University of Belgrade
Institute of Physics Belgrade
Kopaonik, March 10-14, 2024

Book of Abstracts

17th Photonics Workshop

(Conference)

17th Photonics Workshop (2024)

Book of abstracts

Kopaonik, Serbia, March 10-14, 2024

Publisher, 2024:

Institute of Physics Belgrade

Pregrevica 118

11080 Belgrade, Serbia

Editors:

Dragan Lukić, Marina Lekić, Zoran Grujić

ISBN 978-86-82441-62-5

Printed by:

NEW IMAGE d.o.o.

Tošin Bunar 185, Belgrade

Number of copies: 60

CIP - Каталогизација у публикацији

Народна библиотека Србије, Београд

535(048)

681.7(048)

66.017/.018(048)

PHOTONICS Workshop (17 ; 2024 ; Kopaonik)

Book of Abstracts / 17th Photonics Workshop, (Conference), Kopaonik, March 10-14, 2024 ; [organized by Institute of Physics Belgrade, Photonics center [and] Optical Society of Serbia] ; [editors Dragan Lukić, Marina Lekić, Zoran Grujić]. - Belgrade : Institute of Physics, 2024 (Belgrade : New image). - 75 str. : ilustr. ; 25 cm

Tiraž 60. - Registar.

ISBN 978-86-82441-62-5

Scientific Committee:

Aleksander Kovacevic, *Institute of Physics, University of Belgrade, Serbia*

Arne Wickenbrock, *Helmholtz Institute, Johannes Gutenberg University Mainz, Germany*

Borislav Vasic, *Institute of Physics, University of Belgrade, Serbia*

Branislav Jelenkovic, *Institute of Physics, University of Belgrade, Serbia*

Evgeny Gurevich, *University of Appled Sciences in Muenster, Germany*

Gülnur Aygün, *Izmir Institute of Technology, Turkey*

Hrvoje Skenderovic, *Institute of Physics, Zagreb, Croatia*

Jovana Petrovic, *Vinča Institute of Nuclear Sciences, University of Belgrade, Serbia*

Lars Klimaschewski, *Innsbruck Medical University, Austria*

Ljupčo Hadžievski, *Vinča Institute of Nuclear Sciences, University of Belgrade, Serbia*

Marina Lekic, *Institute of Physics, University of Belgrade, Serbia*

Pavle Anđus, *Faculty of Biology, University of Belgrade, Serbia*

Srđan Antic, *Institute for Systems Genomics, Stem Cell Institute, University of Connecticut, USA*

Theo Scholtes, *Leibniz Institute of Photonic Technology, Germany*

Wolfgang Fritzsche, *Leibniz Institute of Photonic Technology, Germany*

Zoran Grujic, *Institute of Physics, University of Belgrade, Serbia*

Organizing Committee:

Marina Lekić (chair), *Institute of Physics Belgrade*

Zoran Grujić (co-chair), *Institute of Physics Belgrade*

Aleksander Kovačević (secretary), *Institute of Physics Belgrade*

Dragan Lukić, *Institute of Physics Belgrade*

Branislav Jelenković, *Institute of Physics Belgrade*

Bojana Bokić, *Institute of Physics Belgrade*

Aleksandra Milenković, *Institute of Physics Belgrade*

Filip Krajinic, *Institute of Physics*

Kolja Bugarski, *Vinča Institute of Nuclear Sciences*

Organized by:

Photonics center, Institute of Physics Belgrade

Optical Society of Serbia

Sponsors:

Ministry of Science, Technological Development and Innovation of the Republic of Serbia

Acknowledgements

Organizing Committee of the „17th Photonics Workshop (2024)" expresses its gratitude for financial support obtained from:

- Optical society of Serbia
- Ministry of Science, Technological Development and Innovation of the Republic of Serbia
- BioQantSense project (finances by European Research Executive Agency (REA) under the GA No 725741)
- Analysis d.o.o.

Conference program

Sunday, March 10th

Chairman: Zoran Grujić

16.00 – 16.30	**Registration & opening**
16.30 - 17.00	**Stanko Tomić** *Quantum Dots: Nanotecnology in Quantum Colours*
17.00 - 17.20	**Pedja Mihailović** *Directions in all-optical computing with an emphasis on the Fabry Perot laser-lock-in approach*
17.20 – 17.40	**Bratislav Marinković** *Magical krypton atom: From definition of meter to ultrafast processes*
17.40 – 18.00	**Vladimir Djokovic** *Fabrication of efficient NIR light-driven micromotors using particles with Janus morphology*
18.00 – 18.15	**Jelena Mitric** *Phonon Investigations in Cd1-xFexTe1-ySey Single Crystals*
18.15 – 18.30	**Filip Krajinić** *Optical system for magnetic field spatial distribution measurement using digital holography*
18.30 – 18.45	**Miljana Piljević** *Selective in vitro labeling of cancer cells using NaGd0.8Yb0.17Er0.03F4 nanoparticles*

Monday, March 11th

Chairman: Goran Mashanovich

16.00 - 16.30	***Refreshment & workshop photo***
16.30 - 17.00	**Vladan Vuletic** *Time-Reversal-Based Quantum Metrology beyond the Standard Quantum Limit*
17.00 - 17.20	**Wenlan Chen** *Observation of universal dissipative dynamics in strongly correlated quantum gas*
17.20 – 17.40	**Alessia Burchianti** *Quantum phenomena and novel matter phases in ultracold atomic mixtures*
17.40 – 18.00	**Stanko Nikolić** *Biomedical Applications of two-Foci Cross-Correlation technique in Massively Parallel Fluorescence Correlation Spectroscopy*
18.00 – 18.15	**Jovana Petrović** *Role of optics in multiparameter monitoring of cardiovascular function*
18.15 – 18.30	**Gabriel Cáceres-Aravena** *Topological Properties of Photonic Systems with Interorbital Interactions*

Chairman: Branislav Jelenkovic

20.00 - 20.10	**Branislav Jelenkovic** *BioQantSense project overview*
20.10 - 20.30	**Caterina Dallari** *Evaluating abnormal levels of intracellular cholesterol through Raman and Surface-enhanced Raman spectroscopy*
20.30 - 20.50	**Markus Gräfe** *Nonlinear interferometers for quantum imaging with undetected light*
20.50 - 21.10	**Frank Setzpfandt** *Entanglement generation at the nanoscale*
21.10 – 21.30	**Sara Nocentini** *The hidden value of responsive materials*
21.30 – 21.50	**Dejan Pantelic** *Classical microscope interference-objectives for quantum holography*
21.50 – 22.10	**Josué Ricardo León Torres** *Mid-Infrared Quantum Scanning Microscopy with Visible Light*

Tuesday, March 12th

Chairman: Ivana Drvenica

16.00 - 16.30	***Refreshment***
16.30 - 17.00	**Srdjan Antic** *Photonics Toolkit for Studying Alzheimer's Disease*
17.00 - 17.20	**Pavle Andjus** *Subcellular and ultrastructural changes in astrocytes induced by ALS IgG*
17.20 – 17.35	**Ana Jakovljević** *The role of tenascin-C in the structural plasticity of perineuronal nets and synaptic expression in the murine hippocampus*
17.35 – 17.50	**Biljana Ristić** *Hemocompatibility evaluation of N-doped carbon quantum dots*
17.50 – 18.10	**Vladimir Srdić** *Light-induced magnetization reversal in heterstructured oxide thin films*
18.10 – 18.30	**Lijian Zhang** *Quantum-limited localization and resolution of optical sources*

Chairman: Bratislav Marinković

20.00 - 20.30	**Goran Mashanovich** *Photonics pathways in higher education*
20.30 - 20.50	**Sanja Djurdjić Mijin** *Cost-Efficient Method for Deterministic Creation of Single Photon Emitters in GaSe*
20.50 - 21.10	**Milica Ćurčić**

	Vibrational properties of the mechanochemically synthesized Cu2SnS3
21.10 – 21.25	**Mirjana Stojanović** *Demultiplexers based on waveguide arrays*
21.25 – 21.40	**Duška Popović** *A dressed states analysis of Autler-Townes patterns in the PES at resonant two-photon ionization of hydrogen by short laser pulses*
21.40 – 21.55	**Dragana Jordanov** *Electronic Properties of Predicted Y2O2S using Theoretical Calculations*
21.55 – 22.10	**Edi Bon** *The Enigma of Changing Look Active Galactic Nuclei*

Wednesday, March 13th

Chairman: Jovana Petrović

16.00 - 16.30	***Refreshment***
16.30 - 17.00	**Vlatko Vedral** *Observing ghost entanglement beyond scattering amplitudes in quantum electrodynamics*
17.00 - 17.20	**Miroslav Dramićanin** *Mn5+: a source of near-infrared photons for LEDs, optical temperature sensors and bioimaging*
17.20 – 17.35	**Vesna Đorđević** *Microwave-Assisted Solvothermal method for synthesis of CsY2F7 and RbY2F7 nanophosphors*
17.35 – 17.55	**Suzana Petrović** *Laser surface patterning of Ti/Zr thin films for biomedical application*
17.55 – 18.15	**Dusan Božanić** *Photoelectron circular dichroism in isolated hybrid nanosystems*
18.15 – 18.30	**Radovan Dojčilović** *Probing cell-nanomaterial interaction with bioimaging of cancer liver cells*

Chairman: Pedja Mihailović

20.00 - 20.20	**Robert Loew** *Precision cw-spectroscopy of Rydberg states of nitric-oxide molecules*
20.20 - 20.40	**Theo Scholtes** *Recent developments in optical magnetometry*
20.40 - 20.55	**Zoran Grujić** *On prospects of the free alignment precession based optically pumped magnetometer*
20.55 - 21.10	**Tim Kügler** *Structured indium tin oxide heating layers on microfabricated alkali vapor cells for optical magnetometry*
21.10 – 21.25	**Marija Ćurčić** *Experimental and theoretical study of the dynamic phase projection error of Mx magnetometer – Progress report*

21.25 – 21.40	**Miloš Subotić** *Lock-in Frequency Estimation Algorithm for Optically Pumped Magnetometer*
21.40 – 21.55	**Milovan Stoiljković** *Hydrogen Balmer-α isotope analysis in aqueous aerosol using LIBS*
21.55 – 22.10	**Nikola Vuković** *Optical and transport properties of THz quantum cascade heterostructures*

Thursday, March 14th

Chairman: Ljupčo Hadžievski

16.00 - 16.30	***Refreshment***
16.30 - 17.00	**Caslav Brukner** *Quantum causal structures: from fundamentals to applications*
17.00 - 17.15	**Milica Vinić** *Diagnostics of laser-induced plasma from a thin oil film*
17.15 – 17.30	**Danijela Danilović** *Ag-Bi-I rudorffite nanoparticles as a new material for photovoltaics*
17.30 – 17.45	**Đorđe Trpkov** *Non-covalent interactions of nitrogen-doped carbon quantum dots and aromatic amino acids, an experimental and DFT study*
17.45 – 18.00	**Dragana Tošić** *Optical Properties of Natural Anthocyanin Dyes Encapsulated in Biopolymers*
18.00 – 18.15	**Danka Stojanović** *Atmospheric aerosols monitoring by scanning mobility and optical particle sizers in an urban area*
18.15 – 18.35	**Robert Loew** *Johannes Kepler, more than an astronomer*

Table of content

Abstracts

Optical system for magnetic field spatial distribution measurement using digital holography

Filip Krajinić[1,2], Petar Atanasijević[1] and Peđa Mihailović[1]

(1) *School of Electrical Engineering, University of Belgrade. Bulevar kralja Aleksandra 73, 11120, Belgrade, Serbia*

(2) *Institute of Physics, University of Belgrade, Photonics Center, Pregrevica 118, 11080, Zemun, Belgrade, Serbia*

Contact: Filip Krajinić (filip@ipb.ac.rs)

Abstract. Spatial distribution of the magnetic field is currently measured with so-called magnetic field cameras, built from the two-dimensional matrix of single point magnetometers, either Hall sensors [1], giant magneto-resistance (GMR) or anisotropic magneto-resistance (AMR) phenomena [2]. Their spatial resolution is limited by the dimensions of the individual sensor element, which is typically in millimeter range. With our research, we present the optical system for measuring the spatial distribution of the magnetic field using the techniques of digital holography to examine the Faraday effect. Faraday crystal in the presence of the magnetic field rotates the polarization of the linearly polarized light. It has been shown that holography with multiple reference waves can be used to measure the state of polarization of the interferometer's object arm [3][4]. We built a holographic setup with two orthogonally polarized reference waves. The laser light is divided into two reference waves and an object wave using a diffraction grating keeping the setup symmetric and simple. We can obtain the intensity of both of the polarization components of the object wave in a single shot. Using the Δ/Ξ normalization of the polarization component's intensities we can calculate the Faraday rotation which is proportional to the applied magnetic field, keeping the result independent on the laser's power fluctuation. The influence of background light on Δ/Ξ normalization is inherently eliminated with holographic approach as the magnetic field information is coded in higher spatial frequencies. Sensitivity of the system is determined by the magnetooptical quality of the Faraday crystal. Spatial resolution is set with the camera's properties (dimensions of the sensor chip), laser's wavelength, and the configuration of the optical setup, and can go down to tens of micrometers. Time resolution is limited by the digital camera framerate.

