBi layers were grown by molecular beam epitaxy (MBE) on semi-insulating GaAs(100) substrates using GaAs buffer. To avoid Bi segregation to the surface bismide layers were grown at low temperatures (320 – 400°C) and the flux ratio for As_2/Ga varying in the range from 1 to 1.1. The crystalline structure and surface quality were studied by XRD and AFM measurements. The influence of technological parameters on optical properties were investigated by luminescence measurements.

Fig. 1 shows reciprocal space map (RSM) (on left) of 100 nm thick GaAsBi layer. From RSM image one can see that GaAsBi layer is fully strained. X-ray diffraction (XRD) rocking curve (on right) measured from (400) planes of GaAsBi layer grown on GaAs substrate demonstrated the peak located on the left which was attribute to GaAsBi layer with the 3% Bi content.

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P22

Synthesis and Structure of Anodic Alumina/Carbon Composites

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Now alumina/carbon composites are used to purify waste water, as catalysts, and catalyst supports, due to their high sorption capacity and efficiency together as well as low cost [1, 2]. In the present study we investigated the peculiarities of synthesis of anodic alumina/carbon composites through one-stage electrochemical oxidation of the aluminum foil in aqueous solutions of oxalic, malonic, glycolic, and tartaric acids. We also explored the chemical composition of the composites.

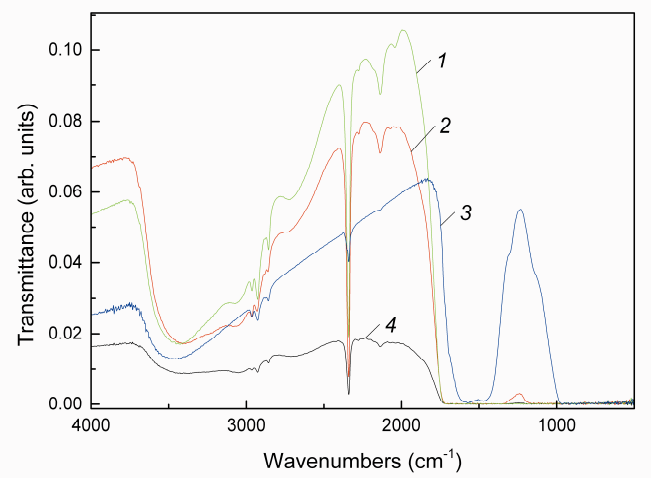

Fig. 1. FTIR spectra of the anodic alumina/carbon composites formed in the aqueous solutions of glycolic (1), malonic (2), oxalic (3), and tartaric (4) acids.

The samples were obtained by double-sided anodizing of the high-purity aluminum foil (99.99 wt. %, 100 μm thick, 15 × 15 mm, AlfaAesar) in aqueous solutions of 0.3 M oxalic, 0.8 M malonic, 1.0 M glycolic, and 0.4 M tartaric acids in a constant current density mode up to the moment when the aluminum was completely oxidized. Surface morphology was analyzed by scanning electron microscopy (SEM) on a LEO 1402 (Leo Electron microscope). The chemical composition of the films was characterized by Fourier transform infrared (FTIR) spectroscopy using a Vertex 70 (Bruker) FTIR spectrometer.

According to the FTIR studies, all samples in addition to alumina (1200–500 cm–1) contain chemisorbed hydroxyl groups (3700–3200 cm–1), and carbon-bearing components, such as CO2 (ca. 2340 cm–1), CO (ca. 2137 cm–1), COO– and CO32– ions (1750–1250 cm–1), and amorphous carbon (3200–2850 cm–1). The variety of products indicates that ions of organic acids are oxidized during aluminum anodizing.

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P23

Preparation method influence on morphology and ultrafast optical properties of graphene layers

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Graphene is an appealing material for photonics and optoelectronics because it offers several advantages compared with other materials. Graphene is gapless, it exhibits ultrafast carrier dynamics, wavelength-independent absorption, tunable optical properties via electrostatic doping, low dissipation rates and high mobility, and the ability to confine electromagnetic energy to unprecedented small volumes [1, 2].

