Apropos 17

Advanced Properties and Processes in Optoelectronic Materials and Systems
30 September – 1 October, 2020

Sattelite Event

Lithuania-Poland Workshop
on Physics and Technology

CONFERENCE PROGRAMME

Center for Physical Sciences and Technology (FTMC), Vilnius, Lithuania
Venue: FTMC at Sunrise Valley, Saulėtekio Ave. 3, Vilnius, Lithuania

30 September		
8:00-9:00		REGISTRATION
9:00-9:15		**CONFERENCE OPENING CEREMONY** **Gintaras Valušis** Director of Center for Physical Sciences and Technology Chair of Apropos 17 conference
9:15-10:35		**Section 1: Semiconductor nanostructures and advanced photonics systems** **Chair Prof. *Carlito Jr.Salonga Ponseca***
9:15-9:45	**Inv 1**	**Linas Minkevičius** *(Center for Physical Sciences and Technology, Vilnius, Lithuania)* Review of innovative diffractive elements for Terahertz imaging applications
9:45-10:15	**Inv2**	**Ramūnas Aleksiejūnas** *(Vilnius University, Lithuania)* Impact of alloy disorder induced localization on hole diffusion in highly excited c-plane and m-plane InGaN quantum wells
10:15-10:35	O1	Janusz Sadowski (*University of Warsaw, Institute of Physics, Warsaw, Poland, Linnaeus University, Sweden)* MoTe2 transition metal dichalcogenide grown by molecular beam epitaxy – polytypes, structural and electrical properties
10:35-11:00		**Coffee break**
11:00-13:00		**Section 2: Nano and Biophotonics** **Chair Dr. *Kaibo Zheng***
11:00-11:30	**Inv3**	**Šarūnas Meškinis** *(Kaunas University of Technology, Lithuania)* Direct synthesis of the graphene on Si(100) substrate for solar cell applications

11:30-12:00	**Inv4**	**Dovydas Banevičius** *(Vilnius University, Lithuania)* Naphthyridine-based deep-blue TADF OLEDs with low efficiency roll-off
12:00-12:20	O2	Rusnė Ivaškevičiūtė-Povilauskienė *(Center for Physical Sciences and Technology, Vilnius, Lithuania)* All-optical modulation of graphene layers
12:20-12:40	O3	Lena Golubewa *(Center for Physical Sciences and Technology, Vilnius, Lithuania)* Raman spectroscopic investigation of multi-walled carbon nanotubes mediated neutrophil activation
12:40-13:00	O4	Adil Rehman (*Institute of High Pressure Physics, Warsaw, Poland*) Modulation of electrical and noise characteristics of carbon nanotubes based devices
13:00-14:00		**Lunch**
14:00-15:50		***Special session:*** **Ultrafast THz techniques** **Chair Dr.** ***Ignas Grigelionis***
14:00-14:30	**Inv5**	**Carlito S. Ponseca, Jr.** (*Linköping University, Sweden*) - Ultrafast transient spectroscopy of organic and hybrid solar cells
14:30-14:50	O5	Kaibo Zheng *(Lund University, Sweden, Technical University of Denmark, Danmark)* Ultrafast spectroscopy of Quantum dot solar cells
14:50-15:10	O6	Ričardas Norkus *(Center for Physical Sciences and Technology, Vilnius, Lithuania)* Terahertz emission from a bulk GaSe crystal excited by above-bandgap photons
15:10-15:30	O7	Daniil Pashnev *(Center for Physical Sciences and Technology, Vilnius, Lithuania)* Investigation of two-dimensional plasma resonances in grating-gated AlGaN/GaN heterostructures by terahertz time domain spectroscopy
15:30-15:50	O8	Marek Maciaszek (*University of Warsaw, Poland)* On the origin of the 4.1 eV luminescence in hexagonal boron nitride
15:50-16:15		**Coffee break**
16:15-18:20		**Section 1: Semiconductor nanostructures and advanced photonics systems** **Chair Prof.** ***Šarūnas Meškinis***
16:15-16:45	**Inv6**	**Tadas Malinauskas** *(Vilnius University, Lithuania)* Remote epitaxy of GaN via Graphene
16:45-17:05	O9	Ivan Yahniuk (*Institute of High Pressure Physics, Warsaw, Poland*) Temperature-& Pressure-induced transitions in HgTe QWs
17:05-17:20	O10	Roman M. Balagula *(Center for Physical Sciences and Technology, Vilnius, Lithuania)* Annealing-induced reduction of strain in GaAs/GaNAs core-shell nanowires
17:20-17:40	O11	Andrea Zelioli *(University of Modena, Italia)* GaInAs/GaAs Quantum Structures For Near Infrared Vertical-External-Cavity Surface-Emitting Lasers
17:40-18:00	O12	Simona Pūkienė *(Center for Physical Sciences and Technology, Vilnius, Lithuania)* A3-B5 QW structures for IR range optoelectronic devices
18:00-19:30		**Poster session (18 posters)** **Coffee and Snaps**

1 October		
9:00-11:00		***Satellite Event:*** **Lithuanian Polish Workshop** **Chair Prof. *Janusz Sadowski***
9:00-9:10		**WORKSHOP OPENING CEREMONY** Ambassador Urszula Doroszewska, Embassy of Poland Jerzy Łusakowski (Chair from Poland)
9:10-9:35	**Inv7**	**Nerija Žurauskienė** *(Center for Physical Sciences and Technology, Vilnius, Lithuania)* Magnetoresistance Relaxation Phenomena in Nanostructured Lanthanum Manganite Films
9:35-10:00	**Inv8**	**Wojciech Pacuski** (*University of Warsaw, Poland)* Narrow excitonic lines and large-scale homogeneity of transition metal dichalcogenides grown by MBE on hBN
10:00-10:20	O13	Maksym Dub (*Institute of High Pressure Physics, Warsaw, Poland*) Graphene gate GaN/AlGaN field effects transistors for THz detection
10:20-10:40	O14	Maria Szoła (*Institute of High Pressure Physics, Warsaw, Poland*) THz magnetospectroscopy of HgCdTe bulk crystals with different Cd content
10:40-11:00	O15	Paweł Komorowski (*Warsaw University of Technology, Poland*) Machine learning enhanced design of diffractive optical elements
11:00-11:25		**Coffee break**
11:25-13:05		**Section 3: Ultrafast and THz phenomena** **Chair Dr. *Linas Minkevičius***
11:25-11:55	**Inv9**	**Alvydas Lisauskas** (*Vilnius University and Institute of High Pressure Physics, Warsaw, Poland)* THz detectors and sources fabricated with CMOS technologies
11:55-12:25	**Inv10**	**Guillaume Ducournau** *(Université Lille, France)* THz communications and advanced RF characterization enabled by THz photonics
12:25-12:45	O16	Dmytro B. But (*Institute of High Pressure Physics, Warsaw, Poland*) Antenna Characterization of Monolithically Integrated Detectors for 0.62 THz
12:45-13:05	O17	Domas Jokubauskis *(Center for Physical Sciences and Technology, Vilnius, Lithuania)* Phase contrast sub THz imaging and applications
13:05-14:00		**Lunch**
14:00-15:50		**Section 3: Ultrafast and THz phenomena** **Chair Prof. *Alvydas Lisauskas***
14:00-14:30	Inv11	**Vincas Tamošiūnas** *(Center for Physical Sciences and Technology, Vilnius, Vilnius University, Lithuania)* Reflectance spectra of selective emitter solar cells in terahertz and sub-terahertz ranges
14:30-14:50	O18	Dmitri V. Lioubtchenko (*KTH Royal Institute of Technology, Stockholm, Sweden)* Effect of lengths, diameters, and density of silver nanowire layers on terahertz conductivity

14:50-15:10	O19	Ieva Žičkienė *(Center for Physical Sciences and Technology, Vilnius, Lithuania)* Terahertz radiation induced by surface ballistic photogalvanic effect in GaAs LIPSS structures
15:10-15:30	O20	Pavlo Sai (*Institute of High Pressure Physics, Warsaw, Warsaw University of Technology, Poland*) AlGaN/GaN dual grating gate structures investigated in high magnetic field
15:30-15:50	O21	Vladislovas Čižas *(Center for Physical Sciences and Technology, Vilnius, Lithuania)* Fractional frequencies in microwave response of GaAs/AlGaAs superlattices
15:50-16:15		**Coffee break**
16:15-17:35		**Section 4: Organics for Optoelectronics** **Chair Dr. Prof. *Nerija Žurauskienė***
16:15-16:35	O22	**Yuri Svirko** *(University of Eastern Finland, Joensuu, Finland)* Light-induced currents and THz emission from graphene
16:35-16:55	O23	Ernesta Poceviciute *(Center for Physical Sciences and Technology, Vilnius, Lithuania)* Studies of Receptor and Its Ligand Interaction Using FRET and TIRF Microscopy
16:55-17:15	O24	Edvinas Navakauskas *(Center for Physical Sciences and Technology, Vilnius, Lithuania)* Structure determination of HEWL protein aggregates at liquid interfaces
17:15-17:35	O25	Wanessa Melo *(Center for Physical Sciences and Technology, Vilnius, Lithuania)* Antimicrobial photodynamic therapy: an alternative to overcome the biofilm resistance
17:40		**Closing Remarks**

Inv1

Review of innovative diffractive elements for Terahertz imaging applications

Linas Minkevičius[1], Domas Jokubauskis[1], Simonas Indrišiūnas[1], Vincas Tamošiūnas[1, 2], Sergej Orlov[1], Irmantas Kašalynas[1], Gediminas Račiukaitis[1] and Gintaras Valušis[1]

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Miniaturization of terahertz (THz) imaging systems is a key-factor for increasing applicability in mobile unattended package inspection systems in airports or public places [1]. Practical potential of THz imaging systems for non-destructive testing encourage a search for a compact and practically convenient solutions. One of the most lucrative solutions is the development of compact diffractive optics for the THz frequency range in order to boost the evolution of practical hand-held terahertz imaging systems applications in real time.

In a given communication, variety solutions of compact diffractive optics, produced with laser direct writing technology [2] are considered. Molybdenum film-based THz zone plates with integrated band-pass filters [3], high efficiency multilevel silicon phase Fresnel zone plates [4] for advanced THz optics up to 4.7 THz [5], are discussed. Focusing performance of these elements are investigated both, theoretically and experimentally. Routes of thick objects THz imaging with inconvenience of precise positioning of the sample using silicon-based Fibonacci [6] and Bessel diffractive elements [7] providing a 2×λ spatial resolution will be also discussed (Fig. 1).

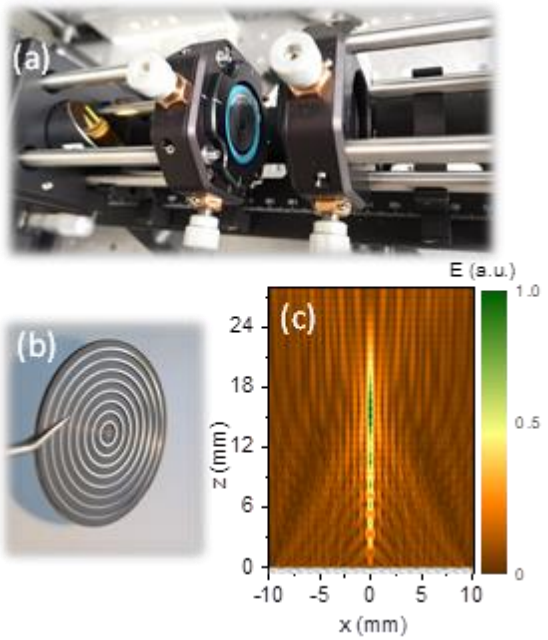

Fig. 1 The photo of innovative terahertz imaging system (a) containing thin silicon-based Bessel zone plates (b) for the 0.6 THz. Bessel beam electric field reconstruction at 0.6 THz along the beam propagation path.