REFERENCES

[1] H. Phuong, B. Tuan, de Souza-Daw, and T. Hoang, "Magnetic camera for visualizing magnetic fields of home appliances," 2014, doi: 10.1109/CCE.2014.6916732.

[2] A. B. Suksmono, D. Danudirdjo, A. D. Setiawan, D. Rahmawati, and R. P. Prastio, "A Magnetic Field Camera for Real-Time Subsurface Imaging Applications," *Appl. Sci.*, vol. 11, no. 8, 2021, doi: 10.3390/app11083302.

[3] T. Colomb, P. Dahlgren, D. Beghuin, E. Cuche, P. Marquet, and C. Depeursinge, "Polarization imaging by use of digital holography," *Appl. Opt.*, vol. 41, no. 1, pp. 27–37, 2002, doi: 10.1364/AO.41.000027.

[4] L. Han, Z.-J. Cheng, Y. Yang, B.-Y. Wang, Q.-Y. Yue, and C.-S. Guo, "Double-channel angular-multiplexing polarization holography with common-path and off-axis configuration," *Opt. Express*, vol. 25, no. 18, pp. 21877–21886, Sep. 2017, doi: 10.1364/OE.25.021877.

Observation of universal dissipative dynamics in strongly correlated quantum gas

Wenlan Chen

Department of Physics and State Key Laboratory of Low Dimensional Quantum Physics, Tsinghua University, 1000841 Beijing, China

Contact: W. Chen (cwlaser@mail.tsinghua.edu.cn)

Abstract. Dissipation is unavoidable in quantum systems. It usually induces decoherences and changes quantum correlations. To access the information of strongly correlated quantum matters, one has to overcome or suppress dissipation to extract out the underlying quantum phenomena. However, here we find an opposite effect that dissipation can be utilized as a powerful tool to probe the intrinsic correlations of quantum many-body systems. Applying highly-controllable dissipation in ultracold atomic systems, we observe an universal dissipative dynamics in strongly correlated one-dimensional quantum gases. The total particle number of this system follows a universal stretched-exponential decay, and the stretched exponent measures the anomalous dimension of the spectral function, a critical parameter characterizing strong quantum fluctuations of this system. This method could have broad applications in detecting strongly correlated features, including spin-charge separations and Fermi arcs in quantum materials.

REFERENCES (max 6 lines)

[1] Y. Zhao, Y. Tian, J. Ye, Y. Wu, Z. Zhao, Z. Chi, T. Tian, H. Yao, J. Hu, Y. Chen, and W. Chen, *arXiv:2309.10257* (2023).

[2] M. Ye, Y. Tian, J. Lin, Y. Luo, J. You, J. Hu, W. Zhang, W. Chen, and X. Li, *Phys. Rev. Lett. 131, 103601* (2023)

[3] L. Liang, W. Zheng, R. Yao, Q. Zheng, Z. Yao, T. Zhou, Q. Huang, Z. Zhang, J. Ye, X. Zhou, X. Chen, W. Chen, H. Zhai, and J. Hu, *Science Bulletin 64, 2550* (2022)

Optical and transport properties of THz quantum cascade heterostructures

Nikola Vuković[1,2], Novak Stanojević[1,3], Aleksandar Demić[4], Aleksandar Atić[2,5], Xizhe Wang[4], Milan Ignjatović[1], Nikola Basta[1], Dragan Indjin[4], Jelena Radovanović[1,2]

(1) *University of Belgrade, School of Electrical Engineering, Bulevar kralja Aleksandra 73, 11120 Belgrade, Serbia*

(2) Centre for Light-Based Research and Technologies COHERENCE, Belgrade, Serbia

(3) Vlatacom Institute of High Technologies, Belgrade, 11000, Serbia

(4) University of Leeds, School of Electronic and Electrical Engineering, Woodhouse Lane LS2 9JT, Leeds, United Kingdom

(5) *University of Belgrade, Vinča Institute of Nuclear Sciences, Mike Petrovića Alasa 12-14, 11001 Belgrade, Serbia*

Contact: N. Vuković (nvukovic@etf.bg.ac.rs)

Abstract. We present our recent work on modeling quantum cascade laser [1] (QCL) gain media tailored for emission at THz frequencies where we have considered the effects associated with MBE growth that may have a prominent impact on THz QCL transport. GaAs/AlGaAs THz QCL structures were numerically simulated using density matrix formalism [2]. Appropriate lifetimes and dipole moments were calculated using a self-consistent Schrodinger-Poisson algorithm and comprehensive models of scattering rates including interface roughness, ionized impurity, alloy disorder, electron-electron, and electron-phonon scattering. We have considered and evaluated theoretically the most common designs as well as a novel THz QCL design promising for nearly room temperature operation [3]. Furthermore, novel wide bandgap oxide material platforms such as nonpolar m-plane ZnO quantum well structures were numerically investigated since they are predicted to be promising candidates for optoelectronic devices in the THz range owing to large ZnO LO phonon energy which reduces the thermally activated LO-phonon scattering, a possibility to greatly improve the temperature performance of THz QCLs [4,5].

REFERENCES

[1] J. Faist et al., *Science* **264** (1994), 553–556.
[2] A. Demić et al., *IEEE Transactions on Terahertz Sci. Technol.* **7** (2017), 368–377.
[3] A. Khalatpour et al, *Appl. Phys. Lett.* **122** (2023), 161101.
[4] B. Meng et al., *ACS Photonics* **8** (2021), 343-349
[5] A. Atić et al., *Materials* (2024), accepted for publication.

Acknowledgments

This work was financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia under contract number: 451-03-47/2023-01/200103, "Multi-Scale Modeling of Terahertz Quantum Cascade Laser Active Regions", Multilateral scientific and technological cooperation in the Danube region 2020-2021, "DEMETRA: Development of high-performance mid-IR / THz quantum cascade lasers for advanced applications", Science Fund of the Republic of Serbia, Serbian Science and Diaspora Collaboration Programme: Knowledge Exchange Vouchers, COST Action CA21159 PhoBioS, Vlatacom Institute of High Technologies under project 178, and Science Fund of the Republic of Serbia, 10504, "Ultra-short pulsations from TERAhertz quantum cascade laser using passive mode-LOCKing with graphene saturable absorber" - TERALOCK.

Vibrational properties of the mechanochemically synthesized Cu2SnS3

Milica Curcic

Institute of Physics Belgrade, pregrevica 118, 11000 Belgrade, Serbia

Contact: Milica Curcic (milicap@ipb.ac.rs)

Abstract. Cu_2SnS_3 (CTS) is a simple and promising material for solar cells. This material exists in nature as a mineral mohite [1]. The ternary CTS is composed of earth abundant, nontoxic, and inexpensive elements such as Cu, Sn, and S and has a good stability within the Cu–Sn–S family and lack of Fermi level pinning [2,3]. Various physical and chemical techniques have been employed for synthesis of CTS nanocrystals among which mechanochemical synthesis is a great alternative due to its simplicity, solvent-free character, and reproducibility. We present the analysis of the vibration properties of mechanochemically synthesized CTS nanocrystals. The milling time influence on CTS synthesis from elemental precursors Cu, Sn, and S was observed. The scanning electron microscopy (SEM), X-ray diffraction (XRD), and Raman spectroscopy was used to characterize the crystal structure and compositional purity of the obtained nanoparticles. In order to investigate the individual steps of the synthesis, samples obtained after 15 s and 5, 10, 15, and 30 min of milling time were analyzed. The detailed analysis of the Raman spectra has allowed us to determine the wavenumber of the main and weaker peaks, and discern the phase, crystal structure, and secondary phases. The formation of monoclinic and tetragonal CTS phases, with oxidized surface (due to milling in air) was confirmed.

REFERENCES

[1] V. R. M. Reddy, M. R. Pallavolu, P. R. Guddeti, S. Gedi, K. K.Y. B. Reddy, B. Pejjai, W. K. Kim, T. R. R. Kotte, C. Park, *J. Ind. Eng. Chem*. (2019), 76, 39.

[2] P. Zawadzki, L. L. Baranowski, H. Peng, E. S. Toberer, D. S. Ginley, W. Tumas, A. Zakutayev, S. Lany, Appl. Phys. Lett. 2013, 103, 1.

[3] L. L. Baranowski, P. Zawadzki, S. Christensen, D. Nordlund, S. Lany, A. C. Tamboli, L. Gedvilas, D. S. Ginley, W. Tumas, E. S. Toberer, A. Zakutayev, Chem. Mater. 2014, 26, 4951.

Directions in all-optical computing with an emphasis on the Fabry Perot laser-lock-in approach

Peđa M. Mihailović, Petar A. Atanasijević[1], Mladen Ž. Banović[1], Marko M. Krstić[1],

Jasna V. Crnjanski[1], Slobodan J. Petričević[1], Dejan M. Gvozdić[1]

(1) *School of Electrical Engineering, University of Belgrade, Bulevar kralja Aleksandra 73, 11120, Belgrade, Serbia*

Contact: P. Mihailović (pedja@etf.bg.ac.rs)

Abstract. What is all-optical-computing, why to research it and how to achieve it? Among the waste number of possibilities [1] the digital computing based on semiconductor optical amplifier it the most widely studied [2] although interferometer-based [3] and photonic crystal-based designs are also widely present [2]. Use of light polarization was also proposed [4]. One way to do the optical computing is to use injection locking of Fabry–Perot laser diodes. We demonstrated "harlequin" NOR logical gate, basis for Boolean logic. We call it "harlequin" since the two input and one output signal are all at different wavelengths. Although this fact prevents forming the binary computer at the moment there are ways to overcome this difficulty in physics and mathematics. We proposed a model of nonlinear transfer function based on two parameters, detuning and light power and experimentally verified it in the stationary case [5]. Lowering dissipation and increasing computing speed while keeping the production cost (energetic and economic) low are unattainable right now. Yet unlike for computers in the electrical domain increased speed leads to decreased power consumption. Also control of the nonlinear transfer function by the third optical signal opens other computational possibilities.

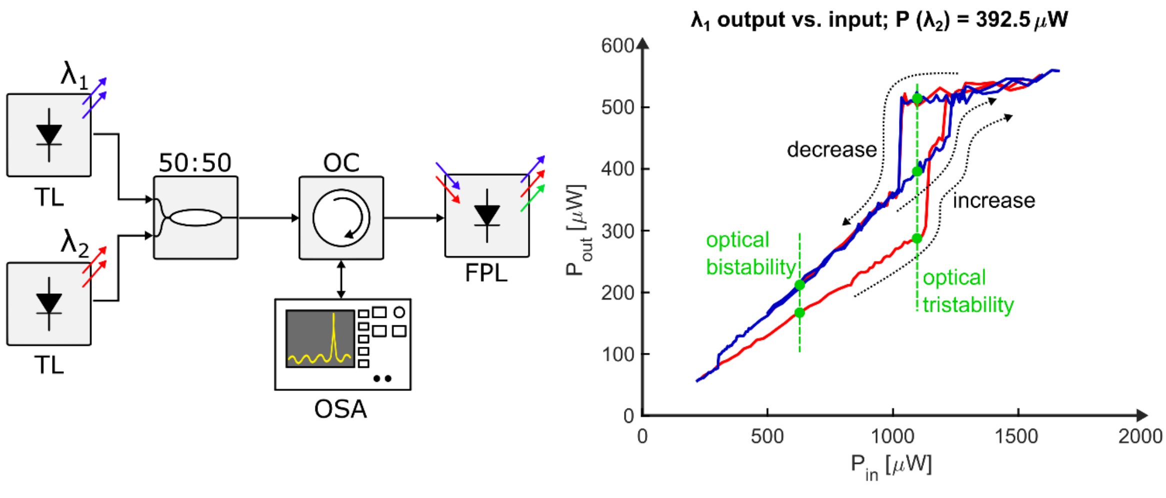

Figure 1. Shematic setup of dual injection-locking with optical power hysteresis loops for both injection-locked modes.

REFERENCES

[1] P. Minzioni et al., *J. Opt.* 21 (2019), 063001.

[2] E. G. Anagha, R. K. Jeyachitra, *Optical Engineering* 61 (2022), 060902-1– 060902-31.

[3] K. Singh, G. Kaur, *Proc. Optics &LaserTechnology* 69 (2015), 122–132.

[4] J. Yi et al., *SCIENCE IN CHINA (Series F)* 46 (2003), 145-150.

[5] M. Banović, P. Atanasijević et al., *Opt. Lett.* 48 (2023), 4165-4168.

Hydrogen Balmer-α isotope analysis in aqueous aerosol using LIBS

Đorđe Kapuran, Filip Veljković, Suzana Veličković, Branko Matović, Milovan Stoiljković

Vinča Institute of Nuclear Sciences,PO Box 522, 11 351, Belgrade, Serbia

Contact: M. Stoiljković (missa@vinca.rs)

Abstract. The aspect of quantifying the D/H isotope ratio in liquids by measuring the corresponding Balmer-α line shapes in laser-induced breakdown plasma was presented. [1] The concept is based on the fact that the resulting line shape should correlate with the H/D ratio in the mixture. A CO_2 laser with a microsecond pulse of 10.6 µm and an average power of 110 kW was used to generate the plasma. After the pulse hit the interface, the emitting plasma expanded into aerosol. The aerosol was generated by spraying pure H_2O, D_2O and their mixtures through a Meinhard nebulizer supported by Ar gas. Since hydrogen as the lightest element has the largest isotopic shift, we were able to measure the H-α and D-α line shapes with a wavelength accuracy of 0.005 nm, despite the moderate spectral resolution we used (0.73±0.02 nm/mm). The line shapes were fitted using the pseudo-Voitgh function and the Doppler and Stark line widths were deconvoluted.