In the current research graphene films were synthesized directly on quartz and single or double copper foils (catalyst) by advanced microwave plasma activated chemical vapor deposition technique (IPLAS, Germany). The latter graphene layers were transferred on preferablesubstrate (quartz, amorphous glass, SiO_2/Si)by etching copper foil in different etchants. Employed Raman scattering spectroscopy (532 nm, inVia, Renishaw, UK) results confirmed successful transfer of the graphene films in a controllable way in the form of mono or multilayers.Atomic force microscope (NanoWizard, Germany) analysis indicated the changes of morphology and uniformity of graphene films depending on preparation method.

Ultrafast excited state relaxation dynamics in graphene was investigated by means of transient absorption spectroscopy (TAS). The samples were excited using a Pharos ultrafast Yb:KGW laser (Light Conversion) with a regenerative amplifier at a 66.7 kHz repetition rate and 290 fs duration pulses at 1030 nm wavelength. The pump beam wavelength was tuned with an Orpheus collinear optical parametric generator and harmonic generator Lyra to 350 nm and an energy density of 20.8 μJ/cm^2. The samples were probed with a white light supercontinuum generated using a 2 mm thickness sapphire plate excited with the fundamental laser wavelength (1030 nm). The ultrafastelectrooptical properties of graphene mono and several layers prepared directly on quartz and applying the transfer (Fig. 1) were compared.

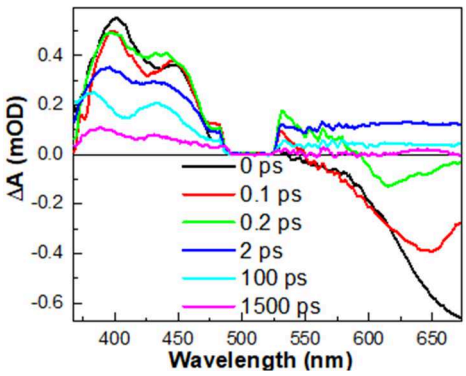

Fig. 1 TAS spectra of graphene transferred on quartz.

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P24

Discrimination between the graphene defects by a combination of the surface analysis methods

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Graphene is a promising material for the future electronic and optoelectronic devices, such as transistors, gas sensors, photo and THz detectors. The chemical vapour deposition (CVD) technique is most developed technology for mass production of single layer graphene on metal substrates such as Cu and Ni. However, the subsequent device manufacturing strongly relies on mechanical transfer of graphene onto various substrates. This and the growth itself induce structural defects into graphene sheet such as wrinkles, cracks, bilayer areas and tear-outs, which reduce graphene homogeneity and effect the performance of final device [1]. For optimization of the technological process of the device fabrication, it is important to "count" defects of individual type.

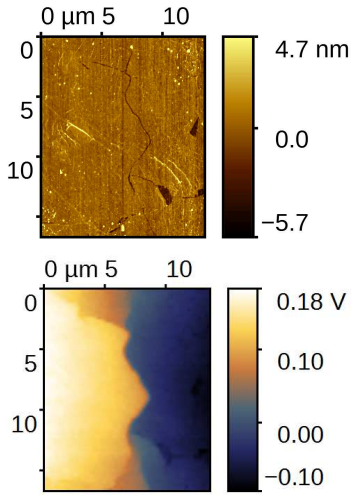

Fig. 1 Topography of the graphene sheet (top) and KPFM image of the same area under 1 V bias visualizing a cracks