REFERENCES

[1].X. Yang et al. Signal Processing, **160** (2019) pp.202–214.
[2].B. Voisiat et al. *Proc. of SPIE*, (2017) **10091**(10 1117/12.2253634) pp. 100910F
[3].L. Minkevičius et al. *J. Infrared, Millimeter, Terahertz Waves* **35**(9) (2014) pp. 699-702
[4] L. Minkevičius et al, *Optics Letters* **42**(10) (2017) pp. 1875-1878
[5].S. Indrisiunas et al. *Optics Letters* **44**(5) (2019) pp. 1210-1213
[6] D. Jokubauskis et al *Optics Letters* **43**(12) (2018) pp. 2795-2798
[7] L. Minkevičius et al. Optics. Express **27**(25) (2019) pp. 36358

Inv2

Impact of alloy disorder induced localization on hole diffusion in highly excited c-plane and m-plane InGaN quantum wells

Ramūnas Aleksiejūnas,[1] Kazimieras Nomeika,[1] Oleg Kravcov,[1] Saulius Nargelas,[1] Leah Kuritzky,[2] Cheyenne Lynsky,[2] Shuji Nakamura,[2] Claude Weisbuch,[2,3] and James S. Speck[2]

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A mystery remains how internal quantum efficiency of InGaN can reach 90% despite a typical dislocation density exceeding 10^8 cm^{-2} [1]. It was proposed that this may be due to carrier localization [2]; however, the detailed mechanism of this phenomenon remains undisclosed. Since holes are strongly localized in InGaN [3], new knowledge may be attained by measuring their diffusion coefficient, *D*. Here, we investigate the dependence of *D* on direction and carrier density in c-plane and m-plane InGaN structures by employing the light-induced transient grating technique. We show that *D* is anisotropic in the m-plane structures due to hole effective mass anisotropy in biaxially strained layers. Also, *D* changes non-monotonously with photoexcitation (Fig. 1), this dependence being different in thick and thin layers. We argue that unexpectedly high diffusion coefficient at low carrier densities in thick QWs can be a signature of efficient hole transport via percolative paths occurring due to compositional disorder. In turn, a decrease of diffusivity with excitation can reflect the effect of Coulomb blockade of these paths. Finally, we demonstrate that disorder impacts carrier diffusivity even at carrier densities above 10^{19} cm^{-3}, where the overflow of localized states must be included to explain the observed increase of diffusion coefficient with carrier density.

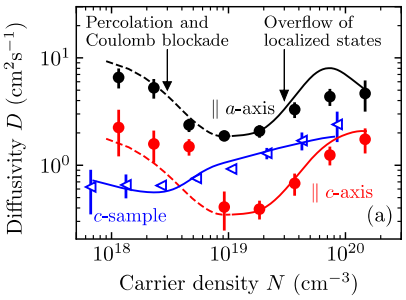

Fig. 1. The dependence of diffusion coefficient *D* on carrier density *N* in thick m-plane and thin c-plane MQW structures

REFERENCES

[1] C. Weisbuch, ECS J. Solid State Sci. Technol. 9, 016022 (2019).
[2] S. Chichibu, T. Azuhata, T. Sota, and S. Nakamura, Applied Physics Letters 69, 4188 (1996).
[3] S. Schulz, M. A. Caro, C. Coughlan, and E. P. O'Reilly, Physical Review B 91, 035439 (2015).

O1

$MoTe_2$ transition metal dichalcogenide grown by molecular beam epitaxy – polytypes, structural and electrical properties

Janusz Sadowski[1,2,3], Bartłomiej Seredyński[1], Zuzanna Ogorzałek[1], Sławomir Kret[2], Rafał Bożek[1], Marta Gryglas-Borysiewicz[1] and Wojciech Pacuski[1]

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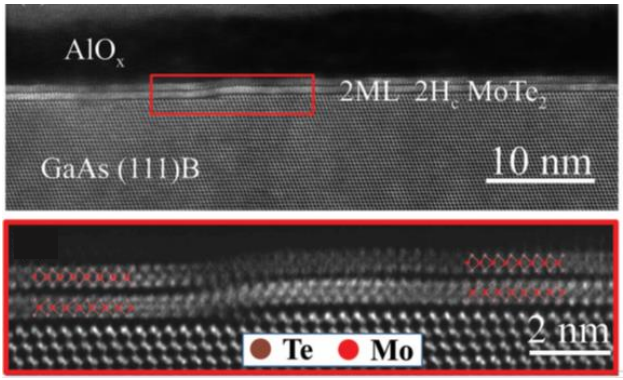
$MoTe_2$ belongs to layered transition metal dichalcogenides (TMD) which, due to their unique optoelectronic properties, gained a tremendous attention of condensed matter research community over the last few years [1]. Excellent optical properties of single molecular layers of semiconducting TMDs, makes them suitable for applications in flexible optoelectronics. The high sensitivity of electric properties of ultra-thin layers of semiconducting and metallic TMDs to external factors such as electrical gating, pressure, chemical environment enables their use for numerous applications. Constantly new TMD materials are synthesized and extensively investigated [2].

Fig.1. Cross-sectional transmission electron microscopy images of AlO_x capped $MoTe_2$ bilayer grown by MBE on GaAs(111B) substrate.



Here we report on the growth of $MoTe_2$ - a representative of semiconducting, (metallic) TMD (depending on the crystallographic phase). We have grown thin MoTe2 layers by molecular beam epitaxy (MBE) - a technique, widely used both for research purposes and in the optoelectronic industry. MBE enables growth on large area substrates – up to 3-inches in our case. The growth proceeds in ultra-clean ultrahigh vacuum environment and is controlled in-situ with reflection high energy electron diffraction (RHEED). In contrast to other TMD materials $MoTe_2$ is quite sensitive to oxidation on exposure to ambient conditions. We show how to protect very thin $MoTe_2$ films (bilayers) against degradation by in-situ deposition of thin capping layers. Using this method we obtain large area ultrathin $MoTe_2$ layers (monolayers, bilayers) stable in air [3]. We have investigated structural and electrical properties of $MoTe_2$ bilayers MBE-grown on GaAs(111)B substrates and capped with thin (~5 nm) AlO_x (see Fig.1).

REFERENCES

[1] W. Choi, N. Choudhary, G. H. Han, J. Park, D. Akinwande and Y. H. Lee; *Mat. Today* **20** (2017) pp. 116-130.
[2] Xiao Zhang, Zhuangchai Lai, Qinglang Ma and Hua Zhang; *Chem. Soc. Rev*. **47** (2018) pp. 3301-3338.
[3] Z. Ogorzałek, B. Seredyński, S. Kret, A. Kwiatkowski, K. P. Korona, M. Grzeszczyk, J. Mierzejewski, D. Wasik, W. Pacuski, J. Sadowski and M. Gryglas-Borysiewicz. *Nanoscale* **12**, (2020) pp.16535-16542.

Inv3

Direct synthesis of the graphene on Si(100) substrate for solar cell applications

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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. Graphene is already considered as a new transparent conductor, monolayer alternative to the Schottky contact metals and even as an active layer of the semiconductor devices. Particularly graphene is intensively explored as a new photovoltaic material for the fabrication of the various solar cells. The list is pretty long: monocrystalline silicon, inorganic chalcogenide thin film, organic, perovskite, dye sensitized solar cells can be mentioned.

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, follows the long process of the graphene transfer onto the targeted semiconductor or dielectric substrates. During that process, graphene can be contaminated by different adsorbents. Transfer causes 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, the development of this technology is the very beginning.

In the present research graphene layers were directly synthesized by microwave plasma enhanced chemical vapor deposition on the semiconducting monocrystalline Si(100) substrates. The structure of the films was investigated by Raman scattering spectroscopy and atomic force microscopy. A number of the graphene layers was evaluated by using Raman scattering spectroscopy and optical reflectance spectra. Graphene/Si(100) Schottky diodes were fabricated.

The effects of the deposition conditions on the structure of the graphene layers were studied. The influence of the nitrogen and fluorene doping was considered. There were revealed that both vertical graphene flakes and planar graphene layers can be synthesized by setting appropriate deposition conditions. Graphene grown on textured silicon surface was studied. Current-voltage characteristics, as well as photovoltaic and photoelectric properties of the different graphene/Si(100) diodes and solar cells, were investigated.

Inv4

Naphthyridine-based deep-blue TADF OLEDs with low efficiency roll-off

Dovydas Banevičius[1], Gediminas Kreiza[1], Justina Jovaišaitė[1], Saulius Juršėnas[1], Tomas Javorskis[2], Vytenis Vaitkevičius[2], Edvinas Orentas[2] and Karolis Kazlauskas[1]

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Thermally activated delayed fluorescent (TADF) emitters are extremely attractive due to their potential to harvest all triplet excitons via reverse intersystem crossing (rISC) process into the singlet manifold thereby ensuring 100% internal quantum efficiency [1]. However, due to pronounced charge-transfer character of TADF compounds, there are difficulties in achieving deep blue emission. Additionally, TADF-OLEDs suffer from early efficiency roll-off associated with high long-lived triplet exciton population. Therefore, TADF emitters with large rISC rate facilitating triplet up-conversion are required.

To this end, we designed new TADF emitters based on 1,8-naphthyridine acceptor (A) and differently substituted carbazole donor (D) groups [2]. Photophysical characterization of the compounds revealed high photoluminescence quantum yield (up to 86%) in mCP host with large rISC rates (up to 1.1×10^6 s^{-1}). We fabricated vacuum and solution processed TADF-OLEDs employing 7% naphthyridine-doped emissive layer. Devices exhibited deep blue emission with CIE colour coordinates (0.14, 0.16), external quantum efficiency of up to 17.6% and high brightness (up to 23000 cd/m^2). Most importantly, due to the large rISC rates TADF OLEDs demonstrated weak efficiency roll-off. The demonstrated emitters are among the best-performing conventional D–A-type blue/deep-blue TADF emitters in terms of EQE and efficiency roll-off properties of their devices.

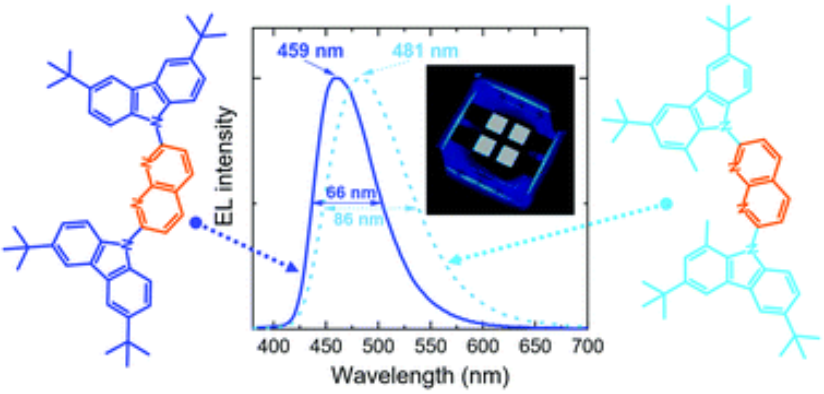

Fig. 1 Electroluminescence spectra of deep-blue and sky-blue TADF OLEDs produced utilizing naphthyridine-based emitters. Inset: picture of such working

REFERENCES

[1] H. Uoyama, K. Goushi, K. Shizu, H. Nomura, and C. Adachi, *Nature* **492**, 234. (2012).
[2] G. Kreiza, D. Banevičius, J. Jovaišaitė et al, *J. Mater. Chem. C* ***8***, 8560-8566. (2020).

O2

All-optical modulation of graphene layers

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Attractive graphene optical properties make it a desirable material for terahertz (THz) range optics. Since it is almost completely transparent in this frequency region, it has to be modulated in order to make it suitable for a functional optical element. It is known that graphene transmittance can be controlled by using electrical, chemical, thermal or optical doping [1].

In this work all-optical modulation is chosen as contactless approach.

In order to investigate the optical modulation of graphene, three types of samples are fabricated. The first one is a high resistive silicon (Si) wafer, which serves as a reference. The second sample is a single graphene layer on top of Si substrate. Since the first layer strongly interacts with a wafer, it's characteristics worsen [2]. Because of this reason, the third sample is made with two graphene layers on Si.

Using THz frequency-domain spectrometer, transmittance spectra is measured, an example of which is depicted in Fig. 1. Results show that after photoexcitation modulation maximum depth for the sample with two graphene layers goes up to 42%. It is shown that application of the second graphene layer can increase the depth of optical modulation.

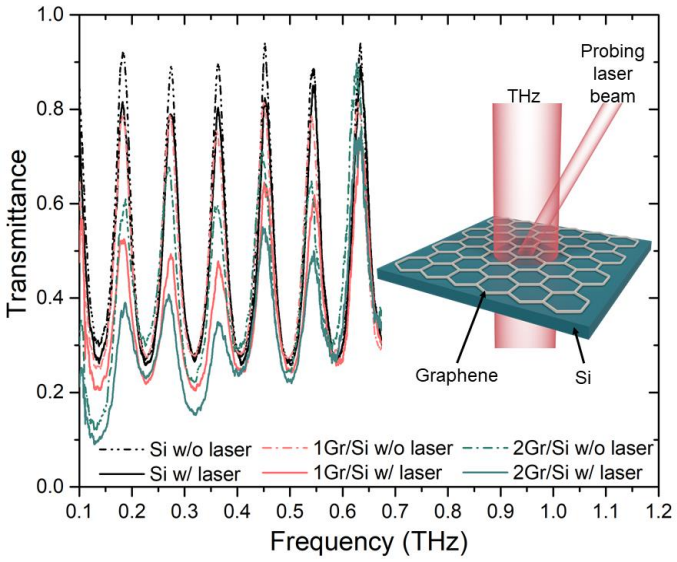

Fig. 1 Transmittance spectra of samples. Inset depicts the principal experiment scheme

Photomodulation features of graphene-on-silicon prepared using different technological approaches will be discussed.

REFERENCES

[1] R. Binder; *Optical properties of graphene*, University of Arizona, USA (2017).