We found an isotopic shift of 0.185±0.005 nm, which agrees well with the NIST database [2] and the results of Mittelmann at al. obtained with deuterium and hydrogen-doped W metal [3]. The Doppler widths of the hydrogen and deuterium shapes are 0.066±0.005 and 0.048±0.005 nm, respectively, corresponding to an H/D isotope ratio of 1.4±0.2, which is $2^{0.5}$, as expected. We have shown that the Doppler and Stark widths are more sensitive to the H/D ratio in the aerosol than the resulting shape shift.

To determine the fraction of D_2O in the mixture with H_2O, which is referred to as DH, we should compare the Doppler widths of the mixture and the pure water H_2O, which is referred to as DH/H. The DH/H ratio should fulfil the criterion $1 \leq DH/H \leq 2^{-0.5}$. Since we are dealing with mixtures, the previous criterion is modified to $(1 \leq m_H \cdot x + m_D \cdot y \leq 2)^{0.5}$, where x and y denote the molar fractions of H_2O and D_2O, respectively, and $m_H=1$ and $m_D=2$ denote the relative atomic weights. The given inequality can be solved numerically by applying the condition x+y=1. For example, when x equals y, the ratio DH/H= 0.82.

REFERENCES

[1] Kuzmanović at al, Spectrochim Acta B, 157 (2019) 37-46
[2] https://physics.nist.gov/
[3] M. Mittelmeann et al., Scientific Reports 13 (2023) 2285 (https://doi.org/10.1038/s41598-023-29138-2)

A dressed states analysis of Autler-Townes patterns in the PES at resonant two-photon ionization of hydrogen by short laser pulses

Duška B. Popović[1], Andrej Bunjac[1], Nenad S. Simonović

(1) *Institute of Physics, University of Belgrade, Pregrevica 118, 11080 Belgrade, Serbia*

Contact: D. Popović (duska@ipb.ac.rs)

Abstract. Interaction of atoms with a strong laser field leads to transitions between the atomic states as well as to modification (shifting and splitting) of the atomic energy levels. We examined the Autler-Townes (AT) splitting and additional modulations (multiple-peak structure) of the resonant peak in the photoelectron energy spectra (PES) at two-photon ionization of hydrogen by intense short laser pulses, which occur via one-photon resonant 1s -> 2p transitions [1]. The number of peaks appearing in the pattern was found to match the number of Rabi flopping of the population between the 1s and 2p states during the pulse [2]. Analysis in terms of dressed states, which are eigenstates of the atomic Hamiltonian including the coupling with the laser field (the so-called dressed Hamiltonian), directly explains the appearance of the AT splitting of the resonant peak in the PES. Using this approach, it is shown that the mechanism of formation of multiple-peak structures during the photoionization process is the same regardless of the pulse [3].

REFERENCES

[1] Bunjac, D.B.Popović and N.S.Simonović, *Eur.Phys.J D* **76** (2022), 249

[2] V.Demekhin, L.S.Cederbaum, *Phys.Rev.A*, **86** (2012), 063412

[3] N.S.Simonović, D.B.Popović and A. Bunjac, *Atoms* **11** (2023), 20

Laser surface patterning of Ti/Zr thin films for biomedical application

Suzana Petrović, Nevena Božinović, Vladimir Rajić, Mirjana Novaković, Jelena Potočnik, Maja Popović

(1) *Department of Atomic Physics, Vinča Institute of Nuclear Sciences, University of Belgrade, P.O.Box 522, 11001 Belgrade, Serbia*

Contact: S. Petrović (spetro@vin.bg.ac.rs)

Abstract. The experimental study of the dynamic femtosecond laser patterning of the Ti/Zr/Ti thin film system is reported. The design of surface pattering with the micro- and nanometre features in the form of laser-induced periodical surface structure (LIPSS) and spikes is investigated to obtain the arrayed surface structures for biomedical applications. Femtosecond laser pulses were used to create a mesh consisting of LIPSS within laser-drawn lines. These well-defined and sufficiently long LIPSS are oriented normally to the laser polarization indicating that LSFL (low frequency spatial LIPSS) periodic structures were formed. The LSFLs are characterized by a spatial period close to the radiation wavelength, which can be attributed to optical interference between the incident laser beam and the surface electromagnetic wave created during irradiation. To acquire black silicon surfaces decorated with conical structures (spikes) on crystalline silicon surfaces, the fs pulses were used under 0.65 bar of SF6 environmental atmosphere. After irradiation, the silicon surface exhibits high aspect ratio spikes, with conical shapes of about 2 mm height, 40° angle opening, 13x106 cm−2 density that remains approximately uniform across the processed area. Spike formation has been attributed to a complex mechanism initiated by partial material melting and subsequent capillary wave formation driven by surface tension gradients within the molten region. On pre-patterned and pure Si substrate were deposited Ti/Zr/Ti composite thin films composed of two Ti and subsurface distributed Zr layers (thickness of 10 nm) by ion sputtering to the total thickness of 300 nm. The composition, surface morphology and wetting properties were analyzed by scanning electron microscopy (SEM-EDS), profilometry and wettability measurements.

Micro- and nanopatterned mesh with LIPSS arrays on composite Ti/Zr/Ti thin film systems was used to observe the effects of surface morphology on survival, adhesion and proliferation of the MRC-5 cell culture line. To determine whether Ti/Zr/Ti thin films have a toxic effect on living cells, an MTT assay was performed. The relative cytotoxic effect as a percentage of surviving cells showed that no difference in cell number between the Ti/Zr/Ti thin films and the control cells. There was also no difference in the viability of the MRC-5 cells.

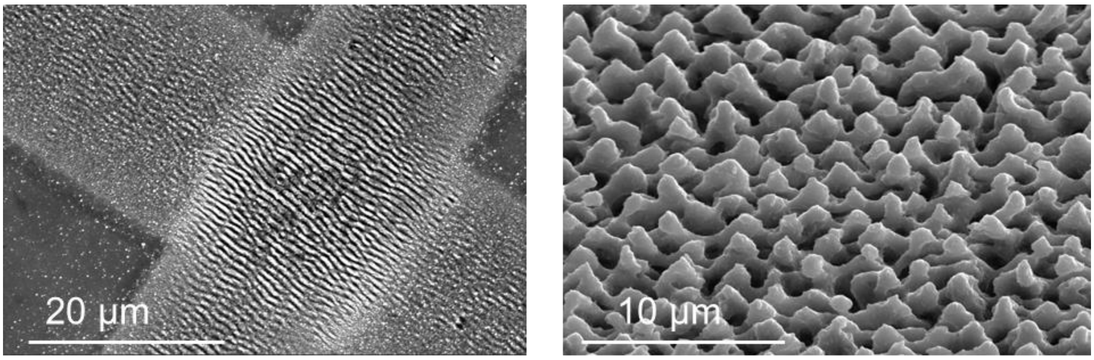

Figure. SEM images of LIPSS periodic structure Ti/Zr/Ti thin films and spikes on the laser-processed silicon surface

Diagnostics of laser-induced plasma from a thin oil film

Milica Vinić

Institute of Physics, University of Belgrade, Belgrade, Serbia

Contact: mvinic@ipb.ac.rs

Abstract. Parameters of plasma formed by ablation of thin oil films deposited on a silica wafer substrate [1] were explored. The preferred oil film thickness was managed by controlling the speed of rotation of samples during the preparation phase. Hydrogen Balmer alpha line (H_α) was used to determine electron number density N_e. Spectral line intensity ratios of the successive ionization stages of the magnesium have been used to determine ionization temperature, T_{ion}. The temperature of heavy particles in the plasma (rotational temperature, T_{rot}, and vibrational temperature, T_{vib}) was estimated by comparing the experimental and simulated emission spectra of C_2 and CN molecules. In addition, time evolutions of the spectral intensities, electron number density, and temperature were deduced from time-integrated measurements by subtracting averaged spectra obtained at different time delays [2]. We must have in mind that all spectral measurements reported in this work were spatially integrated. Therefore, all plasma parameters (N_e, T_{ion}, T_{rot} and T_{vib}), including the calculated time-resolved values, are the apparent values of these parameters. For inhomogeneous spectrochemical sources such as laser-induced plasma, the parameters resulting from spatially integrated measurements represent population averages of the local temperature and electron number density values, *i.e.*, they describe the source but are different from the local values [3]. True plasma parameters, *i.e.*, spatial and temporal distribution of plasma parameters, were difficult to determine due to small plasma volume, large gradients of T and N_e, and the limited reproducibility of emission intensity measurements [4].

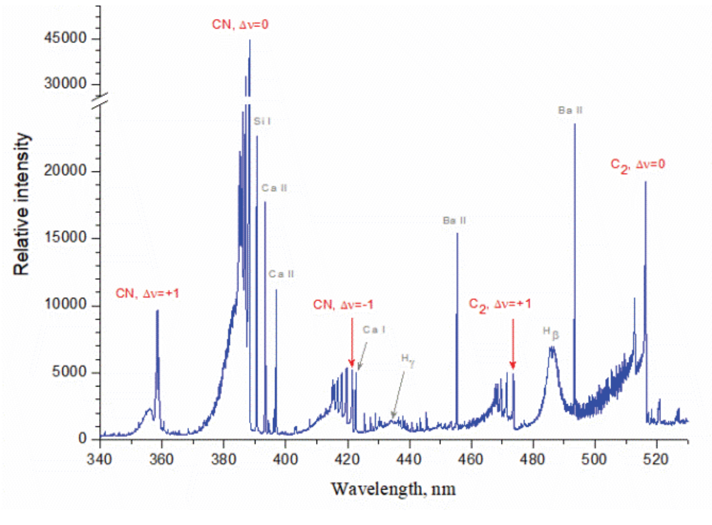

Figure 1. LIBS spectra of oil sample showing characteristic emission bands of C_2 and CN molecules.

REFERENCES

[1] M. Vinić et al., *Spectrochim. Acta, B* **164** (2020), Article ID 105765.
[2] E. Grifoni et al., *J. Spectrosc.* **2014** (2014), Article ID 849310.
[3] C. Aragón, J. A. Aguilera, *Spectrochim. Acta, B* **63** (2008), 893-916.
[4] M. Vinić et al., *J. Serb. Chem. Soc.* **88** (2023), 153–167.

Biomedical Applications of two-Foci Cross-Correlation technique in Massively Parallel Fluorescence Correlation Spectroscopy

Stanko N. Nikolić[1,2,3], Sho Oasa[3], Aleksandar J. Krmpot[1,2,3], Lars Terenius[3], Milivoj R. Belić[1], Vladana Vukojević[3]

(1) *Division of Arts and Sciences, Texas A&M University at Qatar, P.O. Box 23874, Doha, Qatar*

(2) *Institute of Physics Belgrade, Pregrevica 118, 11080 Belgrade, Serbia*

(3) *Department of Clinical Neuroscience (CNS), Center for Molecular Medicine (CMM), Karolinska Institute, 17176 Stockholm, Sweden*

Contact: S. Nikolić (stankon@ipb.ac.rs)

Abstract. We report the use of the two-foci cross-correlation technique in a massively parallel fluorescence correlation spectroscopy (mpFCS) system to analyze the motion of different fluorescent molecules inside the specimen [1]. The mpFCS experimental setup enables the measurements of the raw photon counts over the independent 64x32 confocal observation volume elements (OVEs). Our theoretical model provides connection between characteristics of motion and the features of auto-correlation (ACFs) and two-foci cross-correlation functions (tfCCF), calculated from the large raw dataset. We first perform the cross-correlation analysis of directional motion of 100 nm fluospheres in a 20 nM suspension. We show that tfCCF between signals from two nearby OVEs contains a sharp peak when the OVEs are positioned along the trajectory of molecular motion, and that the time position of the peak corresponds to the average time of flight of the molecule between the two OVEs. Next, we present the proof-of-concept measurements for controlled translation of immobilized quantum dots. The ACFs and tfCCFs reveal the information about the diameter of the OVE and q-dots velocity vector. Finally, we use the cross-correlation analysis in the mpFCS system to map the directionality of glucocorticoid receptor (GR) translocation in live cells. In our setup, the direction and velocity of nucleocytoplasmic transport can be determined simultaneously at several locations along the nuclear envelope. Our data show that mpFCS can characterize the heterogeneity of directional nucleocytoplasmic transport and provide more details on the bidirectional flow of macromolecules through the nuclear pore complex. The experimental setup, illumination matrix, and tfCCFs of GR fused with the enhanced green fluorescent protein (eGFP-GR) are shown in figure 1.