For description of graphene sheet quality and visualization of graphene defects, there are used diverse experimental techniques based on analysis of optical parameters, Scanning Electron (SEM) and Scanning Probe (SPM) microscopies, Raman and terahetz time-domain spectroscopies [2]. None of these techniques is acceptable to visualize complete picture of the graphene defects. In this work we manufactured and evaluated graphene FETs on Si/SiO_2 substrate using Raman spectroscopy, SEM, Atomic (AFM), Kelvin Probe (KFPM) and Electric (EFM) Force microscopies. The data were analyzed by commercial SPIP software. We demonstrate that each technique is effective to separate only a part of defect types - tears, cracks, creases, folds and bilayer spots. The AFM topography is effective to identify folds, tears and comparably wide cracks (Fig.1 top), the KFPM of biased device identifies cracks perpendicular to the electric current (Fig.1 bottom), while Raman mapping reveals the bilayer spots. We then determine how many defects of particular type is measured by each technique and thus build a quality assessment chart for effectiveness of quality measurements.

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P25

Shell-isolated nanoparticle-enhanced Raman spectroscopic analysis of living yeast cells

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SERS is one of the most sensitive vibrational spectroscopic method for *in situ* studies of surface and biological systems in aqueous solutions. Large enhancement can be provided by roughened surfaces and nanoparticles of Ag, Au or Cu metals. Recently, Ag and Au nanoparticles have been used for identification of living yeast cells by SERS approach [1]. However, high luminescent background and direct interaction of living yeast cells with metal colloids were the main disadvantages. Consequently, Tian et al. suggested a novel SERS technique named ‘‘shell-isolated nanoparticle-enhanced Raman spectroscopy’’ (SHINERS) [2]. The method is based on enhancement of Raman signal by strong electromagnetic field provided by gold core nanoparticles surrounded by a few nanometer thick inert silica shell (Au@SiO_2). Inert shells surround Au or Ag cores, protecting them from aggregation and increasing stability. The shells also prevent chemical and electrical contacts among cores and probe substrates.

Yeasts Metschnikowia spp. are capable to produce a red pigment when iron (III) ions present in the growth media. They are potential biocontrol agents against various pathogenic microorganisms. SHINERS method employing synthesized spherical gold nanoparticles with 46 ± 6 nm core size and SiO_2 shell of 3 nm thickness allowed to obtain significantly enhanced SHINERS spectra of Metschnikowia spp. compared to the Raman spectra (Fig. 1).

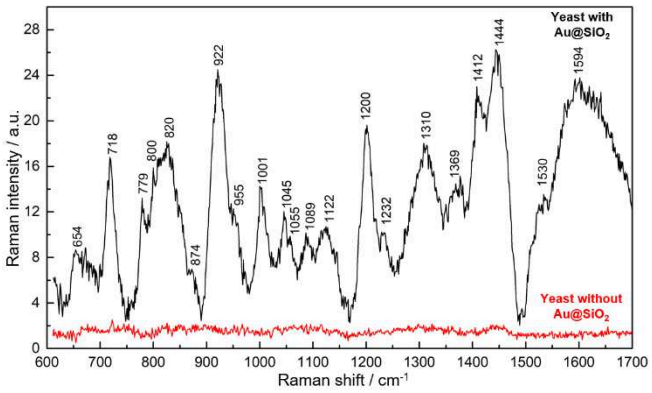

Fig. 1 Raman (red) and SHINERS (black) spectra of yeast cells.

Based on the results, the yeast cell wall and its functional elements (proteins, lipids, amino acids) were identified. It has been determined that spectra, when used Au@SiO_2 NPs in combination with yeast cells, demonstrate the repeatability, vibrational bands do not change and there are no additional bands due to chemical interactions with nanoparticles. Amino acids, C-N, amide vibrations indicate the bioactivity of the living cell. Consequently, SHINERS technique allow to collect molecular level information from yeast for a better understanding of their cell wall biochemical structures.

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P26

New mathematical tools in electrodynamics: geometric (Clifford) algebra

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In optoelectronics, during the last few decades principally new materials such as topological insulators, metamaterials etc having unprecedented properties have been developed. The construction and understanding of devices fabricated from such materials require new mathematical tools, especially deep understanding of relativistic electrodynamics.