[2] M. Aliiofkhazraei, N. Ali, W. I. Milne, C. S. Ozkan, S. Mitura, J. L. Gervasoni; *Graphene science book. Mechanical and chemical properties*, CRC Press (2016).

O3

Raman spectroscopic investigation of multi-walled carbon nanotubes mediated neutrophil activation

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Neutrophils are key players in phagocytosis, during which foreign objects are encapsulated by cells and destroyed in phagolysosomes with the help of reactive oxygen and chlorine species, and cytotoxic, proteolytic enzymes of granules. Multi-walled carbon nanotubes (MWCNT) are promising nanomaterials for nanotheranostics. MWCNTs administration may lead to the immune system response and cause inflammation. Using Raman spectroscopy, we demonstrate the neutrophil activation after exposure to MWCNTs. Fig. 1a shows the Raman spectrum of a neutrophil adhered to the glass. The lines at 1465 cm^{-1} and 1669 cm^{-1} correspond to myeloperoxidase (MPO) with an oxidized redox center of the enzyme, and lines 1167 cm^{-1} and 1399 cm^{-1} correspond to cytochrome b_{558} with an oxidized redox center. As a result of the neutrophil interaction with MWCNTs, a shift of characteristic lines in the spectra occurred, indicating the reduction of the redox center of both MPO and cytochrome b_{558} (Fig. 1b). Near to the neutrophils adhered to the glass, structures of smaller sizes are registered, the Raman spectrum of which is shown in Fig. 1c. In addition to the characteristic lines of CNTs, the 1632 cm^{-1} line indicating the presence of MPO with a reduced redox center in these structures, and the lines indicating the presence of other structural components of neutrophils (proteins: 1133 cm^{-1}, 1165 cm^{-1}, 1244 cm^{-1}, 2338 cm^{-1}; DNA: 1379 cm^{-1}; lipids: 2901 cm^{-1}) are determined. This designates, that interaction of MWCNTs with neutrophils initiates the formation of neutrophil extracellular traps, consisting of chromatin fibers, including the enzymes neutrophilic elastase and MPO [1].

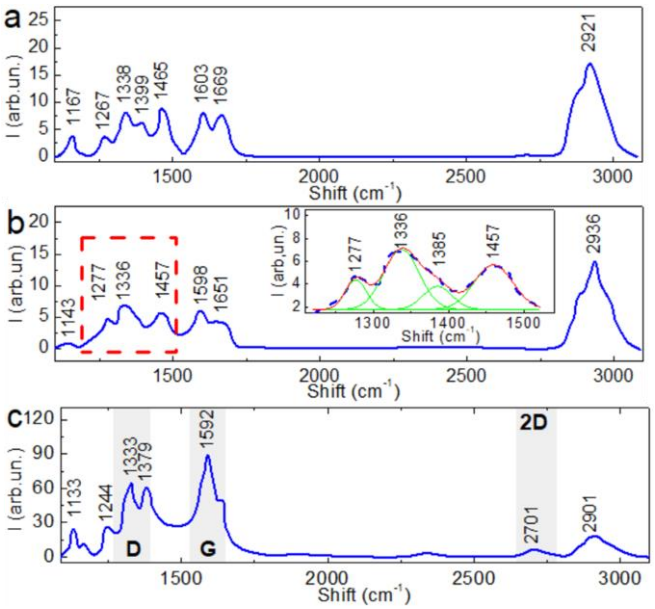

Fig. 1 Raman spectra of (a) – neutrophil, (b) – activated with MWCNTs neutrophil, (c) – NET with MWCNTs

REFERENCES

[1] G. Sollberger, D.O. Tilley, A. Zychlinsky, *Dev. Cell.* **44** (2018) pp. 542–553.

O4

Modulation of electrical and noise characteristics of carbon nanotubes based devices

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Noise originating from electronic devices has significant importance and plays a vital role to understand the general physics behind the device operation. Here, we investigate the low-frequency noise characteristics of carbon nanotubes based devices. Raman, UV-Vis-NIR and scanning electron microscopes are employed for structural and optical characterization of nanotube networks. The noise amplitude (A) in most of our devices is smaller than predicted by Collins relation (i.e. $A \sim 10^{-11} \times R$) [1]. Our results also reveal that quality of nanotube networks can significantly affect the noise amplitude of the devices. This implies that noise spectroscopy can be used to study the defects or distortion in nanotube networks.

The resistance and noise characteristics of carbon nanotubes devices are modulated via back-gate voltages and UV illumination. It is observed that UV illumination increases the device resistance and noise amplitude, while preserving the spectra shapes. The possible effect of temperature increase under UV illumination is excluded by measuring the resistance and noise spectra at elevated temperature. We propose an equation (1) to explain the change in the spectral noise density (S_I/I^2) of nanotube networks under UV illumination and at elevated temperature.

$$\frac{S_I}{I^2} = \frac{R_0}{(R_0+R_n)} \frac{S_{Rn}}{R_n^2} \quad \text{..... (1)}$$

Here, R_0 and R_n denote noiseless and fluctuating resistors, respectively whereas S_{Rn}/R_n^2 represents spectral noise density of the resistance R_n fluctuations. Our study conclude that there are at least two important components of the resistance that contribute into total resistance of nanotube networks rather than generally accepted only tube to tube interconnects [2, 3].

REFERENCES

[1] P. G. Collins, M. Fuhrer and A. Zettl, *Applied Physics Letters*, **76**, 894-896 (**2000)**.
[2] S. Soliveres, J. Gyani, C. Delseny, A. Hoffmann and F. Pascal, *Applied physics letters*, **90**, 082107 (**2007)**.
[3] G. Sassine, F. Martinez, M. El Khoury, F. Pascal and A. Hoffmann, *IEEE transactions on electron devices*, **59**, 2803-2808 (**2012)**.

XX

Understanding the Role of Vibronic Coherence in the Ultrafast Charge Carrier Dynamics of Photovoltaic Materials

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Efforts in understating the ultrafast processes of charge carriers in photovoltaic materials have greatly contributed in the design of solar cell devices that led to higher power conversion efficiency. Early time dynamics such as charge generation, injection and recombination are now almost well-described in most photovoltaic devices. However, the interaction between lattice motion, or vibrational modes of molecules, with charge carriers has not been explored until recently. In this talk, the role of this interaction, i.e. vibronic coherence will be presented on two solar cell materials; ternary organic solar cells[1] and single crystal organo-metal halide perovskites.[2] We surmised that despite the short coherence time between charge carriers and phonons/vibrations, this ultrafast interaction is enough to influence the lifetime and/or charge separation processes.

REFERENCES

[1] Q. Bian, F. Ma, S. Chen, Q. Wei, X. Su, I. A. Buyanova, W. M. Chen, C. S. Ponseca, Jr., M. Linares, K. J. Karki, A. Yartsev, O. Inganäs, *Nature Communications* **11** (2020) pp. 617.
[2] Y. Lan, B. J. Dringoli, D. A. Chavez, C. S. Ponseca, Jr., M. Sutton, Y. He, M. G. Kanatzidis, D. G. Cooke, *Science Advances* **5** (2019) eaaw5558.

XX

Ultrafast excited state dynamics in low-dimensional perovskite nanostructures

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Lead halide perovskites (LHP) have been highly spotted as promising optoelectronic materials for one decade. Derived from their bulk counterparts, low-dimensional LHP nanostructures introduced new photophysical advances that may break the bottlenecks set by the conventional LHPs. For instance, two-dimensional Roddlesden-Popper LHPs are believed to provide high stability towards moisture that used to be the main issues for the solar cell application of LHPs. LHP nanoparticles, on the other hand, can achieve almost unity photoluminescence quantum yield with tunable emission wavelength. However, the low-dimensionality would also drastically change the electronic structures of the LHPs, and consequently modify the photophysics. There always remains a trade-off between the two sides. Therefore, obtaining a systematic picture on the excited state dynamics as well as its dependence on the structures of the low-dimensional LHPs become vital for their device application. We utilized a variety of time-resolved spectroscopic technics with wide range of time windows and probe wavelengths to investigate some crucial photophysical processes of low-dimensional LHPs including their charge carrier transport and recombination, defect trapping and de-trapping, hot electron cooling, polaron formation, inter-phase charge transfer or energy transfer, etc. These helps to rationalize the underlying mechanism when they are applied in specific devices. We also put special focus on the systematic comparison between low-dimensional LHPs and bulk LHPs. We expect this would provide new guidance for further material engineering and device optimization.

REFERENCES

[1] K. Zheng, Q. Zhu, M. Abdellah, M.E. Messing, W. Zhang, A. Generalov, Y. Niu, L. Ribaud, S.E. Canton, and T. Pullerits*, J. Phys. Chem. Lett.* **6** (2015), 2969.
[2] K. Zheng, M. Abdellah, Q. Zhu, Q. Kong, G. Jennings, C.A. Kurtz, M.E. Messing, Y. Niu, D.J. Gosztola, M.J. Al-Marri, X. Zhang, T. Pullerits, and S.E. Canton, *J. Phys. Chem. Lett.* **7** (2016) 4535.
[3] K. Zheng, K. Žídek, M. Abdellah, J. Chen, P. Chábera, W. Zhang, M.J. Al-Marri, and T. Pullerits, *ACS Energy Lett.* **1** (2016) 1154.
[4] Y. Chen, Y. Sun, J. Peng, W. Zhang, X. Su, K. Zheng, T. Pullerits, and Z. Liang, *Adv. Energy Mater.* **7** (2017) 1700162.
[5] K. Zheng, Y. Chen, Y. Sun, J. Chen, P. Chábera, R. Schaller, M.J. Al-Marri, S.E. Canton, Z. Liang, and T. Pullerits, *J. Mater. Chem. A* **6** (2018) 6244.
[6] J. Meng, Z. Lan, M. Abdellah, B. Yang, S. Mossin, M. Liang, M. Naumova, Q. Shi, S.L. Gutierrez Alvarez, Y. Liu, W. Lin, I.E. Castelli, S.E. Canton, T. Pullerits, and K. Zheng, *J. Phys. Chem. Lett.* **11** (2020).

O6

Terahertz emission from a bulk GaSe crystal excited by above-bandgap photons

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Gallium selenide is a layered III-VI semiconductor crystal, and the layers are stacked together by a weak van der Waals force. GaSe is widely used as non-linear optical crystal for infrared and THz generation and electrooptic sampling [1]. Also recently it has attracted interest as it has potential application as photoelectric devices that operate in the visible range [2].

One of the methods to study band structure of a semiconductor is THz emission spectroscopy (TES). Technique was already used to determine band structure parameters such as subsidiary valley position [3] and heterojunction offset value. Many materials were already investigated most of them III-VI semiconductors.

Experiments were done using ~50 μm thick p-type GaSe sheets cleaved from the Bridgman grown crystal. TES spectras of these crystals were measured with different excitation polarizations (fig. 1). THz generation starts near the bandgap (~2eV) of GaSe, then generation efficiency increases up to ~ 2,3 eV, the later efficiency drop could be explained by scattering to subsidiary valleys. When excitation energy reaches ~3 eV THz pulse amplitude starts to increase again due to excitation from lower laying valence band. THz pulse amplitude dependence on azimuthal angle above band-gap shows emission due to effect related to the crystal anisotropy.

In this work GaSe subsidiary valley position was determined - 0,21 eV.

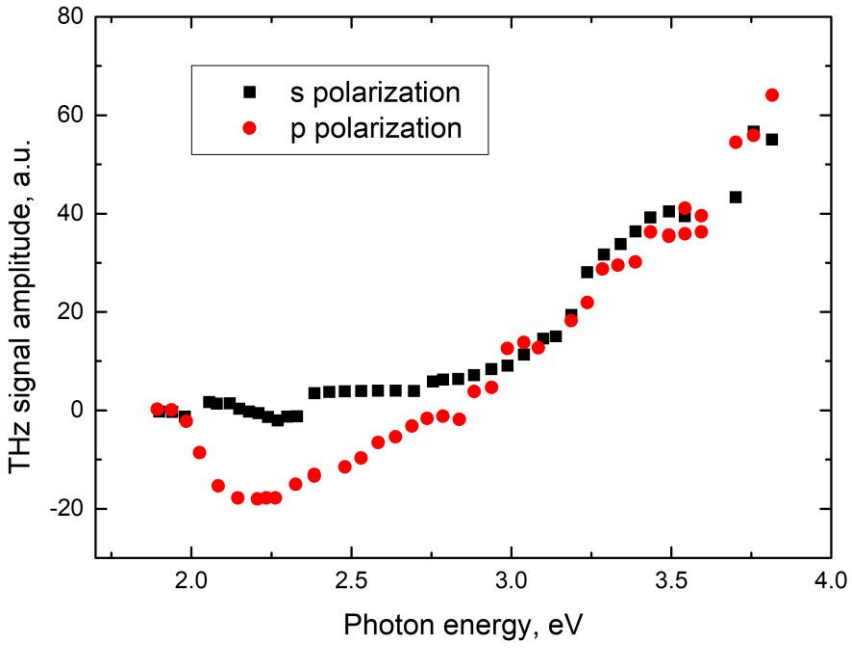

Fig. 1 TES spectra of p- type GaSe excited by 30 degrees angle to the surface normal

REFERENCES

[1] K. Liu, J. Xu, and X.-C. Zhang, “GaSe crystals for broadband terahertz wave detection”, Appl. Phys. Lett. 85, 863 (2004).