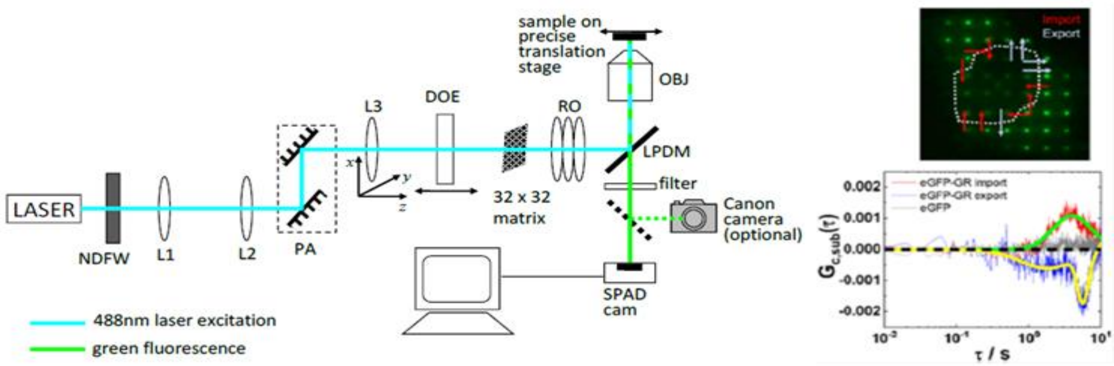

Figure 1. Experimental setup (left), illumination matrix (top-right), and two-foci cross-correlation functions of eGFP import and export motions (bottom-right).

REFERENCES

[1] S. N. Nikolić, S. Oasa et al., *Anal. Chem.* **95** (2023), 15171–15179.

Magical krypton atom: From definition of meter to ultrafast processes

Bratislav P. Marinković

Institute of Physics Belgrade, Pregrevica 118, 11080 Belgrade, Serbia

Contact: bratislav.marinkovic@ipb.ac.rs

Abstract. From 1960 to 1983 the transition $2p_{10}\leftarrow 5d_5$ (in Paschen notation) of krypton-86 was used to define meter by using 1,650,763.73 its wavelengths in vacuum. It is a reddish-orange light of relatively low intensity. The first Nat. Bureau of Standards' spectrum of Kr from year 1929 specified the wavelength for this transition to be 6056.11 Å [1]. That would give, as presently defined speed of light, the length of 0.999803 m. At that time another transition was set for a close look-up to substitute the cadmium 6438.4696 Å line as a primary standard of wave length, i.e., Kr $1s_3\leftarrow 3p_{10}$ line at 5649.56 Å. The partial energy level diagram with Paschen's notation for each manifold could be find e.g. in [2]. Unfortunately, that definition cannot be realized to better than about 4 parts in 10^9 [3]. In *j-l* coupling and todays NIST database notation [4] this is the transition with the wavelength of 6056.12628 Å in air and it is attributed to the transition from the $4s^2 4p^5(^2P^\circ_{3/2})6d\ ^2[1/2]^o$ J=1 (11.35014101 eV) to the $4s^2 4p^5(^2P^\circ_{3/2})5p\ ^2[1/2]^o$ J=1 (11.30345525 eV) state. The basic reference for these NIST states and transition comes from [5]. This wavelength calculated in vacuum by formula $\lambda_{air} = \lambda_{vac}/n$, where n is the index of refraction of air as derived from the five-parameter formula [6], is 6057.80298 Å, giving the deviation of 1.44×10^{-7} m.

Atomic number of krypton is 36 and its ground electron configuration is $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6$. Its inner shell excitation spectrum is rather complex [7]. Auger electrons coming from filling L_2 and L_3 subshells of Kr span the energy range from 1250 eV to 1550 eV [7], while the binding energy of the 1s orbital is of the order of 14.3 keV. Ejected electron spectra in the lower energy region have been studied in [8] where the $M_{4,5}$-NN Auger and $M_{2,3}$-$M_{4,5}$N Coster-Kronig spectra induced by electron impact are shown. The large widths of the $3p_{1/2}$ and $3p_{3/2}$ (1.80 eV and 1.48 eV, respectively) and the natural width of the 3d shell of (88 ±4) meV indicate fast relaxation processes even in this part of the spectrum. Time-and-energy-resolved measurement of Auger cascades following Kr 3d excitation by attosecond pulses [9] reveled that the electrons with a kinetic energy around 25 eV (assigned as $M_{4,5}N_1N_1\ ^1S_0$ normal Auger lines) have a component corresponding to the second-step Auger decay of the ion after resonant Auger transition $3d^{-1}np\rightarrow 4s^2 4p^3 4dnp\rightarrow 4s^2 4p^4$ with a lifetime of 26±4 fs. The calculated lifetime of super-Coster–Kronig transitions is small, of the order of 0.1 fs. A fast transition means a broad line (about 6–7 eV), so, these weak and broad lines can hardly be discerned in the experiment and contribute to the background [9].

ACKNOWLEDEMENTS: This research was supported by the Science Fund of the R. Serbia, grant #6821, project name: "Atoms and (bio)molecules-dynamics and collisional processes on short time scale" (ATMOLCOL).

REFERENCES

[1] W.F. Meggers, T.L. de Bruin, and C.J. Humphreys, *Bureau of Standards J. Research* **3** (1929), 129-162.
[2] J.E. Chilton, M.D. Stewart, Jr., and C.C. Lin, *Phys. Rev. A* **62** (2000), 032714.
[3] Documents Concerning the New Definition of the Metre, *Metrologia* 19, (1983), 163-178.
[4] A. Kramida, Yu. Ralchenko, et al. (2023). NIST Atomic Spectra Database (ver. 5.11), [Online]. Available: https://physics.nist.gov/asd [2024, January 31]. Nat. Inst. Standards and Technology, Gaithersburg, MD.
[5] E.B. Saloman, *J. Phys. Chem. Ref. Data*, **36** (2007), 215-386.
[6] E.R. Peck K. Reeder, K. *J. Opt. Soc. Am*. **62** (1972), 958-962.
[7] L.O. Werme, T. Bergmark and K. Siegbahn, *Physica Scripta* **6** (1972), 141-150.
[8] J.J. Jureta, B.P. Marinković, L. Avaldi, *J. Quant. Spectrosc. Radiat. Transf.* **268** (2021), 107638.
[9] A.J. Verhoef, A.V. Mitrofanov et al. *New J. Phys*. **13** (2011), 113003.

Time-Reversal-Based Quantum Metrology beyond the Standard Quantum Limit

Vladan Vuletić

Department of Physics, MIT-Harvard Center for Ultracold Atoms and Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA

Abstract. Linear quantum measurements with independent particles are bounded by the Standard Quantum Limit (SQL). However, the SQL can be overcome if it is possible to generate entanglement between many particles. Such entanglement can be created via the interaction of atoms with light in an optical resonator. For an optical transition clock, we have demonstrated a 4dB improvement of the clock precision by optically induced entanglement.

However, the metrological gain from entanglement is often limited by the final state readout rather than the state preparation, especially for more complex entangled many-body states. An alternative is to use a time-reversal protocol to amplify small displacement of the entangled state. We implement such a time-reversal protocol through a controlled sign change in the many-body Hamiltonian of atomic spins coupled to an optical cavity. With this approach, we demonstrate an improvement of 12 dB beyond the SQL. We also use the time-reversed Hamiltonian to experimentally investigate the relation between quantum information scrambling, out-of-time-order correlators and metrological gain.

Single-pulse and scanning multiple-pulse ultrafast laser beam interaction with Ti/Zr multilayer thin films

Aleksander G. Kovačević[1], Suzana Petrović[2], Giorgos D. Tsibidis[3], Nevena Božinović[2], Davor Peruško[2], Alexandros Mimidis[3], Aleka Manousaki[3], Emmanuel Stratakis[3]

(1) *Institute of Physics, University of Belgrade, Pregrevica 118, 11080 Belgrade, Serbia*

(2) *Institute of Nuclear Sciences "Vinča", University of Belgrade, P.O.Box 522, 11001 Belgrade, Serbia*

(3) *Institute of Electronic Structure and Laser (IESL), Foundation for Research and Technology (FORTH), N. Plastira 100, Vassilika Vouton, 70013 Heraklion, Crete, Greece*

Contact: A. Kovačević (aleksander.kovacevic@ipb.c.rs)

Abstract. Ultrafast laser surface structuring gains more popularity due to the ability to improve material characteristics, such as reduction of friction and wear, improving solar cell performances, activate biomaterials, increase wettabilty etc. [1]. Compared to longer-pulsed beams, femtosecond beam interaction with materials has small heat-affected zone (HAZ) leading to fine modification with precise ablation [3]. Linearly polarized ultrashort laser beam (multiple pulses) can generate periodic surface structures (LIPSS) of sub-wavelength spatial periods on the surface of materials among which metals are of interest [4-6].

Multilayer nano-scaled thin metal film materials are attractive for applications in biomedicine as implants or tools, as protective coatings, optical devices, catalytic components… [7]. Having similar characteristics, Ti and Zr are metals interesting to combine in specific geometries, like multilayer thin films. The interaction of ultrafast laser beams with multilayer Ti/Zr thin films can lead to the formation of LIPSS and to selective ablation (layer-by-layer) of the material from the surface [8].

After static single-pulse irradiation for specific range of pulse energies, ablation region in the form of concentric circles appeared. For both lower and higher energies, the number of circles decreased. During multipulse scanning irradiation, where scan velocities varied, LIPSS of different spatial periodicity were formed.

Acknowledgements. This project has received funding from the EU-H2020 research and innovation programme under grant agreement N 654360 having benefitted from the access provided by Foundation for Research and Technology Hellas (FORTH) access provider (Institute of Electronic Structure and Lasers i.e. Institution) in Heraklion, Crete, Greece within the framework of the NFFA-Europe Transnational Access Activity. The research was funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia through the Institute of Physics and the Institute "Vinča". Support from COST Action CA17126 - TUMIEE (supported by COST-European Cooperation in Science and Technology) is also acknowledged.

REFERENCES

[1] A.Y. Vorobyev, C. Guo, *Laser Photon. Rev.* **7** (2013), 385–407.
[2] J. Kruger, W. Kautek, *Appl. Surf. Sci.* **96–98** (1996), 430–438.
[3] G.D. Tsibidis, M. Barberoglou, et al., *Phys. Rev. B* **86** (2012), 115316.
[4] J. Bonse, A. Rosenfeld, et al., *J. Appl. Phys.* **106** (2009), 104910.
[5] A.G. Kovačević, S. Petrović, et al., *Appl. Surf. Sci*. **326** (2015), 91–98.
[6] D. Peruško, M. Mitrić, et al., *J. Mater. Sci.* **43(8)** (2008), 2625–2630.
[7] S. Petrović, G. D. Tsibidis, et al., *Eur. Phys. J. D* **75** (2021), 304(10).

Role of optics in multiparameter monitoring of cardiovascular function

Jovana Petrović[1], Aleksandar Lazović[1], Predrag Tadić[2], Natalija Đorđević[2], Vladimir Atanasoski[1], Marija D. Ivanović[1], Boško Bojović[1], Ljupčo Hadžievski[1], Arsen Ristić[3], Vladan Vukčević[3]

Vinča Institute of Nuclear Sciences, National Institute of Republic of Serbia, University of Belgrade, P.O. Box 522, 11001 Belgrade, Serbia
The School of Electronic Engineering, University of Belgrade, Bulevar kralja Aleksandra 73, 11000 Belgrade, Serbia
Department of Cardiology, University Clinical Center of Serbia, Faculty of Medicine, University of Belgrade, Dr. Subotića 8, 11000 Belgrade, Serbia

Contact: J. Petrovic (jovanap@vin.bg.ac.rs)

Abstract. Cardiovascular diseases (CVDs) are the primary cause of human death worldwide. For example, they were responsible for 77.0% of deaths at ages 30 to 70 in 2019, with the burden expected to rise [1]. Therefore, diagnosis, prevention, monitoring and treatment of CVDs are among the primary societal challenges. Mobile sensor devices, notably electrocardiographs (ECGs) and photoplethysmographs (PPGs), are fundamentally changing the approach to CVD diagnostics and monitoring. Optics plays a significant role in this revolution, offering new noninvasive sensing solutions and access to new valuable information.

Here, I will introduce photoplethysmography as a method for noninvasive measurement of arterial and heart waveforms and cardio-respiratory coupling. Two PPG embodiments realized in our group will be presented: optical fibre-grating sensors [2] and free-space PPGs built into a multisensory system [3]. The measured waveforms carry information on heart rhythm, timing of events in the cardiac cycle (e.g., valve opening and closure), blood volume in arteries, and other. They are typically used in the monitoring of heart arrhythmias and arterial stiffness. The combination of PPG and ECG is emerging as a powerful tool for the extraction of biomarkers of hypertension [4] and heart failure [5].

However, the increasing accessibility of the sensors and multisensory systems does not automatically translate into the satisfactory reproducibility and reliability of data collection and interpretation. I will discuss the main challenges before the routine use of multisensory systems in personalized medicine and present the recent efforts of our group aimed at their resolution. These efforts entail using large arteries in PPG measurements [3], experimental and numerical noise cancellation techniques [6] and stratification of benign arrhythmias.

This research is supported by the Science Fund of the Republic of Serbia, Grant. No. 7754338, Multi-SENSor SysteM and ARTificial intelligence in service of heart failure diagnosis – SensSmart, and the Ministry of Science, Technological Development and Innovaton of the RS, Grants No. 451-03-47/2023-01/200017 and 451-03-47/2023-01/200103.