This report is a tutorial devoted to relatively new mathematics which is called geometric algebra by physicists, or Clifford algebra by mathematicians. The tutorial consists of two parts. In the first part, a very short history of electrodynamics (Maxwell's equations) is presented. Here we show that there exists a deep mathematical gap between classical and relativistic electrodynamics.

In the second part it is shown that this gap can be closed if instead of vectorial calculus (needed for classical electrodynamics, including electrostatics and magnetostatics) and covariant tensor calculus (needed for relativistic Maxwell's equations) the students were taught a single mathematics, called geometric algebra [1]. This new mathematics is closely related with vector calculus and has very clear geometrical interpretation both in the 3D Euclidean space and 4D Minkowski space-time. As an example the constitutive relations (or material relations) are discussed from relativistic theory point of view [2-4].

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P27

In vivo CARS microscopy of scytonemin in cyanobacteria *Nostoc commune*

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The study of scytonemin in cyanobacteria applying coherent anti-Stokes Raman scattering (CARS) microscopy [1] is proposed. The chemically specific CARS response from particular chemical compounds in the algae cell is usually weak because of their low concentration and is often overwhelmed by optical emissions from other cellular constituents. This report demonstrates that for scytonemin localized in cyanobacteria *Nostoc commune*, the vibrational response is sufficient for its reliable identification. Scytonemin is known as a sunscreen sheath enclosing the cells of microalgae against ultraviolet radiation. The effectiveness of CARS microscopy as a mapping technique with the aim to visualize the scytonemin sheath in a live culture such as cyanobacteria *N. commune* has been revealed [2].

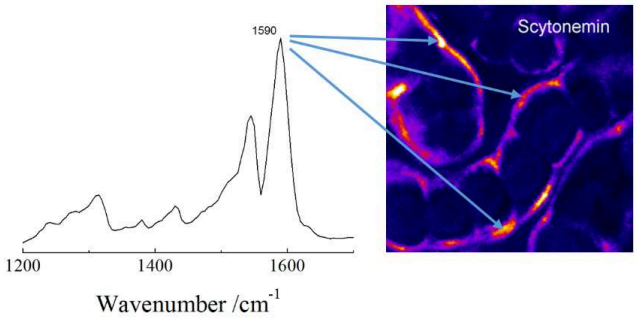

Fig. 1 Image of scitonemin sheath in vibrational contrast at 1590 cm^{-1} wavenumber.

As a powerful tool for microalgae study, the CARS microscopy is capable of fast identifying of the number of the most important biomolecules such as lipids, pigments etc. From now, the scytonemin is one of such biomolecules. In the future, we plan to apply the CARS technique to monitor the accumulation of scytonemin in cultures cultivated under various stress conditions, such as temperature, desiccation, salinity and light intensity.

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P28

THz emission from electrically driven AlGaN/GaN HEMT structures as potential 2DEG plasmonic THz emitters

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Compact tunable frequency terahertz (THz) sources are of great demand for the THz spectroscopy and imaging applications. Coherent electron plasma oscillations in a field-effect transistor (FET) channel have been proposed theoretically by Dyakonov and Shur model [1], suggesting electrically pumped THz emitters of relatively high emission power and of small lateral dimensions. However, in order to induce the plasma instability in FET channel, high electrical current is required to flow through the device what in turn provides an excess heat to the two dimensional electron system and the crystal lattice, and deteriorates the performance of the plasmonic emitter [2]. Therefore, the experimental conditions which would allow an optimized THz emission from 2DEG plasmonic devices have to be found.

In this work the THz emission spectra from electrically driven AlGaN/GaN high electron mobility transistor (HEMT) structures grown on different substrates were studied in order to reveal and optimize THz radiation efficiency of hot electrons and lattice as well as shallow impurity electroluminescence at the temperature range from 20 K up to 110 K.