[2]S. Sorifi, M. Moun, S. Kaushik,and R. Singh, “High-Temperature Performance of a GaSe Nanosheet-Based Broadband Photodetector”, ACS Applied Electronic Materials, 2, 670-676 (2020).

[3] A. Arlauskas, A. Krotkus, “THz excitation spectra of AIIIBV semiconductors”, Semicond. Sc. Technol., 27, 115015 (2012)

O7

Investigation of two-dimensional plasma resonances in grating-gated AlGaN/GaN heterostructures by terahertz time domain spectroscopy

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Exclusive electrical robustness and relatively high electron mobility make III-nitride heterostructures an excellent candidate for the development of plasmonic terahertz (THz) devices [1, 2]. Excitation of 2D plasmons in grating-gated heterostructures has been studied by a Fourier transform infrared spectroscopy only [2, 3]. Meanwhile, THz time domain spectroscopy is a powerful technique used to investigate the material properties measuring both signal amplitude (power) and phase spectra in transmission and reflection geometry [4].

In this work, the power and phase spectra of THz pulses transmitted through the 2D electron plasma in grating-gated AlGaN/GaN structures were investigated in the frequency range 0.1-4 THz by using the T-SPEC 800 spectrometer (from TeraVil). The samples were fabricated of standard AlGaN/GaN high electron mobility transistor (HEMT) structures grown on a 500 μm-thick semi-insulating SiC substrate. Periodic metal grating of 2x2 mm size and 50% filling factor was used for efficient radiation coupling with 2D plasmons. Samples with three different grating periods of 600, 800, and 1000 nm were investigated at 80K.

Resonant excitation of the 2D plasmons was experimentally observed for all samples in the frequency range of 1-3 THz. The features were perceived as the emergence of distinctive minimum and inflection point in the power and phase spectra, respectively. In the case of the samples with grating period of 1000 and 600 nm, the resonance position was found at 1.4 THz and 2.2 THz, respectively. The latest is the largest value of fundamental 2D plasmon mode that has been observed experimentally so far in AlGaN/GaN HEMT structures [5]. Due to resonant THz radiation coupling, the deviation from a nominal value of transmitted power and phase was found up to 30 % and 8 deg, respectively. The quality factor of 2D resonances was estimated to be up to 4. Comparative analysis of amplitude and phase spectra revealed that the phase signal was less sensitive to the defects of the grating-coupler. The resonant features were also simulated in the framework of the rigorous solution of the Maxwell equations [6, 7].

REFERENCES

[1] M. Bauer et. al., IEEE Trans. Terahertz Sci. Technol. 9, 430 (2019)
[2] V.A. Shalygin et. al., J. Appl. Phys. 126, 183104 (2019).
[3] A.V. Muravjov et. al., Appl.Phys.Lett. 96, 042105 (2010).
[4] I. Pupeza et. al., Opt. Express 15(7), 4335 (2007)
[5] D. Pashnev et. al., Appl. Phys. Lett. 117, 051105 (2020); https://doi.org/10.1063/5.0014977
[6] S. A. Mikhailov, Physical Review B, 58(3), (1998)
[7] V.V. Korotyeyev et al, SPQEO 22(2), 237-251 (2019)

Inv6

Remote epitaxy of GaN via Graphene

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Group-III nitrides are promising materials for next generation optoelectronic devices. Extensive effort has been made to optimize group-III nitride heteroepitaxy for many years. However, inherent lattice mismatch and thermal expansion difference between nitrides and foreign substrates is still a limitation for GaN quality. On the other hand, homoepitaxy is still economically rarely viable. Remote epitaxy via two-dimensional (2D) materials such as graphene would enable facile layer release from 2D surfaces preserving expensive bulk nitride substrate[1, 2]. Growth via graphene on the foreign substrates could potentially solve inherent problems of heteroepitaxy allowing relaxation of epilayer.

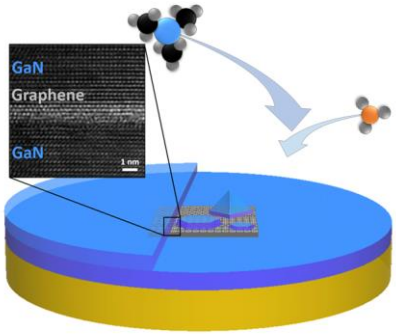

Fig. 1 The scheme of remote epitaxy of GaN via graphene on GaN/sapphire substrates. Inset shows TEM micrograph of GaN/graphene/GaN interface.

We investigated the MOCVD growth of GaN via graphene on different substrates GaN/sapphire and SiC substrates. We investigated wet and dry transfer of graphene onto GaN/sapphire substrate. The quality of transferred graphene was investigated by Raman spectroscopy using 535 nm laser, which confirmed the presence of monolayer graphene with low defect density.

Afterward, a close-coupled showerhead metalorganic chemical vapor deposition reactor (MOCVD) was used to grow GaN on graphene in several growth campaigns. Growth conditions such as temperature, pressure and V/III-ratio were varied in order to optimize GaN layer quality. The structural and optical properties of the grown epitaxial layers were investigated by X-ray diffraction, scanning and transmission electron microscopies, atomic force microscopy and photoluminescence techniques. Developed multi-step growth method ensured the successful growth of GaN films on GaN/sapphire templates with the presence of the graphene layer after all growth steps confirmed by Raman measurements.

REFERENCES

[1] Y. Kim et al., Remote epitaxy through graphene enables two-dimensional material-based layer transfer, Nature 544, 2017
[2]W. V. Lundin et al., Growth of III-N/graphene heterostructures in single vapor phase epitaxial process, J. Cryst. Growth 504, 2018

O9

Temperature-& Pressure-induced transitions in HgTe QWs

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In HgTe quantum wells (QWs), band structure properties of depend on QW widths. For thin quantum wells, conduction band forms by s-orbitals functions resulting from deep penetration of the wave function from CdTe side. Valence band is formed by p-type functions. With increasing of d_{QW} , an energy gap decreases, and when QW width reach critical thickness d_c, conduction band and valence touch each other at k = 0, i.e. the energy gap is equal zero. In case of $d_{QW} > d_c$ sequence of the energy states is inverted, first heavy-hole like subband H1 placed above the first electron-like E1 subband. Such band inversion in HgTe QWs suggests the existence of nontrivial topological insulator phase [1].

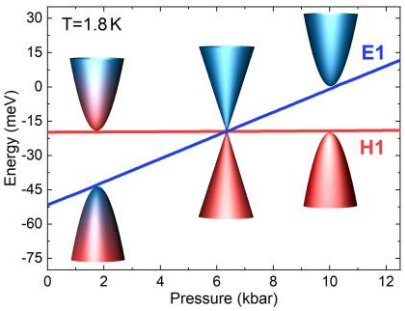

Fig. 1 The evolution of the both E1 and H1 sub-bands at k=0 against hydrostatic pressure for 8nm of HgTe QW grown in (031) crystallographic direction. Blue and red colors correspond to the electron-like E1, the light hole H1 subbands

For normal band ordering ($d < d_c$), an energy gap has tendency opens with applying of pressure [2]. The situation is distinguish in case of WQs with inverted band sequence. For example, in 8 nm of WQ, pressure increasing lead towards vanishing of E_g. At certain value of pressure, denoted as P_c, system is tuned to the band structure with massless Dirac fermions. Further pressure increasing yield to the band gap opening and system has the normal band sequence (see Fig.1). A temperature also can be regarded as external parameter that allow convert the band ordering.

In this work, we report on the clear observation of topological phase transition in HgTe QWs induced by temperature and hydrostatic pressure. Magnetotransport measurements allow us accurately extract critical magnetic fields B_c for various temperature and pressure values. By following the pressure (temperature) dependence of B_c, we define a critical points P_c, T_c, corresponding to the topological- trivial phase transitions.

REFERENCES

[1] M. König, S. et.al., Science 2007, 318, 766.
[2] S. S. Krishtopenko et al., Phys. Rev. B 2016, 94, 245402.

O10

Annealing-induced reduction of strain in GaAs/GaNAs core-shell nanowires.

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Core-shell nanowires (NWs) attract research attention because of their peculiar properties such as flexibility in growth substrates and alloy contents, controllable density of states, large surface-to volume ratio, and in-built potential for strain engineering. III-V nanowires investigated in this work are chosen because of the possibility of efficient variation of the bandgap owing to the giant-bandgap bowing effect observed in the dilute nitrides [1].

GaAs/GaNAs core/shell nanowires MBE-grown on Si substrates were investigated by means of polarization-resolved micro-photoluminescence (μ-PL) measurements. Obtained photoluminescence spectra of NW ensembles demonstrated broad peaks corresponding to nitrogen content of 2% in GaNAs active shell with exponential tails at low temperatures attributed to the localized exciton emission. Post-growth annealing resulted in increase in PL intensity owing to annealing-out of non-radiative defects. A change in localization potential was also observed that was attributed to improvement of long-range uniformity of GaNAs alloy.

Core-shell structures experience global strain owing to the lattice mismatch of core and shell materials [2]. This strain results in the splitting of hole subbands of the active shell that can be probed by means of polarization-resolved μ-PL measurements of single NWs mechanically transferred onto another Si substrate. The value of strain in the studied structures was estimated theoretically and experimentally along with the effects of annealing. The resulting emission from single NWs was predominantly polarized orthogonally to NW growth axis. The decrease in heavy hole-light hole splitting was observed in PL spectra of annealed NWs at room temperature demonstrating the reduction of global core-shell strain in the NWs.

Low-temperature PL spectra of single NWs contained sharp emission lines attributed to QD-like areas in NWs forming due to the nitrogen clustering in the GaNAs shell. The changes in fine structure of these sharp lines with annealing demonstrated the reduction of local strain in these areas as well.

As post-growth annealing is a frequent method of treatment of the semiconductor structures the observed effects of annealing should be considered when attempting the strain engineering approach to the device fabrication.

REFERENCES

[1] W. G. Bi and C. W. Tu, *Appl. Phys. Lett.* **70** (1997) pp. 1608–1610.
[2] J. Grönqvist, *et al.*, *J. Appl. Phys.* **106** (2009) pp. 053508.

O11

GaInAs/GaAs QUANTUM STRUCTURES FOR NIR VECSEL

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Laser devices find many different application in various technologies, such as optical fiber communication, optical digital recording, material processing, spectroscopy analysis and many others. Since when in 1960 the first laser was build, many different types of lasers where developed each of them with some peculiarities that made them suitable for different application. Some of the parameters that define the possible applications of laser in different fields are emission wavelength, beam quality, operation temperature, output power, methods of excitation, power consumption, speed of modulation and device size and the range of tunability of all of this characteristics. Vertical external cavity surface emitting lasers (VECSEL) do combine many different interesting properties and were designed to overcome some of the key issues of conventional semiconductors lasers, mainly low power output, output beam profile with unusual shape and big beam divergence. VECSELs are able to produce high optical output power with circular beam quality.

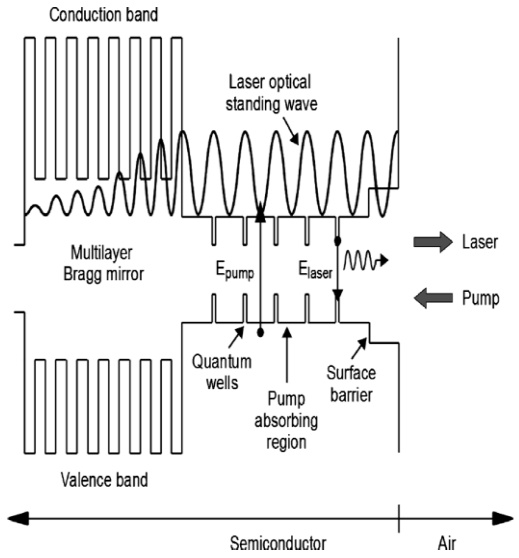

Fig. 1. Energy levels across the VECSEL structure [1].

In this work we investigated the growth parameter of VECSEL shown in figure 1 on a GaAs (001) substrate optimizing the structure for the emission at a wavelength of 976nm. Multiple InGaAs/GaAs quantum wells (MQWs) and AlAs/GaAs Distributed Bragg reflector (DBR) grown by solid MBE system were used for VECSEL architecture. During the optimization process In content, the width of QW and the width of barriers were changed. The reflectance of DBR was modelled for 25-30 GaAs and AlAs periods to obtain higher than 97% at central DBR wavelength of 976 nm. All grown layers and VECSEL structures were characterized by Atomic Force Microscopy, Reflectance and Photoluminescence measurements.