REFERENCES

[1] F. Bray, M. Laversanne et al. *Cancer Treatment Reviews* **100** (2021) 102290
[2] M. D. Ivanović, J. Petrovic et al. *Physiol. Meas.* **39** (2018) 045009
[3] A. Lazović, N. Djordjević et al. Proceedings of the 2nd International Conference on Chemo and Bioinformatics ICCBIKG 2023, pp. 43-50, https://doi.ub.kg.ac.rs/doi/zbornici/10-46793-iccbi23-043l/
[4] M. Elgendi, R. Fletcher at al. *npj Digital Medicine* **2** (2019) 60
[5] A. M. Weissler, W. S. Harris and C. D. Schoenfeld, *Circulation* **37** (1968) 149.
[6] V. Atanasoski, J. Petrovic et al., *IEEE Open J. Eng. Med. Biol.* 4 (2023) 222-225

Quantum causal structures: from fundamentals to applications

Caslav Brukner

Institute for Quantum Optics and Quantum Information Vienna, Austria

Contact: caslav.brukner@univie.ac.at

Abstract. Indefinite causal structures not only enable advanced quantum information processing, but can also represent novel causal structures arising from superpositions of causal orders in quantum mechanics. I will introduce the main concepts and methods and give an overview of the state of this rapidly developing field.

Fabrication of efficient NIR light-driven micromotors using particles with Janus morphology

Vladimir Djoković,[1] Danijela Danilović[1], Jelena Pajović[2], Radovan Dojčilović[1], Djordje Trpkov[1], Dušan K. Božanić[1]

(1)*"VINČA" Institute of Nuclear Sciences - National Institute of the Republic of Serbia, University of Belgrade, P.O. Box 522, 11001 Belgrade, Serbia*

(2) *Faculty of Physics, University of Belgrade, PO Box 368, 110001 Belgrade, Serbia*

Contact: V. Djoković (djokovic@vin.bg.ac.rs)

Abstract. In recent years, there has been a growing interest in the development of micro/nano motors (MNMs). Investigations of these sophisticated systems provide new insights related to manipulation of objects at small scales. Micro/nano motors exhibit controlled movement in fluids, responding to various external stimuli such as thermal, magnetic, and light. They can perform specific operations, including propelling micromachines. In our study, we synthesized two types of hybrid Janus particles: Au/TiO_2 and $AgAg_2S/TiO_2$, exploring their potential as light-driven micromotors. Light serves as a versatile power source, enabling non-invasive control over the motors with high spatial and temporal resolutions. Illumination induces asymmetric reactions on the two sides of the Janus particles, generating propulsion. To enhance the properties of the MNMs, we conducted synchrotron radiation gas-phase photoemission spectroscopy (SR PES) on the freestanding hybrid particles at Synchrotron SOLEIL in France. SR PES offered valuable information about the valence level alignment of the components, potential hybrid states, and the dominant scattering processes involved.

REFERENCES

[1] H. Šípová-Jungová, D. Andrén, S. Jones, M. Källm, Chem. Rev. **120**, 1269–1287 (2020)

[2] D. Danilović, D. K. Božanić, G. A. Garcia, L. Nahon, U. Stamenović, V. Vodnik, V. Djoković, Opt. Quantum Electron., **54**, 604 (2022).

[3] V. Djoković, R. Krsmanović, D. K. Božanić, M. McPherson, G. Van Tendeloo, P. S. Nair, M. K. Georges, T. Radhakrishnan, Colloids Surf. B, 73, 30-35, (2009)

Subcellular and ultrastructural changes in astrocytes induced by ALS IgG

Pavle Andjus[1], Dunja Bijelić[1], Ana Jakovljević[1], Fabricio Quiros-Corella[2], Lidija Radenović[1], Reynaldo Pereira Reyes[3], Jose Roberto Vega Baudrit[3], Yendry Corales Urena[3]

(1) Center for laser microscopy, Institute for Physiology and Biochemistry "Jean Giaja", Faculty of Biology University of Belgrade, Belgrade, Serbia

(2) Advanced Computing Laboratory National High Technology CenterSan Jose, Costa Rica

(3) National Laboratory of Nanotechnology, National High Technology Center, San Jose, Costa Rica

Contact: P. Andjus (pandjus@bio.bg.ac.rs)

Abstract. We and others have shown previously that immunoglobulin G (IgG) from Amyotrophic Lateral Sclerosis (ALS) patients induces various biophysical changes on cells of the neural system – neurons and glia as well[1-4]. These changes are: induced excitability in neurons, calcium transients in neurons and astrocytes, induced vesicle trafficking in astrocytes and generation of free radicals in microglia. In addition we observed changes in biomolecular expression in glial (astrocytes and primary microglia) cells under the influence of ALS IgG (not published).

In this work we wanted to check if ALS IgG can also cause observable subcellular and ultrastructural changes on cultured primary astrocytes. In this respect we used Scanning Electron Microcopy (SEM) and Atomic Force Microscopy (AFM) on fixed rat astocytes previousl y treated with ALS or healthy (CTRL) IgG.

With SEM and subsequent fractal analysis and texture analysis (grey-level co-occurrence matrix method – GLCM). The fractal analysis showed a rise in the fractal dimension and lacunarity with IgG treatment that was different from un-treated (naïve) cells, however there was no significant difference between the two types of IgG treatments. On the other hand the GLCM analysis in addition showed also the difference (in most of the parameters) between cells treated with CTRL IgG and those treated with ALS IgG. We also performed a Semantic Segmentation in microscopic images of cell membrane protrusions – the microvilli on astrocytes using a visual learning pipeline. It consists of an unsupervised categorization method based on a Machine Learning algorithm that clusters sub-cellular structures detected with Computer Vision tools[5]. There was a significant ($p<0.0001$) increase in microvilli area in ALS and control group compared to the naive group. Regarding morphology, microvilli were divided into 0-most elongated, 1- medium and 2 – most rounded. A significant increase in microvilli number was seen in ALS compared to the non-treated group for classes 1 and 2 ($p=0.046$ and $p=0.048$, resp.), where no difference between groups was reported in microvilli number from class 0.

AFM of the cell membrane of astrocytes demonstrated an increase in roughness and decrease in Young's modulus upon treatment with IgGa and a difference between the two IgG treatments. The cells become "softer" with ALS IgG compared to CTRL IgG and naive cells. This study thus demonstrates that the biophysical effects of ALS IgG is also followed by fine morphological and ultrastructural changes observed on the cell surface that deserve to be further studied for their physiological significance.

REFERENCES

[1] Andjus et al. J Physiol. 1997; 504 (Pt 1):103
[2] Milošević et al. Cell Calcium 2013; 54:17
[3] Stenovec et al. Acta Physiol (Oxf). 2011; 203:457
[4] Milošević et al. Front. Immunol. 2017; 8:1619
[5] Quiros-Corella et al. IEEE 2024 (in press)

Light-induced magnetization reversal in heterstructured oxide thin films

Jelena Vukmirović[1], Danica Piper[1], Iva Toković[1], Sara Joksović[2], Mirjana Novaković[3], Ivan Stijepović[1], Marija Milanović[1], Pavla Šenjug[4], Damir Pajić[4], Vladimir V. Srdić[1,*]

(1) *Department of Materials Engineering, Faculty of Technology, University of Novi Sad, Serbia*

(2) *Biosense Institute, University of Novi Sad, Serbia*

(3) *Department of Atomic Physics, Vinča Institute of Nuclear Sciences - National Institute of the Republic of Serbia, University of Belgrade, Serbia*

(4) *Department of Physics, Faculty of Sciences, University of Zagreb, Croatia*

Contact: V.V. Srdić (srdicvv@uns.ac.rs)

Abstract. Recent developments in big data, the internet and artificial intelligence are causing an enormous growth of digital data usage and storage. Thus, a faster and more energy efficient approach of writing and recording data into magnetic data storage are required. For this application, multifunctional materials, such as multiferroics, characterized with the coexistence of at least two ferroic orders have attracted considerable attention of many researchers. Another type of novel multifunctional materials with magneto-electro-optical coupling has also come into the focus of current research. Namely, it was shown that the use of short laser pulses makes them more attractive alternative to the classical devices in which magnetic field is used to reverse the magnetization. It has been recognized that such multifunctional materials in form of thin films are not only important in information technologies, but will also contribute to the development of other nanoelectronic devices and offer new applications in different fields.

Manganite-based materials with a perovskite structure offer an optimal platform for designing multifunctional heterostructured systems. Within this class of materials, the influence of a small external force can be greatly magnified owing to electronic correlations. Among them, doped lanthanum manganite based structures have attracted great attention due to interesting physical properties (colossal magnetoresistance effect, ferromagnetic-metallic to paramagnetic-insulating transition, charge ordering, phase separation, etc.). In this work doped $LaMnO_3$ epitaxial films were prepared by polymer assistant deposition technique from lanthanum manganite water based solutions. The prepared solutions were deposited on single crystal $SrTiO_3$ (001) substrate by spin coating technique and thermally treated at different temperatures up to 900 °C. In addition, epitaxial heterostructured films on $SrTiO_3$ (001) substrate, composed of ferromagnetic manganite and ferroelectric titanate layers, were obtained by solution deposition technique, i.e. combination of polymer assisted deposition and sol-gel method. Structure of the prepared ultrathin films, as well as magnetic and electro-optical properties was investigated.

Ag-Bi-I rudorffite nanoparticles as a new material for photovoltaics

Danijela Danilović[1,2*], Dušan K. Božanić[1,2], Aleksandar R. Milosavljević[2], Radovan Dojčilović[1,2], Vladimir Djoković[1,2]

[1] *Vinča Institute of Nuclear Sciences, University of Belgrade, P.O. Box 522, 11001 Belgrade, Serbia*

[b] *Center of Excellence for Photoconversion, Vinča Institute of Nuclear Sciences - National Institute of the Republic of Serbia, University of Belgrade, Serbia*

[2] *Synchrotron SOLEIL, l'Orme des Merisiers, St.Aubin, BP48, 91192 Gif sur Yvette Cedex, France*

Lead-halide perovsiktes are one of the most promising materials studied as absorption layer in solar cells. In the last decade power conversion efficiency (PCE) of solar cells obtained using these materials got close to the values of commercially used Si-based solar cells [1]. However, there are several problems for use lead-based perovskites in large-scale production such as toxicity of lead and decomposition of material under exposure to moisture, oxygen, and low energy electrons [2].

Silver-bismuth-iodide (Ag-Bi-I) rudorffite hybrid materials emerged as a lead-free, chemically stable, and low-cost absorber material in photovoltaic devices that can replace lead-based perovskites. These materials can be fabricated in the form of macroscopic crystals or as thin films, in which case they can be integrated into solar cells that show good photoconversion efficiency. Fabricating Ag-Bi-I in nanocrystal form could facilitate further their integration in the photovoltaic devices and enhance device performance.

Here, we report on the fabrication of ligand-free Ag-Bi-I rudorffite nanosystems in two forms; as aerosol nanoparticles and two-dimensional layered nanoplatelets [3,4]. The valence band electronic structure of isolated nanoparticles was investigated using sinhroton radiation X-ray aerosol photoelectron spectroscopy (XASP). By combining the results of UV-Vis absorption spectroscopy and XASP the complete valence electronic structure of Ag-Bi-I nanosystems was reconstructed. Furthermore, the quantum confinement effect in 2D nanosheets was examined.

REFERENCES:
[1] Yoo, Jason J., Seo, G., Chua, M. R…., Nature (2021) 587-593.
[2] Milosavljević, A. R., Božanić, D. K., Sadhu, S…, J. Phys. Chem. Lett. (2018) 3604-3611.
[3] Danilović, D., Božanić, D. K., Dojčilović…, J. Phys. Chem. C **124**, (2020) 23930
[4] Danilović, D., Milosavljević A. R., Sapkota, P..., J. Phys. Chem. C **126**, (2022) 13739−13747.

Demultiplexers based on waveguide arrays

M. G. Stojanović[1], K. Bugarski[1], P. Vildoso[2,3], R.A. Vicencio[2,3], A. Maluckov[1], J. Petrović[1]

(1) Vinča Institute of Nuclear Sciences, National Institute of Republic of Serbia, University of Belgrade, P.O. Box 522, 11001 Belgrade, Serbia

(2) Departamento de Física, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Chile

(3) Millenium Institute for Research in Optics - MIRO, Chile

Contact: M. G. Stojanović (mirjana.stojanovic@vin.bg.ac.rs), K. Bugarski (kolja.bugarski@vin.bg.ac.rs)

Abstract. Finite photonic lattices have emerged as a significant new resource for the construction of multiport devices in integrated optics. They have been used for the construction of interconnects, filters, splitters [1-3], as well as quantum devices [4]. Device design relies on the inverse engineering of the coupling between waveguides to achieve a targeted functionality. Remarkably, a restriction of the lattice parameter space to that supporting the periodic propagation of light does not significantly limit the range of achievable devices, yet improves the algorithm efficiency and energy consumption by a few orders of magnitude.

Here, we examine the potential of this design technique for the construction of wavelength demultiplexers. This is possible due to the dependence of the coupling strength on wavelength. The semi-analytical design is combined with numerical simulations in RSoft (Synopsys) to account for the exact waveguide fabrication conditions. The principle is proved by fs-laser fabrication of wavelength splitters in borosilicate glass [5]. Finally, we show that the number and spacing of waveguides in the lattice can be used to tailor the splitter characteristics.