The AlGaN/GaN structures were grown either on a sapphire or a silicon carbide substrate and electrical contacts were defined by a standard UV photolithography processing [3]. The samples were investigated in cryogenic temperatures provided by a closed cycle liquid helium croystat. Samples were pumped electrically using meander type voltage pulses with a duty circle in range of 0.5-2 %. The emission spectra were collected with a Fourier Transform Far-Infrared spectrometer using a conventional lock-in amplifier technique.

The measured spectra revealed black body-like emission caused by excess heating of electrons and crystal lattice. This type of emission was present at maximum power provided by the voltage pulses. At lower excitation power intensive radiation of resonant character was observed and attributed to 2p-1s electronic transitions in residual impurity atoms of silicon (Si), oxygen (O), and carbon (C).

In conclusion, the radiative mechanisms responsible for THz emission in electrically pumped AlGaN/GaN heterostructures with different pumping power were demonstrated. A much lower level of lattice heating as well as smaller intensity of impurity electroluminescence were found in a case of SiC substrate suggesting that an AlGaN/GaN on SiC could be an optimal solution for further development of the plasmonic 2DEG THz emitters.

The present work was supported by the Research Council of Lithuania project “KOTERA-PLAZA” under contract No. DOTSUT-247.

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P29

Terahertz detection and harmonic generation in AlGaN/GaN high electron mobility transistors.

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In the seminal work, Dyakonov and Shur predicted efficient detection, mixing and multiplication of terahertz (THz) radiation by two-dimensional gas which forms in the channel of field-effect transistor [1]. The experimental results published in [2] show, that current responsivity to terahertz radiation in FETs can change the sign when increasing gate voltage from threshold value. This effect cannot be explained within the framework of simplified hydrodynamic transport description without using energy balance equation.

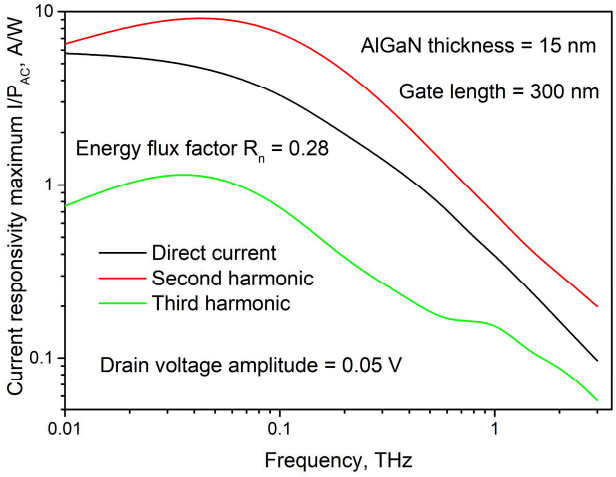

Fig. 1 AlGaN/GaN HEMT current responsivity maximum on 0.01-3 THz radiation. Source-Gate region – 300 nm, Gate-Drain region – 500 nm. Source and Drain length – 300 nm. Gate width – 1000 nm.

Here we present results on two dimensional hydrodynamic transport modeling in typical AlGaN/GaN high electron mobility transistor (HEMT). The model is implemented in Synopsys TCAD Sentaurus program package. Our calculations show, that plasma waves are not the only mechanism related to terahertz detection. Significant role in detection process plays nonuniform electron temperature distribution in the 2D channel, which is controlled by electron energy flux factor R_n in energy balance equation. In Synopsys TCAD, the default value of R_n = 0.6 corresponds to well-known Stratton model. In our calculations we used R_n as a fitting parameter to match the experimental findings of [2]. Figure 1 summarizes our main simulation results presenting the spectra of THz detection and second harmonic generation in HEMT with parameters indicated therein. The amplitude of current, generated at second harmonic slightly exceeds value of direct current resulting from THz detection. Power conversion efficiency η (data not shown) for the second harmonic depends almost linearly on drain voltage amplitude U_{da}. η = 0.15 % at U_{da} = 0.05 V and η = 2.83 % at U_{da} = 0.38 V (2nd harmonic frequency = 0.4 THz, gate voltage U_g = -1.7 V).