REFERENCES

[1] Mark Kuznetsov, VECSEL Semiconductor Lasers: A Path to High-Power, Quality Beam and UV to IR Wavelength by Design, Semiconductor Disk Lasers. Physics and Technology. Edited by Oleg G. Okhotnikov, 2010, WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim.

O12

A3-B5 QW structures for IR range optoelectronic devices

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A3-B5 family semiconductors, especially Bi containing GaAs compound, are currently under investigation because of important role in various optoelectronics devices, including lasers for optical fiber communications (1.3 μm and 1.55 μm), undersea, space, and high-data-rate applications (780 nm – 830 nm).

In this work, laser diode structures were grown by molecular beam epitaxy (MBE) using Veeco GENxplor R&D reactor on n-GaAs substrate. To optimize the multiple quantum well (MQW) structure for applications as an active area in infrared laser diodes, the complex investigation of influence of structure geometry (QW number, thickness, QW and barrier material) on LD parameters was performed. Since our previous work revealed that room temperature photoluminescence (RT-PL) can be increased by more than 50 times in the GaAsBi QWs using parabolic graded barriers, compared to standard rectangular quantum well (RQW) structures [1], two-design structures were epitaxially grown and characterized. Laser diodes were fabricated by a UV photolithography. The metal contacts were deposited by e-beam on top and bottom of laser crystal. The comparative study of LDs containing PQW and RQW structures was performed to clarify the role of architecture and to establish the key parameters.

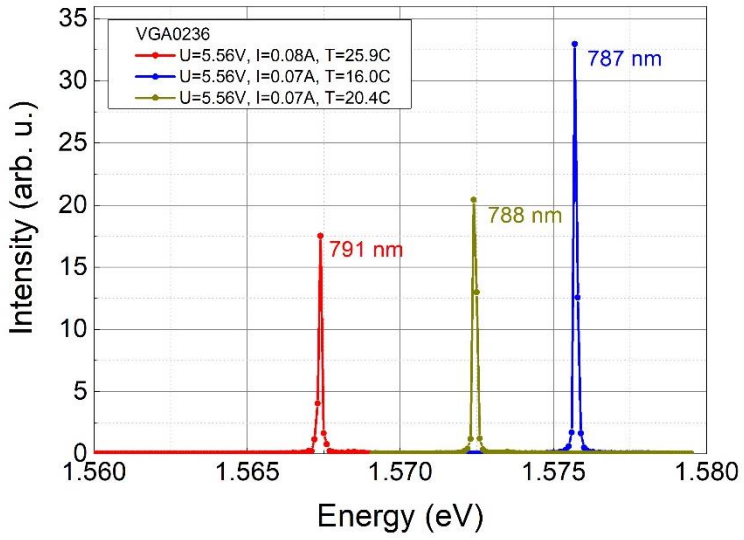

Fig. 1. EL spectra of laser diode containing GaAs QW with parabolic AlGaAs barriers measured at different temperatures

Laser diodes were characterized by measurements of RT-PL, current-voltage (I-V) and current-power (I-P) behaviors. The electroluminescence (EL) spectra measured in temperature range of 15 ^{o}C - 30 ^{o}C for laser diode with single PQW exhibiting lasing properties in near infrared region are presented in Fig. 1.

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REFERENCES

[1] S Pūkienė, et al.Nanotechnology, Vol. **30**, 455001 (11pp) (2019).

Inv7

Magnetoresistance Relaxation Phenomena in Nanostructured Lanthanum Manganite Films

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Recently, it was demonstrated that nanostructured lanthanum manganite films which exhibit the colossal magnetoresistance effect (CMR) can be successfully used for the development of CMR-B-scalar sensors [1]. These are able to measure the magnitudes of high-pulsed magnetic fields of millisecond duration in very small volumes. Such sensors have been used at room temperatures to measure the magnetic diffusion processes during railgun operation and the distribution of transient magnetic fields in non-destructive pulsed-field magnets. However, for condensed matter physics and other special applications sensors operating at cryogenic temperatures and measuring magnetic fields in a wide range of amplitudes are required. In such cases, it is important to avoid or minimize the magnetic memory effects [2] which limit the speed of such sensors.

In this study, we present the results of an investigation of magnetoresistance (MR) and resistance relaxation in nanostructured lanthanum manganite films grown by the pulsed injection MOCVD technique onto polycrystalline substrates.

It was found that the dynamics of resistance relaxation in nanostructured manganite films upon removal of the external magnetic field has two components: ‘fast’ occurring in hundreds of microseconds and ‘slow’ which takes place longer than several milliseconds. It was demonstrated that the ‘fast’ process can be analyzed by the Kolmogorov–Avrami–Fatuzzo model [3], taking into account the reorientation of the magnetic domains into their equilibrium state, and the ‘slow’ process – by the Kohlrausch–Williams–Watts [4] model considering the short-range interaction of the magnetic moments in disordered grain boundaries as having spin-glass properties. The dependences of the time constants and remnant amplitudes of these processes on ambient temperature and magnetic field are presented and analyzed. The relation of relaxation processes with microstructure of manganite films will be demonstrated and discussed.

REFERENCES

[1] T. Stankevic et al., Rev. Sci. Instrum., 85, 044704 (2014).
[2] M. Sirena et al., Phys. Rev. B, 64, 104409 (2001).
[3] E. Fatuzzo, Phys. Rev., 127, 1999, (1962).
[4] G. Williams and D. C. Watts, Trans. Faraday Soc., 66, 80 (1970).

Inv8

Narrow excitonic lines and large-scale homogeneity of transition metal dichalcogenides grown by MBE on hBN

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Monolayer transition metal dichalcogenides (TMDs) are two-dimensional materials with exceptional optical properties such as high oscillator strength, valley related excitonic physics, efficient photoluminescence, and several narrow excitonic resonances. However, above effects have been so far explored only for structures produced by techniques involving mechanical exfoliation and encapsulation in hBN inevitably inducing considerable large-scale inhomogeneity. On the other hand, techniques which are essentially free from this disadvantage, such as molecular beam epitaxy (MBE), have to date yielded only structures characterized by considerable spectral broadening, which hinders most of interesting optical effects.

We report for the first time on the MBE-grown TMD exhibiting narrow and fully resolved spectral lines of neutral and charged exciton (see Fig. 1). Moreover, our MBE-grown TMD exhibits unprecedented high spatial homogeneity of optical properties, with variation of the exciton energy as small as 0.16 meV over a distance of tens of micrometers. Our recipe for MBE growth [1,2] is presented for $MoSe_2$ and includes extremely slow growth rate, the use of atomically flat hexagonal boron nitride (hBN) substrate and the annealing at very high temperature. Importantly, good optical properties are achieved for as-grown sample, without any post growth exfoliation and encapsulation in hBN. This novel recipe opens a possibility of MBE growth of TMD and their heterostructures with optical quality, dimensions and homogeneity required for optoelectronic applications.

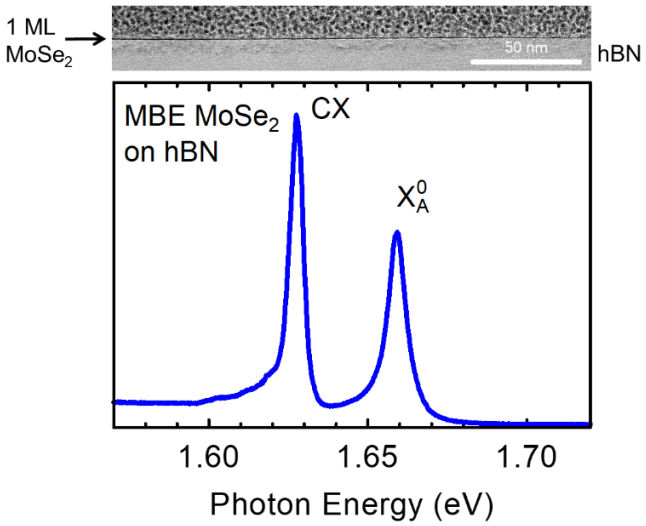

Fig. 1. Crossesciton and low temperature PL spectrum with excitonic resonances for $MoSe_2$ monolyaer grown by MBE on hBN.

REFERENCES

[1] W. Pacuski, et al; *Nano Letters* **20**, (2020) pp. 3058-3066.
[2] Z. Ogorzałek, et al; *Nanoscale* **12** (2020) pp. 16535-16542.

O13
Graphene gate GaN/AlGaN field effects transistors for THz detection

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Graphene (GR) is transparent for electromagnetic radiation in the very wide spectral range, including sub-terahertz and terahertz frequency ranges. Particularly, at frequency of 1 THz, graphene transmittance is ~ 96 percent [1]. This makes graphene very promising for such applications like opto-transistors and terahertz devices with transparent electrodes.

We report on GaN/AlGaN fin-shaped field-effect transistors (FinFETs) with GR gate. Small gate area and narrow channel make this transistors promising for terahertz applications. FinFETs structures were fabricated using the technology described in details in Ref. [2]. GR gates were formed by high-speed electrochemical delamination method (see insert in Fig. 1) on pre-deposited metal pads which were used as the contacts to GR. Barrier height and ideality factor of GR/AlGaN Schottky barrier found from current-voltage characteristics were φ_b = (1.0 - 1.26) eV and (1.7 - 2.5), respectively.

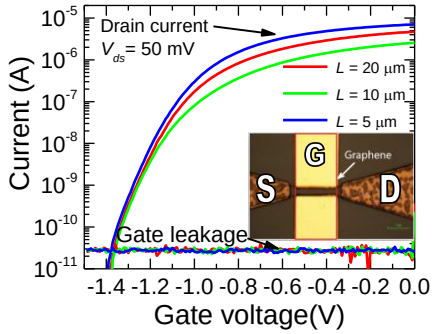

Fig. 1. Transfer characteristics of FinFETs with GR gate, channel width W = 4 μm and gate length L = 5, 10, 20 μm; photo of the device active area is present on insert.

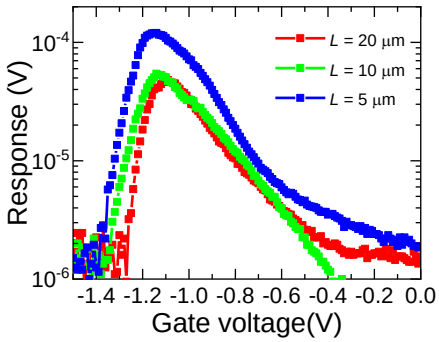

Fig. 2. Response of GR gate FinFETs with different gate length L = 5, 10, 20 μm and constant channel width W = 4 μm at the frequency f = 120 GHz and RT.

Characteristics of GaN/AlGaN FinFETs with GR gate are shown in Fig. 1. The devices were characterized by 6 order of magnitude on/off ratio and subthreshold slope ~ 1.1. Aging during 6 months did not indicate noticeable change in the current voltage characteristics. Measurements of the low frequency noise allowed us to extract the effective trap density responsible for noise, which was similar as for Ni/Au gate FinFETs. Results of detection at the frequency f = 120 GHz by FinFET with GR gate at room temperature are shown in Fig. 2. The signal peaks are located near the threshold voltage of investigated FinFETs.

To summarize, we have demonstrated GR gate GaN/AlGaN FinFETs. Combined properties of high transmittance in THz frequency range of GR, high sheet density of two-dimensional electron gas in GaN/AlGaN, and fin shape of these devices make them promising for plasmonic THz detection.

REFERENCES

[1] Choi, Hyun Joo, et al., Scientific Reports **7**, 42833 (2017)
[2] P. Sai, et al., Semicond. Sci. Technol. **34** 024002 (2019)

XX

THz magnetospectroscopy of HgCdTe bulk crystals with different Cd content

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The constant development of science and industry requires inventing novel methods and techniques of THz radiation detection, therefore the search for new detectors and research of new materials is still a vital part of THz studies. Additionally improvements in techniques of growning crystals such as HgCdTe have brought back the interest of the scientific world for these materials due to their Dirac properties.

Four HgCdTe samples were chosen for the experiments, each with different cadmium content: 15.1 % Cd, 15.2% Cd, 16.2% Cd and 17.5% Cd. Transmission experiments were carried out at pumped LHe at T=2 K and carbon bolometer was used as a THz radiation detector. As a THz radiation source FIR laser was used, with its six lines: 70.6 μm, 96.5 μm, 118.8 μm, 163 μm, 186 μm and 454 μm.

Performed measurements were used to extract the velocity $\tilde{c}$ and rest mass $\tilde{m}$ of carriers. Both of those values were obtained after fitting of the simplified Kane model described in [1]. The rest mass value increased with the cadmium content, while the velocity of carriers remained roughly the same throughout the measurements of various samples.