REFERENCES

[1] M. Bellec, G. M. Nikolopoulos, and S. Tzortzakis, Opt. Lett. 37, 4504 (2012).
[2] J. Petorivic, J. Krsic, J.J.P. Veerman, A. Maluckov, J. Opt. Las. Technol. 163, 109381 (2023).
[3] P. Vildoso, R.A.Vicencio, J.Petrovic, *Optics Express.* **31, 12703** (2023).
[4] M. Gräfe and A. Szameit *J. Phys. B: At. Mol. Opt. Phys.* **53** 073001(2020).
[5] D. Guzmán-Silva, G. **Cáceres-Aravena,** R**.** A. Vicencio *Phys. Rev. Lett.* **127** (2021), 066601 (2021).

Probing cell-nanomaterial interaction with bioimaging of cancer liver cells

Radovan Dojčilović[1], Jelena Pajović[2], Dragana Tošić[1], Dušan Božanić[1], Vladimir Djoković[1], Slávka Kaščáková[3] and Matthieu Réfrégiers[4]

(1) *Vinča Institute of Nuclear Sciences, National Institute of the Republic of Serbia, University of Belgrade, P.O. Box 522, 11001 Belgrade, Serbia.*
(2) *University of Belgrade, Faculty of Physics, P. O. Box 368, 11001 Belgrade, Serbia.*
(3) *University Paris-Sud XI, UMR-S1193, Villejuif F-94800, France*
(4) *Centre de Biophysique Moléculaire, CNRS UPR4301, Rue Charles Sadron, Orléans 45071, France*

Contact: Dojčilović Radovan (radovan@vinca.rs)

Abstract. Noble-metal nanoparticles and carbon-based nanostructures have become the most used subjects in contemporary nanoscience, as they hold great promise for many applications, particularly in nanomedicine. These nanomaterials can be used as platforms with high drug loading capacity and high ability for targeted delivery with localized potency. To keep developing new fabrication and functionalization routes for more efficient employment of the mentioned nanomaterials, controlling and monitoring their interaction with the cell material is necessary. Fluorescence imaging represents a powerful tool for studying cell properties. The optical resolution limit poses a great challenge for the detection and localization of nanomaterials in cell milieu. To preserve the physiological context and to employ non-invasive imaging techniques, the advantageous photophysical properties of the nanomaterials are being explored for probing cell-nanomaterial interaction. In this presentation, we will show the effects of energy transfer, photosensitization, and fluorescence dynamics of nanomaterials on imaging capability. The results from bioimaging of biofunctionalized gold nanoparticles and graphene with cancer liver cells will be presented, together with the preliminary data and future perspective.

[1] J. Pajović, R. Dojčilović et al, Enhanced resonance energy transfer in gold nanoparticles bifunctionalized by tryptophan and riboflavin and its application in fluorescence bioimaging *Colloids and Surfaces B: Biointerfaces*, **227** (2023), 1133402023
[2] R. Dojčilović, J. Pajović et al, DUV fluorescence bioimaging study of the interaction of partially reduced graphene oxide and liver cancer cells, *2D Materials*, **5** (2018), 0450192018

Microwave-Assisted Solvothermal method for synthesis of CsY2F7 and RbY2F7 nanophosphors

Katarina Milenković, Ivana Zeković, Bojana Milićević, Zoran Ristić, Miroslav D. Dramićanin, Vesna Đorđević

Center of Excellence for Photoconversion, Vinča Institute of Nuclear Sciences-National Institute of the Republic of Serbia, University of Belgrade, PO Box 522, 11001 Belgrade, Serbia

Contact: V. Đorđević (vesipka@vin.bg.ac.rs)

Abstract. Nanoparticle tailoring and understanding offer a whole new world of possibilities for improving technology and addressing challenges in a variety of industries. The capacity to design nanoparticles with precise luminous properties makes them useful for a variety of research and technological breakthroughs. Lanthanide-doped materials, often known as phosphors, are critical components in various lighting technologies, including solar energy converters, latent fingerprint detection, security labelling, and biological imaging, among others. The exact qualities and applications of phosphors are determined by the lanthanide ion used, the nanoparticle's host material, and surface functionalization. Microwave-assisted hydro/solvothermal synthesis allows for rapid reaction times, homogenous heating, and excellent repeatability. We used the Microwave-Assisted Solvothermal technique to produce Eu^{3+}-doped CsY_2F_7 and RbY_2F_7 nanomaterials. We investigated the effects of reaction temperature and fluoride ion concentration on the product phase and crystal structure. Fluoride ions are routinely inserted more than the stoichiometric amount, which might be a limiting issue in attaining the desired phase. In our study, we demonstrate the issue with the quantity of fluoride ions required to achieve a pure orthorhombic phase for CsY_2F_7, as well as the transfer from RbY_3F_{10} (cubic, Fm-3m, No. 225) to RbY_2F_7 (orthorhombic, Pnna, No. 52). The crystal structure, shape, and optical properties of nanoparticles have been investigated.

Mn5+: a source of near-infrared photons for LEDs, optical temperature sensors and bioimaging

Miroslav D. Dramićanin[1]

(1) *Centre of Excellence for Photoconversion, Vinča Institute of Nuclear Sciences – National Institute of the Republic of Serbia, University of Belgrade, P.O. Box 522, Belgrade, 11001, Serbia*

Contact: M.D. Dramićanin (dramican@vinca.rs)

Abstract. This lecture explains the process of producing near-infrared photons by the integration of Mn^{5+} ions into insulating materials. The structure and properties of such materials will be highlighted. They provide a strong and narrow (FHWM < 5 nm) phosphorescence emission in the near-infrared (1110–1300 nm, Mn^{5+} spin forbidden $^1E \rightarrow {}^3A_2$ electronic transition), which is significantly affected by a nephelauxetic effect [1]. They possess strong absorption in the red spectral region from the spin-allowed $^3A_2 \rightarrow {}^3T_1$ electronic transition of Mn^{5+} ions, which facilitates easy phosphorescence excitation. The interplay of optoelectronics and materials science provides highly valuable applications. We will primarily focus on the application of these materials in near-infrared LEDs, optical temperature sensors [2], bioimaging, and biothermal imaging in the near-infrared spectral region [3].

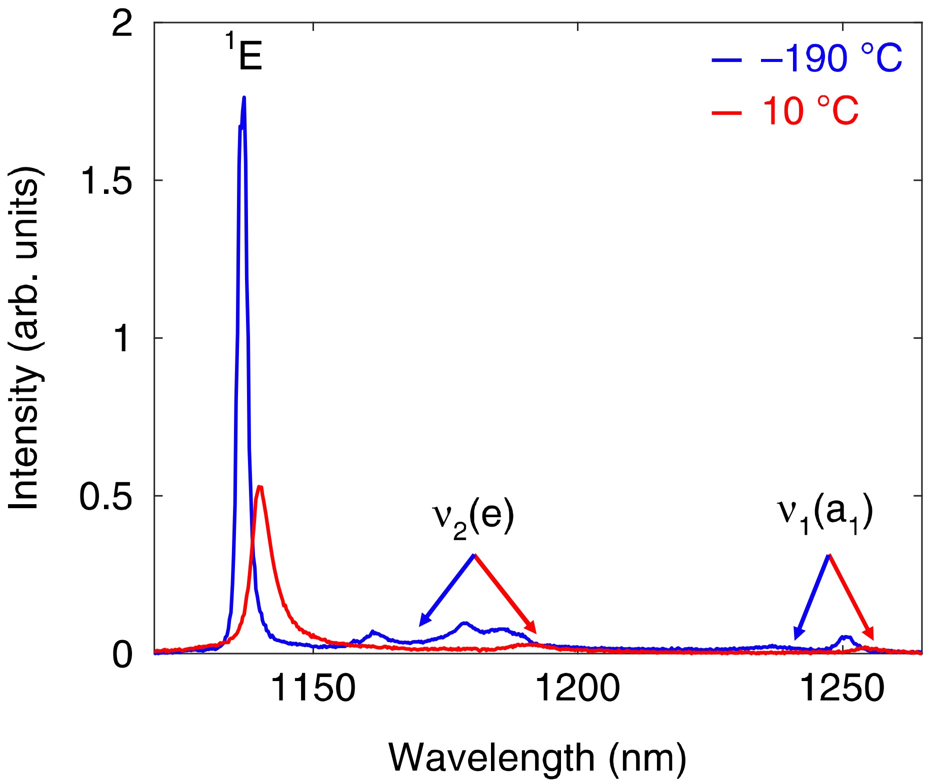

Figure 1. Photoluminescence of Mn^{5+}:$Ca_6Ba(PO_4)_4O$.

REFERENCES

[1] M.D. Dramićanin, Ł. Marciniak, S. Kuzman, W. Piotrowski, Z. Ristić, J. Periša, I. Evans, J. Mitrić, V. Đorđević, N. Romčević, M.G. Brik, C.-G Ma, *Nature Light Sci. Appl.* **11** (2022) 279.

[2] Ł. Marciniak, K. Kniec, K. Elzbieciak-Piecka, K. Trejgis, J. Stefanska, and M. D. Dramićanin, *Coord. Chem. Rev.* **469** (2022) 214671.

[3] W.M. Piotrowski, R. Marin, M. Szymczak, E. Martín Rodríguez, D.H. Ortgies, P. Rodríguez-Sevilla, M.D. Dramićanin, D. Jaque, and L. Marciniak, *Adv. Opt. Mater.* **11** (2023) 2202366.

Topological Properties of Photonic Systems with Interorbital Interactions

Gabriel Cáceres-Aravena

Institute of Physics, University of Rostock, 18051 Rostock, Germany

Contact: G. Cáceres-Aravena (gabriel.caceres-aravena@uni-rostock.de)

Abstract. We present the main findings of the study of topological properties and band structure of photonic systems with inter-orbital interactions. Initially we study theoretically the inclusion of a second order mode of each waveguide in a simple periodic array of waveguides, and we find a flat band condition and a topological transition with nontrivial Zak phase[1]. Moreover, we observe experimentally the interaction between the first and the second order modes (interorbital coupling)[2]. Furthermore, we study the topological properties of a dimerized diamond lattice theoretically and experimentally[3]. Finally, we show the transport properties of a diamond lattice interorbital interactions[4] (Fig. 1).

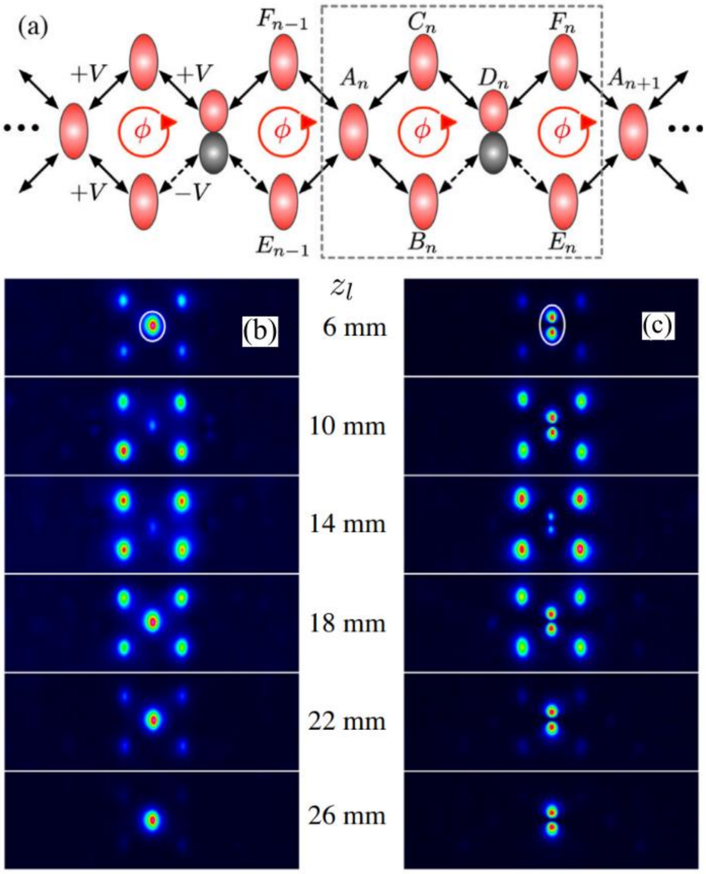

Figure 1. (a) The diamond lattice with interorbital coupling[4]. The D sites is the second order mode of the waveguide. (b-c) Experimental realization of the lattice with an initial condition in the A-site (b) and D-site (c).

REFERENCES

[1] G. Cáceres-Aravena, L.E.F. Foa Torres, and R. A. Vicencio, *Phys. Rev. A* **102**, 023505(2020).
[2] D. Guzmán-Silva, G. Cáceres-Aravena, and R. A. Vicencio, Phys. Rev. Lett. **127**, 066601 (2021).
[3] G. Cáceres-Aravena, et al. APL Photonics **8**, 080801 (2023).
[4] G. Cáceres-Aravena, D. Guzm ́an-Silva, I. Salinas, & R. A. Vicencio, *Phys. Rev. Lett.* **128**, 256602 (2022).