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P30

Fibonacci terahertz imaging

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Terahertz (THz) imaging is a powerful tool in many versatile applications covering security package inspection, biomedicine diagnostics, food control, etc. From point of view of practical implementation, THz imaging system should be compact, free of optical alignment, reliable and providing an ability of relatively rapid scans. On the other hand, an important advantage would be a possibility to combine advantages of compact diffractive optics with benefits of tomographic imaging.

Fibonacci or bifocal terahertz (THz) imaging is demonstrated experimentally employing Fibonacci diffractive lens [1] in a continuous wave mode. In contrast to recently presented 3D printed diffractive terahertz lenses [2], we demonstrate design, operation and high-resolution imaging using silicon-based Fibonacci lens for 0.6 THz frequency. It was fabricated on a monocrystalline silicon wafer using laser patterning earlier employed to produce multilevel phase Fresnel lenses of high efficiency [3].

THz images of different objects packaged in a specially constructed container were simultaneously recorded in two different planes at 0.6 THz frequency. Using resolution target spatial resolution is estimated which was found to be in the range of wavelength. Multi-focus imaging operation of the Fibonacci lens is compared with a performance of the conventional silicon phase zone plate. Spatial profiles and focal depth features are discussed varying the illumination frequency from 0.3 THz to 0.6 THz.

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P31

Oxide Layer Enhances Photocurrent Gain of the Planar $MAPbI_3$ Photodetector

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It is nearly eight years since the hybrid perovskites have attracted the significant interest of the scientific community, mainly due to the outstanding performance of hybrid perovskite solar cells. A high achievable efficiency of the perovskite-based solar cells, currently reaching 22.7, [1] shows that carrier generation efficiency in perovskites may approach 100%, suggesting that perovskites may be promising materials not only for solar cells but also for sensitive photodetectors, which may compete with conventional semiconductor analogs. Despite tremendous interest in solar cell research perovskite photodetectors still lack a basic understanding of their operating principles. Here, we study the performance of planar polycrystalline $MAPbI_3$ perovskite photodetectors produced on interdigitated comb of electrodes made from various metals. We demonstrate that a hole blocking oxide layer between metal electrodes and perovskite may enhance responsivity and photocurrent gain of the planar photodetector based on the polycrystalline film by order of magnitude. Application of the Cr interdigitated comb of electrodes with naturally formed oxide layer enabled to reach responsivity of 152 A/W an external gain of more than 350. We suggest that the gain enhancement originates from the hindered extraction of photogenerated holes and the migration of ions, which creates additional hole traps at interfaces. These effects reduce the barrier for electron injection and enable the passage of a larger number of electrons during the prolonged lifetime of photogenerated holes. The achieved photodetector sensitivity, suggested gain enhancement approach and obtained better understanding of the photocurrent gain mechanism in hybrid metal halide perovskites open a way towards the further development of a cheap and easily producible planar perovskite photodetectors based on interdigitated electrode arrays.

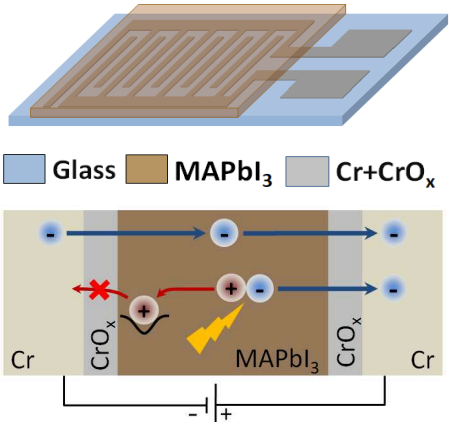

Fig 1. The device structure and working mechanism of $MAPbI_3$ perovskite planar photodetector

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P32

LSO and GAGG scintillators for picosecond timing.