It has to be noted that the obtained values of velocity and rest mass were compared with values determined from the technological parameters of growth. Relationships of those values are $E_G = 2\tilde{m}\tilde{c}^2$ and due to the fact that obtained results are in agreement with expected values of E_G, it can be concluded that the simplified Kane model can be used to determine the pseudo-relativistic Kane fermion parameters of the velocity $\tilde{c}$ and rest mass $\tilde{m}$ of carriers as a function of cadmium content.

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REFERENCES

[1] F. Teppe et al. Nature Comm. **7**, 12576 (2016).

O15

Machine learning enhanced design of diffractive optical elements.

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Diffractive optical elements (DOEs) are capable of reshaping of incoming radiation within very thin structure (often referred as single surface). It results not only in much lighter, compact and cost-effective structures, but also gives opportunity of obtaining light distributions unattainable by refractive approach. So far, DOEs have most commonly been designed with utilization of numerically calculated diffraction integrals as discrete Fourier transforms or convolutions [1], which is usually time and memory consuming, especially for bigger matrices.

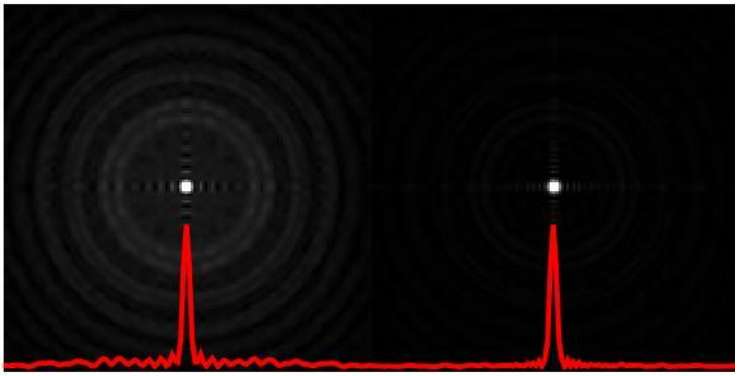

Fig. 1 Comparison of the focal spots obtained from the unoptimized (left) and optimized (right) Fresnel lenses.

Here, we propose application of convolutional neural network for emulation of light propagation, which can be utilized for optimization of DOEs, realizing focusing of light into arbitrary shapes. Learnable parameters of the net correspond to the phase distribution of designed element. Therefore, proper network training results in ready to use, optimized structure. This method is especially appealing for designing structures, working in the terahertz spectral range. It comes from the fact, that size of the smallest details of the structures depends linearly on the wavelength, which here is in order from hundreds of microns to single millimeters. Therefore, structures designed for sub-THz frequencies can be easily manufactured with 3D printing techniques and with proper production and design methods [2] also higher frequencies are attainable.

Results of the optimization of the structures for different applications as well as comparison with other methods will be presented during the conference. As an example, results of the optimization of the simple, convergent Fresnel lens are shown in Fig. 1.

REFERENCES

[1] Goodman, J. W. (2005). Introduction to Fourier optics. Roberts and Company Publishers.

[2] Siemion, A., Komorowski, P., Surma, M., Ducin, I., Sobotka, P., Walczakowski, M., & Czerwińska, E. (2020). Terahertz diffractive structures for compact in-reflection inspection setup. Optics Express, 28(1), 715-723.

Antenna Characterization of Monolithically Integrated Detectors for 0.62 THz

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Here we report on comprehensive investigations of receiving antenna characteristics of monolithically integrated field-effect-transistor-based terahertz detectors with patch antennas which are often used for a variety of applications [1, 2]. Devices are implemented using a standard 65-nm CMOS process technology. Furthermore, we investigate a set of devices coupled to the antenna with same geometrical parameters but connected to a device with a different channel length thus allowing to vary the impedance of antenna load not only through the bias voltage.

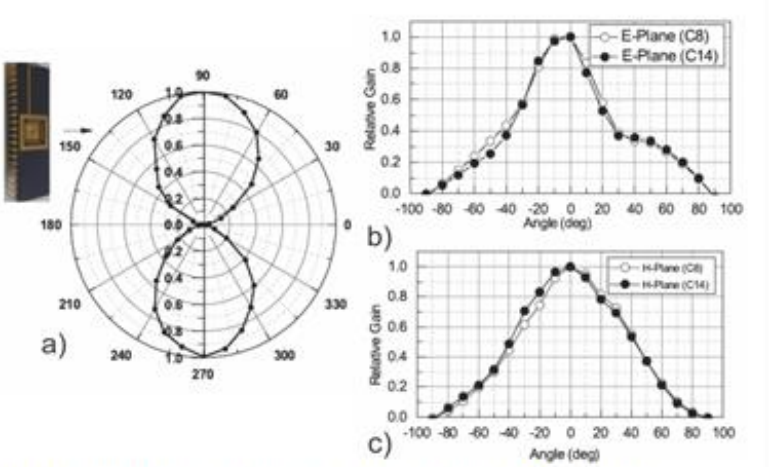

Fig. 1. Dependence of the response of the CMOS on its angular orientation relative to the polarization of the radiation: a) azimuthal, b) vertical or E-plane and c) horizontal or H-plane. Measurements are performed at 0.62 THz.

The directivity values of antennas were determined by measuring the angle dependence of rectified voltage as a function of the tilt in E- and H-planes which are presented in Fig. 1 and through the thorough comparison with the results of electromagnetic simulations using CST software. Considering the amount of input radiation power impinging to the determined effective area of the detector, we report a room-temperature cross-sectional noise-equivalent power of 17.1 pW/√Hz at the resonant frequency of 0.62 THz. This value represents the state of the art for electronic detectors operating at room temperature in this frequency range.

REFERENCES

[1] J. Zdanevicius et al., *IEEE Transactions on Terahertz Science and Technology* **8** .(2018) pp. 613–621.

[2] J. Zdanevičius et al., *Journal of Infrared, Millimeter, and Terahertz Waves* **36** (2015) pp. 986–997.

O17

Phase contrast sub THz imaging and applications

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Terahertz (THz) imaging becomes a handy tool to identify the contents of various packages [1]. Additional attention is needed when objects have low absorption in THz frequencies. It induces a poor signal-to-noise ratio and small contrast images. To overcome those problems comprehensive imaging techniques is needed [2].

In this contribution, spatial filtering methods – phase contrast and dark field – will be demonstrated both experimentally and theoretically to resolve weakly absorbing objects in THz imaging at 0.3 THz. Imaging was performed using sensitive, working at room temperature, antenna-coupled titanium-based microbolometer [3]. Phase contrast techniques were implemented via employment of two different THz imaging setups – using focused and collimated beams. Figure 1 presents images recorded for 0.3 THz obtained by setup 1 (upper panel) and setup 2 (bottom panel), without and with different spatial filters. Application of phase filters improves the image contrast and allows to discriminate low-absorbing objects from the background and from each other. Also, filtered image enables to resolve nearly transparent objects, to enhance their edges resolution and thus reveal advantage in respect to direct imaging (bright field).

Introduced spatial filtering methods allowed to enhance image contrast up to 30 dB and to increase signal-to-noise ratio by an order of magnitude in detecting weakly absorbing objects. It extends THz imaging applications in biology and medicine, where mostly weakly absorbing objects are under the interest.

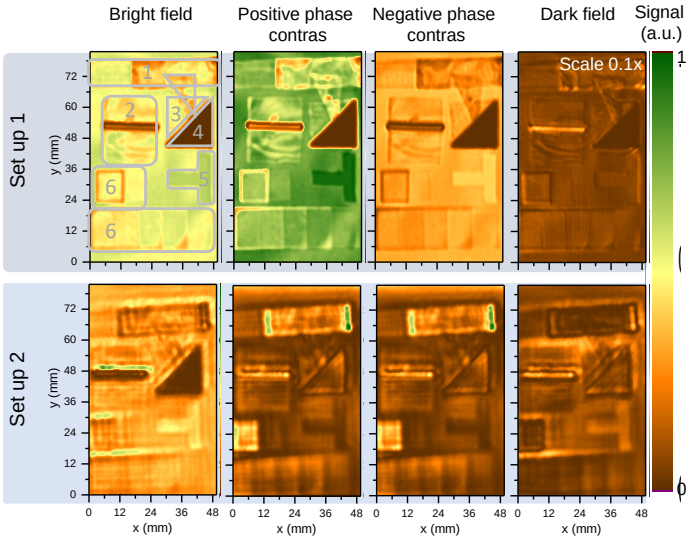

Fig. 1. THz images recorded at 0.3 THz by setup 1 (upper panel) and setup 2 (lower panel), without and with different filters. Contents of the sample are marked by gray squares: (1) - gauze cloth with different number of layers, (2) - a low density polyethylene bag, (3) - piece of a rubber glove, (4) - aluminum foil, (5) - a T-shaped aperture, (6) - paper sheets. THz image pixel size: 0.3 mm x 0.3 mm; images consist of 165 x 273 pixels.

REFERENCES

[1] I. Kašalynas, R. Venckevicius, and G. Valušis, IEEE Sensors J. 13 (2013), pp. 50-54.
[2] M. Wan, J. J. Healy, and J. T. Sheridan, Opt. Laser Technol.122, (2020) pp. 105859
[3] J. Trontelj, G. Valušis, R. Venckevičius, I. Kašalynas, A. Sešek and A. Švigelj; Terahertz Emit. Receiv. Appl. V 9199 (2014) pp. 91990K.

Inv11

Reflectance spectra of selective emitter solar cells in terahertz and sub-terahertz ranges

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One of multitude of terahertz (THz) range imaging applications is investigation of solar modules, solar cells and their structures. For example, THz imaging previously was successfully applied to study profiles of contacts on silicon solar cells [1], etched wafers, complete cells and encapsulation materials [2]. In these terahertz-time domain spectroscopy (THz-TDS) experiments, time-of-flight information was used to reveal precise positions of surfaces of interest with sub-wavelength resolution, approaching micron range precision. Simultaneously, small pyramid-like etched structures on the surfaces of silicon (Si) wafers were investigated by studying amplitude information of THz-TDS pulses. Combination of THz-TDS, successive etch-back and numerical calculations can even reveal doping profiles and carrier lifetime within highly doped Si layers of several hundred nm thickness, as it was recently demonstrated by M. Lenz *et. al.* [3].

Silicon solar cells industry also underwent both impressive quantitive and qualitive changes during last decade. These changes include both exponential growth of shipments and dramatic changes to dominating device structures [4]. Once dominating so-called back-surface field (BSF) design with uniform emitter doping is now rapidly being replaced with advanced novel structures based on selective doping technologies. Free carrier absorption and refractive index changes in doped layers are two of the most important mechanisms of interaction between THz radiation and solar cell structures. Therefore, possible novel applications have to be reassessed due to changing (sometimes by orders of magnitude) typical doping levels.

In this contribution, we present simulations of propagation of THz waves within silicon solar cell structures. Novel low-doped selective emitter structures were investigated in series of Finite-Difference Time-Domain (FTTD) simulations. Revealed new potential THz spectroscopy application limits will be discussed. Simulation results were supported by series of measurements.

REFERENCES

[1] L. Minkevičius, R. Suzanovičienė, S. Balakauskas, G. Molis, A. Krotkus, G. Valušis, and V. Tamošiūnas; *Electronics Letters* **48** (2012) pp. 932-934.
[2] V. Tamošiūnas, L. Minkevičius, A. Vaitkūnas, A. Urbanowicz, A. Maneikis, A. Šetkus, and G. Valušis; *Energy Procedia* **77** (2015), pp. 202-207.
[3] M. Lenz, C. Matheisen, M. Nagel, and J. Knoch; *Applied Physics Letters* **110** (2017), p. 072103.
[4] VDMA Photovoltaic Equipment, *International Technology Roadmap for Photovoltaic (ITRPV) – 2019 Results*, 11th ed. (2020).

O18

Effect of lengths, diameters, and density of silver nanowire layers on terahertz conductivity

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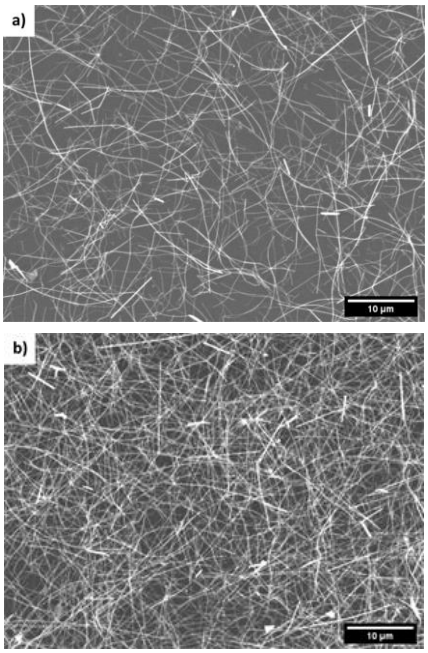
The high-frequency conductivity (0.1 THz to 1.1 THz) of composite nanomaterials is substantially impacted by the lengths, diameters, densities, and thickness of the constituent materials. We have fabricated and experimentally characterized thin layers of silver nanowires in the terahertz frequency range. In particular, the samples of different densities of nanowires and two different nanowire lengths were measured in a transmission geometry by terahertz spectroscopy, both in time and frequency domains. The results obtained in time and frequency domains are in a very good agreement and prove a high reflectance of the metallic nanowire layer. We extracted the conductance, reflectance, transmittance, and absorbance of the samples from the measurements. We have shown that all these characteristics can be tuned by varying the density and geometry of the nanowires. The experimentally observed dependencies were successfully described/fitted by the theory establishing the relation between the nanowire layer structure and the electromagnetic response of the composite. The relatively constant conductance of the nanowire layers in a broad frequency range is of particular interest, as tunable transparent coatings are distinctly demanded for high-frequency applications. Our results pave the way toward the application of silver nanowires as a perspective material for nanoelectronic circuits, transparent and conductive coatings and printable THz antennas, important for future 5G wireless communication systems and above.