Phonon Investigations in Cd1-xFexTe1-ySey Single Crystals

Jelena Mitric[1*], Maja Romcevic[1], Witold D. Dobrowolski[2], A. Mycielski[2], Nebojsa Romcevic[1]

[1] *Institute of Physics Belgrade, University of Belgrade, Pregrevica 118, 11080 Belgrade, Serbia*

[2] *Institute of Physics, Polish Academy of Sciences, Aleja Lotnikow 32/46, PL-02668 Warsaw, Poland*

Contact: jmitric@ipb.ac.rs

Keywords: *Semiconductors, electron-phonon interactions, light absorption and reflection*

Abstract: The interaction between electrons and phonons represents a notable phenomenon in the realm of condensed matter physics, exerting a substantial influence on diverse electronic and optical characteristics of materials [1]. Within this context, an exhaustive investigation of the Raman and Far – Infrared reflectivity spectra of $Cd_{1-x}Fe_xTe_{1-y}Se_y$ single crystals can yield valuable insights into the various impacts of Plasmon – phonon interactions on the fundamental physics of II – IV semiconductors. Spectral analysis was executed employing a suitable fitting procedure. In the analysis of Far – infrared spectra, a dielectric function incorporating the presence of Plasmon – LO phonon interaction was employed [2]. Three principal lines in the spectra, contingent upon the composition, were discerned at approximately 140 cm^{-1}, 170 cm^{-1} and 200 cm^{-1}. 140 cm^{-1} feature corresponds to the longitudinal – transverse (LO – TO) splitting of the CdTe – like mode. The 170 cm^{-1} feature is associated with CdSe, while the 200 cm^{-1} feature is linked to the local Fe mode. These features were elucidated within the framework of the modified random – element – isodisplacement (MREI) mode [3 – 4]. The calculated phonon frequencies demonstrated a high level of agreement with experimentally determined values. Additionally, in all samples, a surface layer characterized by a low concentration of free carriers (depleted region) was formed [5]. Consequently, a surface optical mode (SOP) was registered at approximately 150 cm^{-1} in samples with a predominant CdTe component (y less that 15%) and at around 190 cm^{-1} in samples with a majority CdSe content (y greater that 95%).

REFERENCES

[1] A. Gogolin, E. I. Rashba, *Solid State Commun*. 19, **1976**, pp. 1177 – 1179.

[2] A.A. Kukharskii, *Solid State Comm*. 13, **1973**, pp. 1761.

[3] J. Mitric, N. Paunovic, M. Mitric, B. Vasic, U. Ralevic, J. Trajic, M. Romcevic, W.D. Dobrowolski, I.S. Yahia, and N. Romcevic, *Phys. E: Low – Dimens. Syst. Nanostructures*, 104, **2018**, pp. 64 – 70.

[4] J. Mitric, U. Ralevic, M. Mitric, J. Cirkovic, G. Krizan, M. Romcevic, M. Gilic, N. Romcevic, J. Raman Spectrosc. 50 (6), **2019**, pp. 802 – 808.

[5] A. Mycieksy, M. Arciszewska, W. Dobrowolski, A. Lusakowski, K. Dybko, R, Szymczak, A. Szadkowski, C. Rigaux, A. Mauger, M. Menant, M. Guillot, *Phys. Rev. B*. 53 (16), **1996**, pp. 10732 – 10739.

Cost-Efficient Method for Deterministic Creation of Single Photon Emitters in GaSe

Sanja Djurdjić Mijin[1,2], Ismael de Pedro Embid[3], Snežana Lazić[1,4,5]

(1) *Departamento de Fısica de Materiales, Facultad de Ciencias, Universidad Autonoma de Madrid (UAM), 28049 Madrid, Spain*

(2) *Institute of Physics Belgrade, University of Belgrade, Pregrevica 118, 11080 Belgrade, Serbia*

(3) *Paul-Drude-Institut fur Festkorperelektronik, Leibniz- Institut im Forschungsverbund Berlin e.V., Hausvogteiplatz 5 – 7, 10117 Berlin, Germany*

(4) *Instituto Universitario de Ciencia de Materiales "Nicolas Cabrera" (INC, UAM, 28049 Madrid, Spain*

(5) *Condensed Matter Physics Center (IFIMAC), UAM, 28049 Madrid, Spain*

Contact: Sanja Djurdjić Mijin (sanja.djurdjic@uam.es)

Abstract. In recent years, there has been a significant interest in exploring the potential of two-dimensional (2D) materials for quantum light emission, owing to their tunable bandgaps, layer-dependent excitonic properties, and efficient charge carrier confinement. Our research focuses on a cost-efficient and practical methodology for the precise placement of single-photon emitters (SPEs) within GaSe through strain engineering utilizing optically active microparticles with a distinctive bipyramidal shape. The bipyramidal shape enhances strain-induced effects crucial for single-photon emitter creation, whereas the optical activity of the particles allows precise identification of their position via conventional optical spectroscopy measurements, eliminating the need for SEM or AFM. Using presented method, we successfully generated localized SPEs in a thin GaSe flake, producing exciton-biexciton cascades with elliptically polarized emission. The detection of excitonic complexes in locally engineered traps within GaSe sheets indicates the system's potential for producing entangled photon pairs through an XX-X radiative cascade. This holds particular significance, considering that externally applied strain and/or electric field can also control the polarization state of the emitted X-XX cascade. The excellent agreement between our results and prior reports on strain-induced SPEs in GaSe undeniably affirms the suitability of our method for the precise creation of highly localized SPEs. The introduction of this cost-effective and practical platform for quantum emitter generation expands the accessibility of 2D SPEs, fostering advancements in both research and practical applications in the field.

Selective in vitro labeling of cancer cells using NaGd0.8Yb0.17Er0.03F4 nanoparticles

Miljana Piljevic[1], Ivana Dinic[2], Marta Bukumira[1], Mihailo D. Rabasovic[1], Aleksandar J. Krmpot[1], Milos Lazarevic[3], and Lidija Mancic[2]

(1) *Photonic Center, Institute of Physics Belgrade, University of Belgrade, Pregrevica 118, Zemun, 11080, Belgrade, Serbia*

(2) *Institute of Technical Sciences of SASA, Kneza Mihaila St. 35, 11000, Belgrade, Serbia*

(3) *School of Dental Medicine, University of Belgrade, dr Subotica 8, 11000, Belgrade, Serbia*

Contact: Miljana Piljevic (miljana@ipb.ac.rs)

Abstract. Cancer represents one of the leading problems of today, with clinical detection oftentimes being difficult, currently based on imaging techniques, such as X-ray, computed tomography (CT) and magnetic resonance imaging (MRI). However, mortality rate is often reduced by early detection, therefore much focus has been directed towards developing methods for early detection of the disease. Recent research in the field of nanotechnology is focused on the use of nanoparticles, particularly Lanthanide-doped up-conversion nanoparticles (UCNPs), for the detection of cancer cells using near infrared (NIR) fluorescence microscopy. The reason for this is that in long-term tracking tests, near-infrared (NIR) light, has lower phototoxicity and higher tissue penetration depth in living systems as compared with UV/VIS light. In this research, $NaGd_{0.8}Yb_{0.17}Er_{0.03}F_4$ UCNPs were prepared by solvothermal synthesis in the presence of chitosan, a ligand which enables UCNPs biocompatibility and the specific antibody conjugation. Morphological and structural characterization of synthetized UCNPs were performed based on X-ray powder diffraction (XRPD), scanning electron microscopy (SEM), transmission electron microscopy (TEM), Fourier transform infrared spectroscopy (FTIR) and photoluminescence spectroscopy (PL). Results confirmed the presence of the cubic phase with a minor portion of hexagonal phase in nanoparticles. Synthesized nanoparticles were conjugated further with anti-human CD44 antibodies, labeled with fluorescein isothiocyanate (FITC), which signal is used for confirmation of nanoparticles positioning in cells. Such obtained conjugates were successfully used for selective *in vitro* biolabeling of oral squamous cell carcinoma cells.

Electronic Properties of Predicted Y2O2S using Theoretical Calculations

Dragana Jordanov[1], Dejan Zagorac[1], Klaus Doll[2], Johan Christian Schön[3], Milena Rosić[1]

(1)*"Vinča" Institute of nuclear science, National Institute of the Republic of Serbia, University of Belgrade, Belgrade, Serbia*
(2) Institute for Theoretical Chemistry, University of Stuttgart, Stuttgart, Germany

(3) Nanoscale Science Department, Max Planck Institute for Solid State Research, 70569 Stuttgart, Germany

Contact: D. Jordanov (djordano@vinca.rs)

Abstract. Crystal structure prediction has been accomplished to investigate the energy landscape of Yttrium Oxysulfide (Y_2O_2S). Global optimizations on the energy landscape of Y_2O_2S have been carried out using empirical potentials followed by, a local optimization using *ab initio* calculations [1]. Our calculations showed the *Alpha* phase in good agreement with the experimentally observed trigonal structure. Furthermore, novel *Beta* and *Gamma* modifications of pure Yttrium Oxysulfide have been discovered. Y_2O_2S is a material known as a wide-gap semiconductor. From the calculation of the bulk, it is found that the material has an indirect band gap and that the top of the valence bands shows an anisotropic character which means an anisotropic mass of the hole [2]. We included the calculation of the Density of States (DOS) for the most stable structures (*Alpha*, *Beta* and *Gamma*) and discuss the band gaps, also [3]. The results presented here have all been performed using the B3LYP functional and local density approximation (LDA). Our calculations are in good agreement with the literature data [4].

REFERENCES

[1] D. Zagorac, J. C. Schön, J. Zagorac, and M. Jansen, Prediction of structure candidates for zinc oxide as a function of pressure and investigation of their electronic properties, *Phys. Rev. B* **89**, 075201 – Published 3 February 2014

[2] Masayoshi Mikami, First-principles band-structure calculation of yttrium oxysulfide Yokohama Research Center, Mitsubishi Chemical Corporation, 1000 Kamoshida-cho, Aoba-ku, Yokohama 207, Japan Atsushi Oshiyama Institute of Physics, University of Tsukuba, 1-1-1 Tennodai, Tsukuba 305, Japan, Received 16 December 1997

[3] Klaus Doll, Fundamentals of Quantum Chemistry, Molpro Quantum Chemistry Software, Institute of Theoretical Chemistry, University of Stuttgart (book)

[4] Masayoshi Mikami, Atsushi Oshiyama, „ First-principles study of yttrium oxysulfide: bulk and its defects " *Journal of Luminescence* 87-89 (2000) 1206-1209

Photoelectron circular dichroism in isolated hybrid nanosystems

Dušan K. Božanić[1], Gustavo Garcia[2], Laurent Nahon[2], Jelena Pajović[3], Radovan Dojčilović[1], Željko Šljivančanin[1], Vladimir Djoković[1]

(1)*"VINČA" Institute of Nuclear Sciences - National Institute of the Republic of Serbia, University of Belgrade, P.O. Box 522, 11001 Belgrade, Serbia*

(2) *Synchrotron SOLEIL, F-91192 Gif sur Yvette, France*

(3) *Faculty of Physics, University of Belgrade, PO Box 368, 110001 Belgrade, Serbia*

Contact: D. K. Božanić (bozanic@vin.bg.ac.rs)

Abstract. Circular dichroism (CD) is a unique property of chiral systems, including molecules, macromolecules and crystals, to exhibit different optical activity when exposed to circularly polarized radiation of different helicity (left-LCP or right-RCP). In that sense, CD spectroscopy, an experimental technique that measures difference in absorption ($\Delta A/A$) of a chiral system upon irradiation by RCP and LCP, became a valuable method for investigation of biomolecular conformation, charge-transfer processes in chiral systems, or induced chirality in conjugated hybrid nanosystems. However, typical $\Delta A/A$ values in CD spectroscopy are in the order of magnitude of 10^{-4}, which limits the application of the technique to optically dense systems with pronounced optical transitions. Photoelectron circular dichroism (PECD), or circular dichroism in photoemission, on the other hand, is a technique that measures the difference in the number of electrons photoemitted by RCP and LCP ionizing radiation in direction parallel or antiparallel to the direction of the propagation of the radiation [1, 2, 3]. Due to the selectivity of the orbitals from which the photoemission is being initiated, this technique allows for dichroic signals that can reach as much as 20% of the total electron count, with typical values of few percent. In this report, we describe the methodology for PECD experiments on isolated nanosystems and present the results of the analyses of the induced chirality in amino acid conjugated nanostructures, including tryptophan-functionalized gold nanoparticles and partially reduced graphene oxide aerosols loaded by phenylalanine and tryptophan chiral molecules.