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Fast response to short pulse excitation is one of the key properties of novel scintillators . A fast signal rise time is essential for the future applications of scintillation detectors in high-spatial-resolution medical imaging and high energy physics experiments at high luminosity colliders. In this report we present an in-depth insight into the processes responsible for the rise time of the luminescence response in prospective scintillators. The study has been carried on to purposefully engineer the timing properties of the scintillators by manipulating the growth conditions, crystal composition and doping.

We report on the study of excitation transfer in two cerium-doped scintillators showing promising timing performance: lutetium oxyorthosilicate (Lu_2SiO_5:Ce, LSO:Ce) and gadolinium aluminium gallium garnet ($Gd_3Al_2Ga_3O_{12}$, GAGG). Properties of the samples of undoped GAGG, GAGG doped with Ce, Ce and Mg, Ce, Mg and Ti were compared, and the influence of substituting lutetium with yttrium in LYSO was also investigated.

We employed the optical pump and probe technique to investigate the dynamic of population of different states by non-equilibrium carriers. 200-fs-long laser pulses were used for pumping. The differential absorption (DA) in the range of 460–950 nm with and without the pump was measured as a function of the delay between the pump and probe pulses. Tunable wavelengths of the pump pulses allowed for resonant excitation of different structural units in the crystal, while a wide spectrum of the white-light continuum used for probing ensured spectrally resolved detection of free and localized photoexcited non-equilibrium carriers.

The pump and probe experiments at a short-pulse resonant excitation to $5d^1$ level of Ce^{3+} in GAGG:Ce revealed that the DA signal appears instantly and decays within the same time constant, about 50 ns, in all the differently codoped samples studied. After the resonant excitation to $5d^2$ level of Ce^{3+}, the DA signal builds up within a few tens of picoseconds in a sample without codoping, while in the codoped samples the buildup time was by an order of magnitude shorter. The additional codoping with Ti has no influence on the signal rise time.

At direct excitation of cerium ions, the kinetics of the rise of the nonlinear absorption due to the excited Ce^{3+} centers in LSO and LYSO crystals is identical, but the signal decays at a slower rate for the LYSO crystal. When pumped by 5.91 eV photons, LYSO:Ce initially shows the same rise time as LSO:Ce, however, exhibits a second, significantly slower rise component. We attribute this second component to the trapping of non-equilibrium carriers, which is expected to be stronger in a mixed crystal due to the intrinsic composition disorder and, probably, due to additional defect-related trapping centers.

P33

Carbon nanolayers for diffractive terahertz optics

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One of the important topics in terahertz (THz) science and technology is to reveal routes for convenient-in-use THz imaging systems and find new ways to control THz radiation using planar solutions [1]. In particular, these issues become essential designing imaging systems using on-chip approach, because metal diffusion cannot be further used as suitable tool to fabricate THz diffractive optics components.

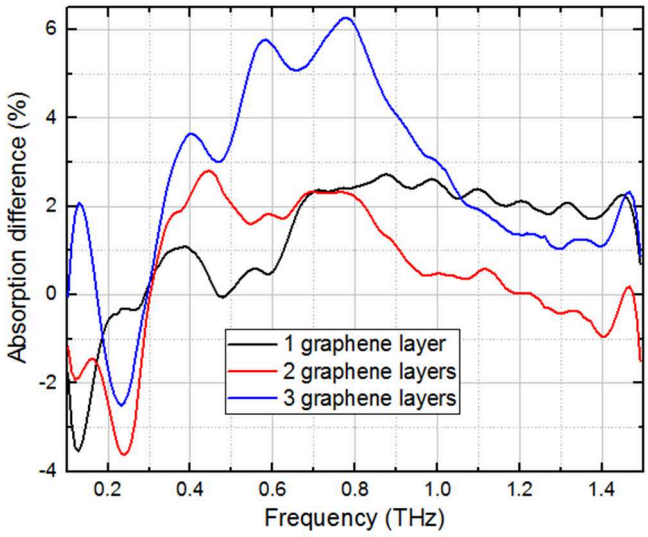

Fig. 1 Absorption difference of THz radiation in one, two and three graphene layers placed on silicon.