SEM images of AgNWs sample B (35 nm × 25 µm) with **a)** the lowest density – 67 mg/m^2 and **b)** the

O19

Terahertz radiation induced by surface ballistic photogalvanic effect in GaAs LIPSS structures

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As it is well-known, a transient photocurrent arising near the semiconductor surface, after its illumination with femtosecond laser pulses, can generate terahertz radiation. When analysing this effect, it is generally assumed that the transient photocurrent is directed perpendicular to the illuminated semiconductor surface, along the direction of the surface electric field that is built-in or can be induced by spatial separation of photoexcited electrons and holes. However, the optical alignment of electron momenta (the optical momentum alignment effect in semiconductors manifests itself in the anisotropic momentum distribution of photocarriers excited by linearly polarized light) can result in the appearance of a lateral (parallel to the illuminated semiconductor surface) component of the transient photocurrent.

Recently, we developed a technique for determining the direction of transient photocurrent in a semiconductor [1]. Using this methodology, it was found that upon excitation of p-polarization light, a transient photocurrent component parallel to the surface appears in the GaAs LIPSS structures. This lateral component is very small when exciting the semiconductor near the absorption edge. However, as the excitation photon energy continues to increase, the surface photocurrent grows very rapidly and becomes the dominant source of THz emission (Fig.1). These results suggest that the cause of lateral photocurrent is the ballistic photogalvanic effect [2]. The influence of this effect on THz radiation was mentioned in [3] work, but it has not been observed experimentally so far.

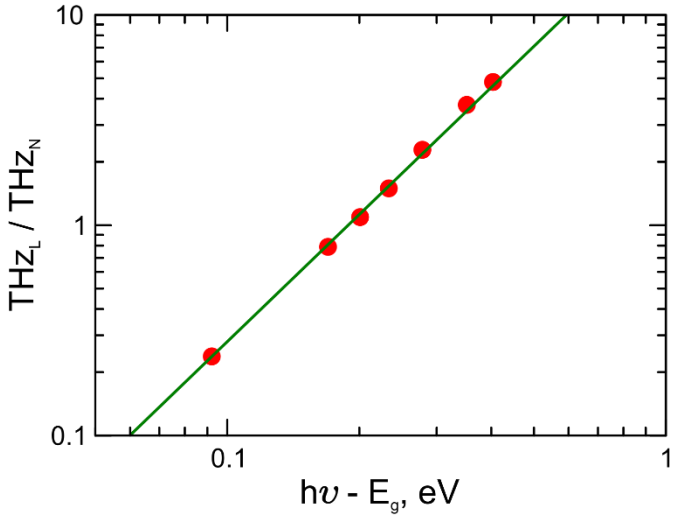

Fig.1 Relative contribution of lateral photocurrent to THz radiation generation. Red circles – experimental results, green line – quadratic dependence. THz_L and THz_N – amplitudes of THz pulses generated by lateral and normal transient photocurrents accordingly.

REFERENCES

[1] I. Beleckaitė and R.Adomavičius, J. Appl. Phys. 125, 225706 (2019)
[2] V. L. Al'perovich et al., Sov. Phys. JETP 53, 1201 (1981)
[3] V. L. Malevich et al., J. Appl. Phys. 112, 073115 (2012)

O20

AlGaN/GaN dual grating gate structures investigated in high magnetic field

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The accurate evaluation of the two-dimensional electron gas (2DEG) parameters in AlGaN/GaN heterostructures is essential for the development of the device based on this materials system, such as high electron mobility transistors, Schottky diodes, THz plasmonic detectors, ultraviolet detectors, piezoelectric and pyroelectric sensors. Cyclotron resonance (CR) and magnetotransport measurements proved themselves as the powerful techniques for 2DEG study in AlGaN/GaN system [1, 2].

We report on high magnetic fields (up to 16 T) magnetotransport, Shubnikov-de-Haas (SdH), CR and photovoltage measurements in AlGaN/GaN high frequency transistors with a dual grating gate (DGG) of large squared area (2×2 mm^2). This kind of DGG device was developed for THz plasmonic detection. Ni/Au grating of symmetric and asymmetric structure was evaporated on AlGaN surface. The epilayer structure for the samples of this study consisted of 1μm-thick undopedGaN and a 25nm-thick undoped AlGaN barrier layer grown on 500μm-thick SiC and bulk GaN substrates using metalorganic chemical vapor deposition (MOCVD).

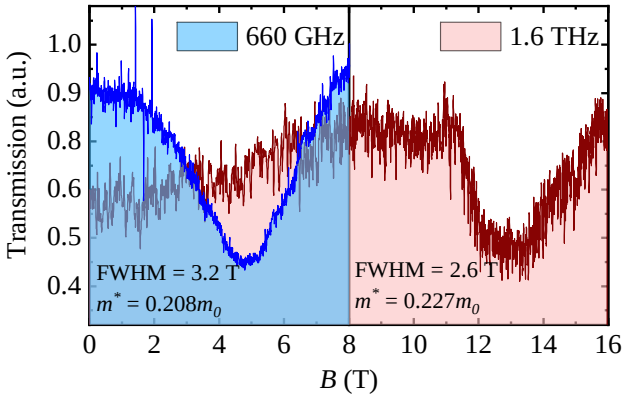

Fig. 1. CR measurements used a VDI source (660GHz) and CO_2 pumped far infrared laser (1.6THz)

The analysis of magnetotransport measurements and SdH oscillations yields information about the carrier concentration and mobility in this channel. Additionally, the transport lifetime (τ_t) was derived using the Drude model and the quantum scattering time (τ_q) was estimated based on the high-magnetic-field part (6-16T) of longitudinal magnetoresistance. The ratio ($\tau_t/\tau_q \approx 5$) indicates a long range character of a disordered potential or may be attributed to a weak inhomogeneity of the 2DEG density.

The CR measurements used a VDI source, CO_2 pumped far infrared laser and 18 T superconducting coil. The results of the experiments are shown in Fig. 1. In this case, two nicely resolved, interference-free lines were found in transmission for the 660 GHz and 1.6 THz incoming radiation frequency. CR measurements allow us to determine the in-plane effective mass of the free electrons.

REFERENCES

[1] Knap, W., et al., Applied Physics Letters. 70(16), 2123-2125 (1997).
[2] Lorenzini, P., et al., Applied Physics Letters. 87(23), 232107 (2005).

O21

Fractional frequencies in microwave response of GaAs/AlGaAs superlattices

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Emerging versatile applications of sub-terahertz and terahertz electromagnetic waves stimulate development of miniature, solid-state sources and amplifiers which can operate at room temperature.

Since the pioneer work of Esaki and Tsu [1], semiconductor superlattices attract much attention as unique platform for the studies of various high-frequency effects related to an existence of the negative electron mobility in the band transport.

Parametric generation and amplification at harmonics and low-order sub-harmonics in superlattices, biased by DC and AC electric fields, and the physical processes behind the phenomenon have been rather well understood theoretically ([2,3] and references cited therein). Additionally, there exist a few publications that predict the parametric generation at fractional frequencies [4,5]. To the best of our knowledge neither generation at sub-harmonics nor at fractional frequencies was observed in experiments so far.

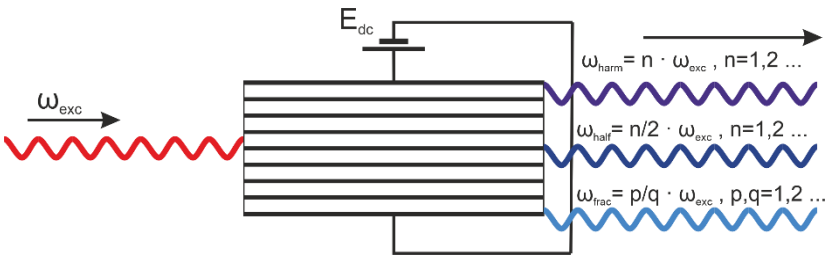

Fig. 1 Sketch of the superlattice frequency response

In this work, we present an analysis of experimental data on the spectral response of moderately doped GaAs/AlGaAs superlattices to a microwave pump (Fig 1). It is shown that the frequencies generated in the superlattice are linked to the pump frequency ω_{exc} by the relations:

$$n\omega_{exc} = \frac{p_1}{q_1}\omega_{exc} \pm \frac{p_2}{q_2}\omega_{exc}$$

where n, $p_{1,2}$ and $q_{1,2}$ are integers. The effects are explained by using the notion of Esaki-Tsu nonlinearities in the superlattice.

REFERENCES

[1] L. Esaki and R. Tsu; *IBM Journal of Research and Development* **14-1** (1970) pp. 61-65.
[2] T. Hyart, A.V. Shorokhov and K.N. Alekseev; *PRL* **98-22** (2007) p. 220404.
[3] T. Hyart, N.V. Alexeeva, A. Leppanen and K.N. Alexeev; *APL,* **89** (2006) p. 132105.
[4] Y.A. Romanov and J.Y. Romanova; *JETP* **91-5** (2000) p. 1033-1045.
[5] J. Isohätälä and K.N. Alexeev, arXiv:1201.6280; Jukka Isohätälä, PhD Thesis, University of Oulu (2012).

O22

All-optical injection and control of currents in carbon films

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Strong and broadband light absorption in graphene allows one to achieve high carrier densities essential for observation of nonlinear optical phenomena making graphene a unique playground for studying many-body effects. Being of strong fundamental importance, these effects also open a wide range of opportunities in photonics and optoelectronics. Here, we make use of strong photon-drag effect to generate and optically manipulate ultrafast photocurrents in graphene at room temperature. In contrast to the injection of photocurrents in graphene due to external or built-in electric field [1] and by quantum interference [2], we force the massless charge carriers to move via direct transfer of linear momentum from photons of incident laser beam to excited electrons in unbiased sample [3]. Direction and amplitude of the drag-current induced in graphene are determined by polarization, incidence angle and intensity of the obliquely incident laser beam. We also demonstrate that the irradiation of graphene with two laser beams of the same wavelength offers an opportunity to manipulate the photocurrents in time domain. At the femtosecond excitation, the interplay of the ultrafast photon drag currents enables control of the polarization and amplitude of the THz emission from graphene [4].

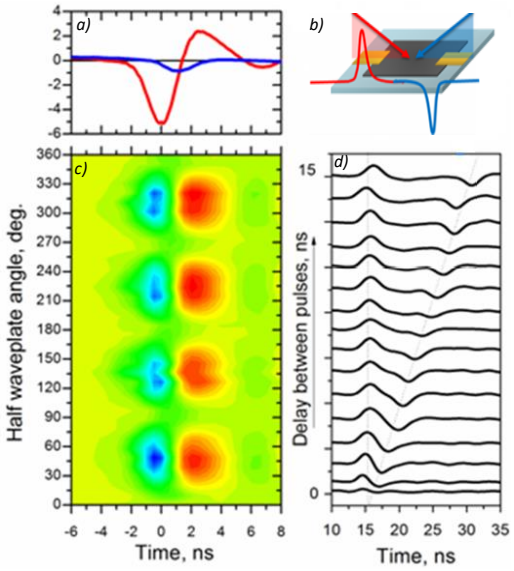

Fig. 1 The photocurrent (a) induced by two 10 ns pulses arriving at the graphene simultaneously at mirror-reflection angles (b) measured as a function of the polarization of the first pulse (c). Two pulses of the same intensity produce currents of opposite sign that cancel one another at zero time delay (d).

All-optical control of photocurrent was demonstrated in the two-beam experiment when sample was irradiated with two mirror-reflected beams (see Fig.1b). At a zero time delay between the excitation pulses of the same intensity, the photocurrents completely compensate each other resulting in a zero net current. Since the drag current strongly depends on the polarization of the excitation beam, the net current was tuned by rotating the polarization plane azimuth of the first beam. The net current signal waveforms as a function of the first beam polarization azimuth obtained at nanosecond excitation is presented in contour plot on Fig.1c.

REFERENCES

[1] L. Prechtel, et al, Nature Communications 3, 646 (2012)
[2] D. Sun et al, Nano Letters 10, 1293 (2010).
[3] P. A. Obarztsov, et al, Sci. Rep. 4, 4007 (2014).
[4] P.A. Obraztsov, Phys. Rev. B 90, 241416(R) (2014)

O23

Studies of Receptor and Its Ligand Interaction Using FRET and TIRF Microscopy

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An important area in medicine, pharmacy and biotechnology is the study of interacting molecules, which allow the knowledge gained to be used to develop more effective drugs for the treatment of diseases. Most of these studies are in artificial systems, and there is a huge need for models that enable studies of the interaction between biomolecules on the cell surface under natural conditions. The β2-adrenergic receptor (B2ADR) is a widely studied protein, with a particular focus on interactions with various ligands, which is often the starting point for other receptor interactions, but little is known about their interaction. The interaction of the granulocyte colony stimulating factor receptor (GCSFR) with the ligand has been much less studied. Physical methods such as Forster resonance energy transfer (FRET) and total internal reflection fluorescence (TIRF) microscopy enable the study of monomer interactions in the presence or absence of a ligand, changes in receptor monomer interactions following ligand binding in a cell. During the work, the effect of glass coating with poly-l-lysine, APTES, BSA, peptide containing RGD sequence or fibronectin on cell attachment and background signal was investigated. The lowest background signal was found to be achieved by coating the glass surface with fibronectin or 20% NHS-PEG-COOH and 80% NHS-PEG-O-CH_3 and immobilizing at 0,2 mg 44 a.a. length peptide with RGD sequence. Using the FRET method, it has been investigated that β2-adrenergic receptor interactions occur without ligand binding. Also, stimulation with agonist ISO increases the interactions between the receptors and the interacting receptors are internalized after 20 min. stimulation. Inhibition of cell endocytosis increases the number of interacting receptors on the cell membrane, even in the absence of an agonist. By the same method, ligand stimulation for 5 minutes resulted in a 10-fold increase in GCSFR interactions compared to ligand-unstimulated cells. Peak internalization of the complex was observed after 15 minutes of ligand stimulation. The results show similarity between receptors in the ability to interact without ligand binding, and the interaction is seen inside the cell after internalization during long-term incubation with the ligand.

O24
Structure determination of *HEWL* protein aggregates at liquid interfaces

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Protein aggregation is associated with more than 30 different human diseases including Alzheimer's, Parkinson's, and others. Each of these diseases is caused by the aggregation of a particular protein and accumulation of aggregates at the cell's membrane. The most recent studies showed that the membrane has an immense effect on protein aggregation and adsorption. Thus, structure characterization at the liquid surfaces, especially at the model Lipid/Water interface, remains a major subject of the protein aggregation research.

Here, we use vibrational sum-frequency generation (VSFG) spectroscopy to understand and compare the structure and adsorption behavior of hen egg-white lysozyme (HEWL) and its aggregates at Air/Water and Lipid/Water interfaces. In addition, we applied Fourier transform infrared spectroscopy and atomic force microscopy (AFM) to verify the structure and the morphology of lysozyme aggregates formed in bulk solution.

In our study, we found that HEWL aggregates with different molecular structures, such as small unordered aggregates, and larger aggregates with a parallel and antiparallel β-sheet structure were adsorbed to both interfaces. We identified that the main driving force for adsorption to the Air/Water interface is hydrophobicity. Meanwhile, adsorption to the Lipid/Water interface is mainly determined by electrostatic interaction between the lipid's headgroups and the charged protein groups, though it is also influenced by hydrophobicity. Moreover, we demonstrate that varying the pH of the solution has a substantial effect on the intensity of VSFG spectra at Lipid/Water, which we attributed to changes in the vibrational dipole orientation of adsorbates.

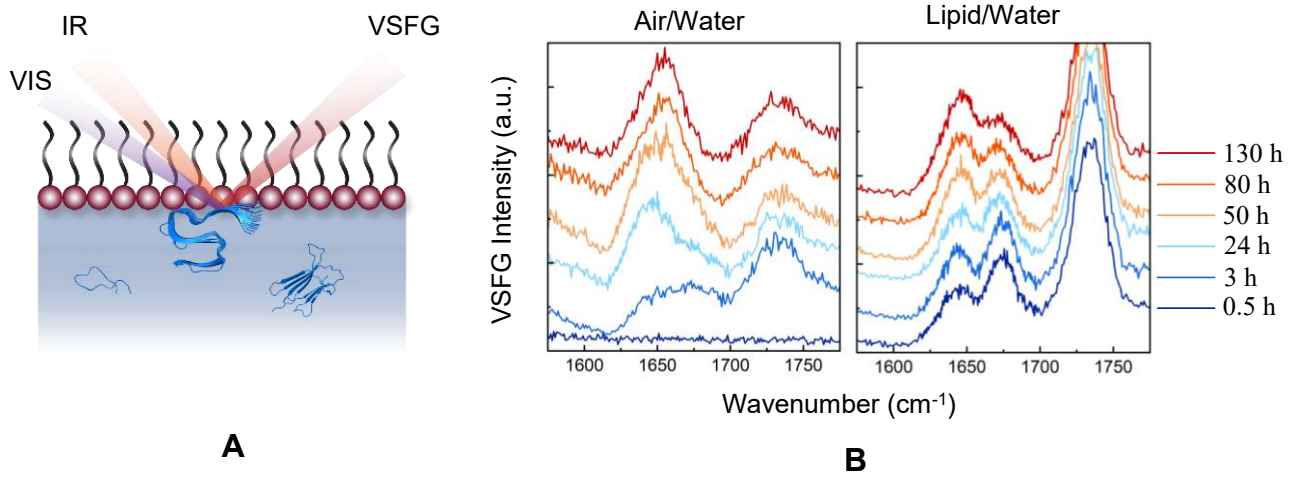

Fig. 1 (A) Schematics of the VSFG experiment **(B)** The VSFG spectra of HEWL and its aggregates adsorbed at different interfaces in Amide I vibrational region. Different spectra correspond to aliquots that were heated for various times (see the legend).

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Antimicrobial photodynamic therapy: an alternative to overcome the biofilm resistance.

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Currently, the microbial biofilms are responsible for a wide variety of infections in the human body, reaching 80% of all bacterial and fungal infections [1]. The biofilms presents specific properties which increase the resistance to antimicrobial treatments. Thus, the development of new approaches is urgent, and antimicrobial photodynamic therapy (aPDT) have been shown as a promising candidate. aPDT basically involves the synergistic combination of a photosensitizer (PS), molecular oxygen and visible light of appropriate wavelength in order to produce highly reactive oxygen species (ROS), which leads to the oxidation of several cellular components (Fig. 1) [2]. Several studies have demonstrated a substantial biofilm inactivation once the aPDT promotes damage to non-specific target [3-5]. This therapy attack many components of the biofilm, including proteins, lipids, and nucleic acids present within the biofilm matrix; causing the inhibition even in the cells that are inside the extracellular polymeric substance (EPS) [6]. So, the presentation aims to show the progress of aPDT against the biofilms and the several applications of this therapy.

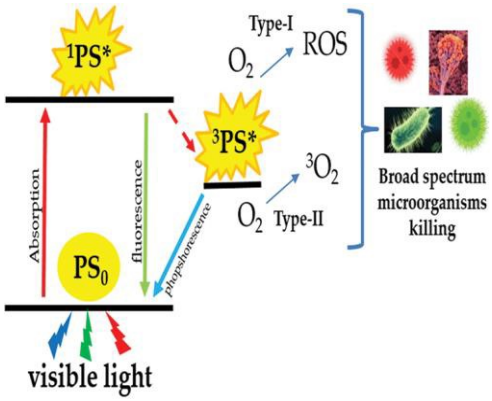

Fig. 1. aPDT mechanism of action

REFERENCES

1. Del Pozo, J.L., *Biofilm-related disease.* Expert Rev Anti Infect Ther, 2018. **16**(1): p. 51-65.
2. Mahmoudi, H., et al., *Antimicrobial Photodynamic Therapy: An Effective Alternative Approach to Control Bacterial Infections.* Journal of lasers in medical sciences, 2018. **9**(3): p. 154-160.
3. Abrahamse, H. and M.R. Hamblin, *New photosensitizers for photodynamic therapy.* Biochem J, 2016. **473**(4): p. 347-64.
4. Rajesh, S., et al., *Antimicrobial photodynamic therapy: An overview.* J Indian Soc Periodontol, 2011. **15**(4): p. 323-7.
5. Hu, X., et al., *Antimicrobial Photodynamic Therapy to Control Clinically Relevant Biofilm Infections.* Frontiers in Microbiology, 2018. **9**(1299).
6. Pinto, R.M., et al., *Innovative Strategies Toward the Disassembly of the EPS Matrix in Bacterial Biofilms.* Frontiers in microbiology, 2020. **11**: p. 952-952.

XX

Ultrafast X-ray techniques applied to solar-cell characterization

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Visualizing on the atomic scale the full extent of the electronic and structural changes that are triggered by charge separation and subsequent charge transport is crucial for developing the rational design of next-generation solar cells. The rapid progress of ultrafast X-ray techniques, both at synchrotrons (100 ps) and at X-ray free electron laser facilities (sub-ps) have equipped the scientific community with novel analytical tools that are capable of delivering unique feedback with spin and elemental sensitivity about the highly-correlated nonadiabatic dynamics that follow photoabsorption. The present talk will review the technical state-of-the art and the ongoing developments that are currently taking place. The talk will also highlight several of the recent results that have been obtained for intramolecular and interfacial processes of relevance for the function and optimization of solar cells.

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Luminescent properties of GaAsBi quantum wells

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Bismide-based material systems are an attractive candidate to develop GaAs-based applications for long wavelength optoelectronics, such as infrared lasers [1], photodetectors [2], solar cells [3], terahertz devices [4] etc. In order, to design and optimize these devices it is essential to know their optical properties, electronic structure, nature of defects, the emission channels, and the efficiency of carrier recombination. In recent years, luminescent properties of GaAsBi quantum wells (QW) are extensively studied. Though, not all questions are clearly answered.

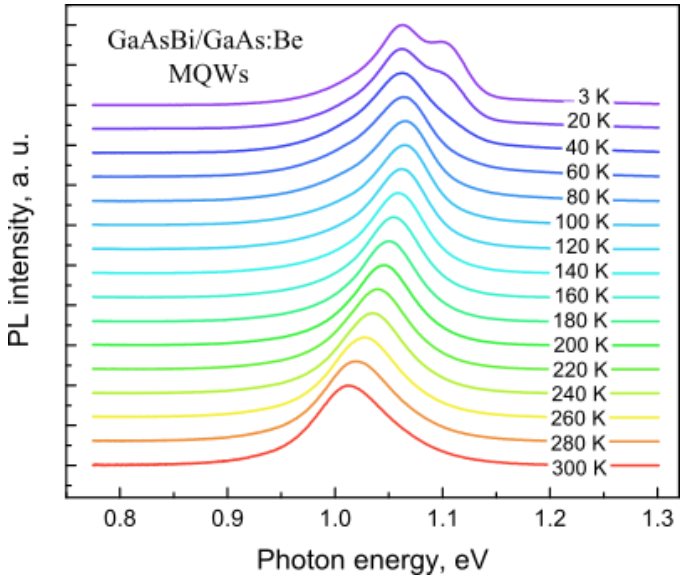

Fig. 1 Temperature-depenedent photoluminescence spectra of GaAsBi/GaAs:Be multiple quantum wells.

This work presents a temperature- and excitation- dependent photoluminescence (PL) study of GaAsBi/GaAs, GaAsBi/AlGaAs and GaAsBi/AlAs QWs grown by molecular beam epitaxy (MBE) and migration enhanced epitaxy (MEE).

Temperature-dependent PL measurements revealed that PL band associated with radiative transitions in GaAsBi QWs has an inner structure, which for some samples can be clearly seen at low-temperatures (Fig. 1). Moreover, temperature-dependence of PL peak energy position was analysed using Varshni expression [5]. A broad PL peak at room temperature together with S-shape character of PL peak position variation with temperature indicated effect of carrier localisation. As further matter, activation energies derived from PL measurements provided insight into thermal quenching of luminescence processes. Finally, the influence of the barrier layer on the optical emission from electronic states in the GaAsBi QWs are also presented in this work.

REFERENCES

[1] X. Wu, et al.; *ACS Photonics* **4**(6) (2018) pp. 1322-1326.
[2] Y. Gu, R. D. Richards, J. P. David, and Y. Zhang; *Dilute Bismide Photodetectors*. In Bismuth-Containing Alloys and Nanostructures, Springer (2019) pp. 299-318.
[3] A. Muhammetgulyyev, O. G. Erbas, B. Kinaci, O. Donmez, Y. G. Celebi and A. Erol; *Semiconductor Science and Technology* **34**(8) (2019) pp. 085001.

[4] M. Karaliūnas, A. Udal and G. Valušis; *Lithuanian Journal of Physics* **60(**2) (2020).
[5] Y. P. Varshni; *Physica* **34**(1) (1967) pp. 149-154.