In this communication, we consider graphene-based solutions for diffractive THz optics on a high-resistivity silicon substrate. One, two and three CVD grown graphene layers were deposited on the substrate by a wet-transfer technique. The quality of the layers was evaluated by four probe measurements and Raman spectroscopy. It was determined that the spectra exhibit typical features of graphene mono, double and triple layers and indicate small amount of defects.

The structures were characterized using THz Time Domain Spectroscopy which enabled to evaluate layers' parameters, such as electric conductivity, scattering time, carriers density and their mobility. It was demonstrated that THz Continuous Wave images recorded at 0.3 THz and 0.6 THz frequencies are suitable technique to check the quality of the layers.

THz zone plate with integrated resonant filter for 0.6 THz frequency [2] was design and produced. Three-dimensional time-domain calculations indicated reasonable performance of the produced structures. Experiments correlate well with the theoretical predictions.

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P34

EdgeFET Terahertz Detector Based on Two Lateral Schottky Barrier Gates

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We report on a study of AlGaN/GaN heterostructure field effect transistors with gate based on lateral Schottky contact [1]. A possibility to control channel width in a wide range is interesting for terahertz (THz) resonant detection and emission application using field effect transistor (FET) [2]. Particularly, detection experiments showed lower responsivity and the resonant maxima much broader than predicted by the theory [2] and depends on the transistor channel dimension. One of the possible reasons for this discrepancy is the existence of the oblique modes in the transistors with the channel width higher than the channel length [3].

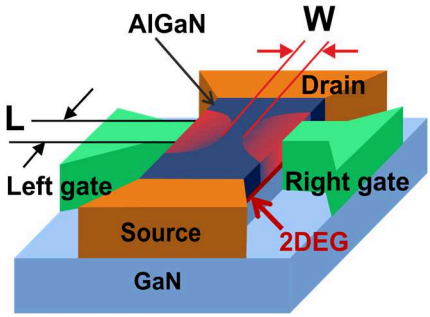

Fig. 1 EdgeFET device with lateral Schottky barrier (LSB) gates.

The AlGaN/GaN structures were grown by Metalorganic Vapour Phase Epitaxy. More detailed processing information could been found in Ref. 1. Using these heterostructures, we made two types of transistors. First is a field effect transistor with the fin-shaped channel (FinFET) where gate crosses the whole channel and second – a new device, where unlike the common FinFET design, the gates were deposited only in the contact to the edges of the two-dimensional electron gas (2DEG) channel (see Fig. 1). We suggest EdgeFET as short name for this device. We have made DC comparison studies between FinFETs and EdgeFETs, which will be explained in details. Moreover, for both types of devices, we have performed the first photoresponse experiments at 140 GHz using the probe station setup and results will be discussed towards possibilities of THz resonant detection experiments. Such EdgeFET devices could be important in sense of research of high frequencies in applied and basic sciences.

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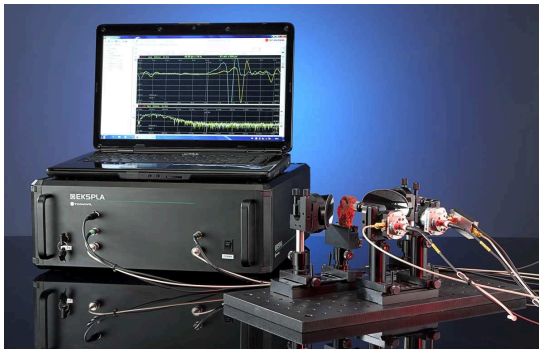

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