REFERENCES

[1] R. Hadidi, D.K. Božanić, H. Ganjitabar, G.A. Garcia, I. Powis, L. Nahon, Comm. Chem. **4**, 72 (2021)
[2] S. Hartweg, G.A. Garcia, D.K. Bozanic, L. Nahon, J. Phys. Chem. Lett. **12**, 2385 (2021)
[3] R. Hadidi, D.K. Bozanic, G.A. Garcia, L. Nahon, Advances in Physics: X **3,** 1477530 (2018)

Quantum Dots: Nanotecnology in Quantum Colours

Stanko Tomić, FInstP

Vinca Institute for Nuclear Sciences, The University of Belgrade, PO Box 522 Belgrade, Serbia

Contact: Stanko Tomić (stanko.tomic@vinca.rs)

Abstract. The Nobel Prize in Chemistry 2023 recognizes the discovery and synthesis of nanometre-sized semiconductor crystals, the properties of which are determined by quantum size effects [1]. When 2023 Laureates, Alexei Ekimov, Louis Brus and Moungi Bawendi carried out their first work on quantum dots over 40 years ago, none of them anticipated the enormous impact these tiny crystals would have on our daly life. Their work [2-4], alongside the others, was part of the birth of nanoscience and nanotechnology. The name, quantum dots was given by Mark Reed in 1986, and marks nanoparticles so small that their physical size determines the quantum mechanical states of the material's charge carriers. Quantum dots constitute a new class of materials that is neither molecular nor bulk. They have the same structure and atomic composition as bulk materials, but their properties can be tuned using a single parameter, the particle's size. Changing the size of a quantum dot changes its properties, in particular its fluorescence, meaning that they can be tuned to different colors. For example, the smallest dots will emit more shorter-wavelength blue light than longer-wavelength red light. The principle of quantum confinement, used to describe the QD, also referred to as the 'particle-in-a-box' problem, was theoretically proposed in the 1930s by H Fröhlich [5]. He has shown that particles when become extremely small there is less and less "space" for electrons to reside, hence electrons are squeezed together forming the discrete spectra in order to find the space for themselves. It is less known that Institute Vinča played the pioneering role in the discovery of quantum dots. In 1986 some of the most fundamental quantum properties were discovered there, like, light matter interaction in QD, ionization potentials of QD, and redox potentials of QD, all as they change with the QD size [6]. Along the overview of the historical context, I will review my contribution to the current QD technology: (1) luminescence solar concentrates, (2) utilization of QD as very efficient energy conversion sources for high efficiency solar cells with the intermediate band, (3) physics of the "Russian Doll" QD and its multi-excitonic properties, and (4) QD as single photon sources in quantum information processes [7]. And while quantum dots already have an array of applications – from QLED television displays to medical imaging – we are still just scratching the surface of their full potential [8].

REFERENCES

[1] https://www.nobelprize.org/prizes/chemistry/2023/

[2] A. I. Ekimov, A. A. Onushchenko, V. Tsekhomskii, Sov. Glass Phys. Chem. **6**, 511 (1980) (in Russian)

[3] L.E. Brus, J. Chem. Phys. **79**, 5566 (1983).

[4] C. B. Murray, D. J. Norris, M. G. Bawendi, J. Am. Chem. Soc. **115**, 8706 (1993).

[5] H. Frölich, Physica IV **5**, 406 (1937)

[6] J. M. Nedeljković, M. T. Nenadović, O. Micić, A.J. Nozik, J. Phys. Chem. **90**, 12 (1986).

[7] S. Tomić, Phys. Rev. B **82**, 195321 (2010)

[8] S. Tomić, Elementi **35**, 10 (2024) (in Serbian)

Atmospheric aerosols monitoring by scanning mobility and optical particle sizers in an urban area

Danka B. Stojanović[1], Željko Cirović[1], Bojana Petrović[1], Maja Jovanović[1], Marija Živković[1], Miloš Davidović[1], Milena Jovašević-Stojanović [1]

(*1) VIDIS Centre, Vinca Institute of Nuclear Sciences – National Institute of the Republic of Serbia, University of Belgrade, Serbia;*

Contact: D. B. Stojanović (dankas@vin.bg.ac.rs)

Abstract. Particulate matter in urban areas can range in size from a few nanometers to a few micrometers and is closely related to human health. They have a detrimental influence when inhaled and can lead to deposition of toxic particles in the human respiratory system [1]. This is the motivation to measure particulate matter number and concentration more accurately, which implies that it is necessary to combine several measurement instruments including different measurement principles. The optical particle sizer (OPS) [2] uses light scattering to obtain the number of particles and concentrations in the range from 300 to 10000 nm, while scanning mobility particle sizers (SMPS) [3] derive particle number concentrations from measured particle size distributions covering particle number concentration in bin from less than 10 nm to 1000 nm. Furthermore, it is possible to modify the distribution obtained by optical measurements by searching for the optimal value of the refractive index of the particles to obtain the best possible agreement with the size distribution obtained by measuring the electrical mobility.

This research shows the findings of a campaign conducted in the winter of 2020, which aimed to collect urban atmospheric aerosols at three specific locations in the city center of Belgrade. This study comprehensively analyses the diurnal and seasonal variations for urban aerosol particles size distributions in the range from less than 10nm to 10000 nm. Pollution episodes reflected in increased particle number concentration are identified. Particle number-size distribution data contour plots were generated and presented as a function of particle number diameter and sampling time for the period of pollution episodes and for the short events of fireworks.

ACKNOWLEDGMENT

Funding for this work has been provided by the European Union’s Horizon Europe Research and innovation program under grant agreement 952433, H2020 VIDIS project and the Ministry of Science, Technological Development and Innovations of the Republic of Serbia under contract number 451-03-66/2024-03/ 200017 which is being realized in Vinca Institute of Nuclear Sciences.

REFERENCES

[1] G. Oberdörster, E. Oberdörster and J. Oberdörster, Nanotoxicology: an emerging discipline evolving from studies of ultrafine particles. *Environ Health Perspect*, **11** (2005), 823-839.

[2] T. Njalsson and I. Novosselov, Design and optimization of a compact low-cost optical particle sizer. *Journal of Aerosol Science*, **119**, (2018), 1-12.

[3] S.C. Wang and R. C. Flagan. "Scanning electrical mobility spectrometer." *Aerosol Science and Technology* **13.2** (1990), 230-240.

Photonics Toolkit for Studying Alzheimer's Disease

Srdjan D. Antic

Institute for Systems Genomics, Department of Neuroscience, UConn Health, School of Medicine, 263 Farmington Avenue, 06030 Farmington, Connecticut, USA

Contact: Srdjan Antic (antic@uchc.edu)

Abstract. Ideally, photonics should service humanity. In 2024, the mankind is plagued by a disease (Alzheimer's) that destroys brain function but leaves other organs intact. This has led to a rising population of individuals living long lives but experiencing complete dysfunction. This situation imposes an unprecedented, multilayered burden on society. The only generally agreeable mechanism of Alzheimer's disease (AD) is a pathological accumulation of faulty amyloid proteins in the brain tissue (plaques), causing a progressive (slowly worsening) and completely irreversible loss of cognitive functions. Modern photonics has developed a set of tools for neurobiologists to tackle the issues of AD pathogenesis, as well as the AD therapy. In the initial segment of my presentation, I will delve into optogenetic methods for inducing artificial plaques. Researchers have successfully developed fluorescently-labeled, optogenetically-activated amyloid peptides capable of oligomerizing upon illumination. Now we can ask if and how intracellular amyloid oligomers cause metabolic and physical damage to neurons and delineate between the damage caused by light-induced oligomerization from mere protein expression. The physical damage induced by amyloid oligomers is indicative of tissue loss, a characteristic feature of advanced AD. The subsequent part of the seminar will focus on photonics methods employed to study physiological changes in the mouse brain, serving as an AD model. Briefly, researchers utilize patterned beams of photons to monitor the electrical activity of living nerve cells both before and after the accumulation of (harmful) plaques. In the final segment of my presentation, I will focus on the use of photonics tool in therapy of AD. Specifically, I will elaborate on recent endeavors in animal AD research involving targeting of photon-pulses directly into the brain tissue of transgenic mice expressing photon-sensitive membrane proteins ("optogenetics"). Such optogenetic stimulations can cause firing of neurons and excitation of neuronal axons leading to a release of various transmitters in brain regions targeted by beams of light. This approach (optogenetic therapy) aims to intervene or slow-down amyloid plaque formation and alleviate behavioral deficits caused by the pathological processes in AD patients.

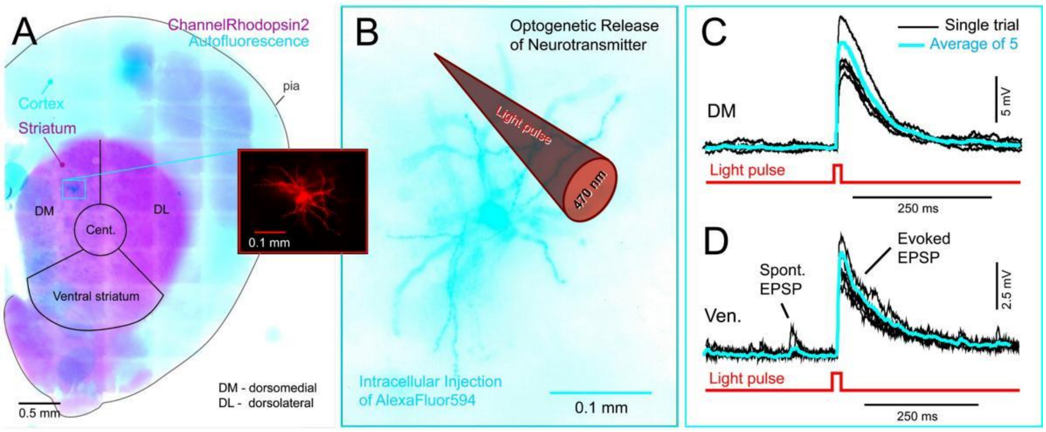

Fig. 1. Optogenetic release of neurotransmitters from axon terminals. (**A**) Brain slice from a transgenic mouse expressing an optogenetic actuator, channelrhodopsin2 in axons of dopamine-releasing neurons. The greatest density of ChR2-expressing axons is in the striatum (center of the brain slice). (**B**) One striatal neuron is injected with a fluorescent dye, AF594. (**C**) Patch electrode recordings of electrical signals evoked by light pulses delivered to dorsomedial (DM) striatum. Average of 5 traces is represented by a thick cyan trace. (**D**) Same as *C*, except a different neuron is patched (recorded) in a different part of the striatum (ventral striatum). Each pulse of 470 nm light causes a significant depolarization of the postsynaptic neuron.

Quantum phenomena and novel matter phases in ultracold atomic mixtures

Alessia Burchianti[1,2], Luca Cavicchioli[1,2], Chiara Fort[1,2], Francesco Minardi[1],[2,3]

(1) *Istituto Nazionale di Ottica, CNR-INO, 50019 Sesto Fiorentino, Italy*

(2) *LENS and Dipartimento di Fisica e Astronomia, Università di Firenze, 50019 Sesto Fiorentino, Italy*

(3) *Dipartimento di Fisica e Astronomia, Università di Bologna, 40127 Bologna, Italy*

Contact: A. Burchianti (burchianti@lens.unifi.it)

Abstract. In this talk, we discuss recent results and perspectives of the CNR-INO quantum mixture experiment in Florence. Mixtures of ultracold atoms are ideal systems for studying quantum phenomena and novel matter phases enabled by the interplay of two interacting superfluids. To this aim, in our lab, we produce dual-species condensates of ^{41}K-^{87}Rb with tunable contact interactions [1, 2]. Varying the interspecies scattering length by means of Feshbach resonances, we explore the mixture phase diagram from the strongly repulsive to the strongly attractive limit, where the system is stabilized by quantum fluctuations [3].

In recent experiments, by exploiting the tunability of our system, we have produced long-lived liquid-like quantum droplets [2, 4] and studied the coupled dipole dynamics of the mixture over a wide interaction range [5]. In the near future, we plan to combine interaction control and optical manipulation to engineer non-trivial superfluid structures, like rings and shells, as well as exotic vortex states and rotating droplets. For this purpose, we have developed a microscope objective for imaging and imprinting of optical potentials. We present our tests of this optical system, which we use to detect quantum droplets with micrometric resolution. We report preliminary results on the formation of multiple droplets and their dynamics, following an interaction quench, in a quasi-1D optical trap.

REFERENCES

[1] A. Burchianti et al., *Phys. Rev. A* **98** (2018), 063616.
[2] A. Burchianti et al., *Condens. Matter* **5** (2020), 12.
[3] D. S. Petrov, *Phys. Rev. Lett*. **115** (2015), 155302.
[4] C. D'Errico et al., *Phys. Rev. Res.* **1**, (2019), 033155.
[5] L. Cavicchioli et al., *Phys. Rev. Res.* **4**, (2022), 043068.

The role of tenascin-C in the structural plasticity of perineuronal nets and synaptic expression in the murine hippocampus

Ana Jakovljević[1], Vera Stamenković[2], Joko Poleksić[3], Igor Jakovcevski[4], and Pavle R. Andjus[1]

(1) Center for Laser Microscopy, Institute for Physiology and Biochemistry "Jean Giaja", Faculty of Biology, University of Belgrade, 11000 Belgrade, Serbia

(2) Center for Integrative Brain Research, Seattle Children's Research Institute, 1900 9th Ave, Seattle WA 98125, USA

(3) School of Medicine, Institute of Anatomy "Niko Miljanic", University of Belgrade, Belgrade, Serbia

(4) Institut für Anatomie und Klinische Morphologie, Universität Witten/Herdecke, Witten, Germany

Contact: A. Jakovljević (ana.jakovljevic@bio.bg.ac.rs)

Abstract. Neuronal plasticity is a fundamental property of the nervous system that allows a change in the response to stimulation by reorganizing its structure, functions and connections. Among the main regulators of neuronal plasticity are perineuronal nets (PNNs), condensed forms of extracellular matrix (ECM) that enwrap mainly parvalbumin expressing (PV+) inhibitory interneurons. Glycoprotein tenascin-C (TnC) is one of the ECM molecules that interacts with components of PNNs and that modulates the synaptic plasticity in the hippocampus. The aim of this study was to investigate whether TnC deficiency affects the number, intensity and structure of PNNs around PV+ and PV- cells, the ultrastructure of PNNs, as well as the expression of inhibitory and excitatory synaptic terminals (puncta) penetrating the PNN mesh in the hippocampus. In order to enhance neuronal plasticity, TnC-deficient (TnC-/-) and wild-type (TnC+/+) young adult male mice were reared in an enriched environment and in control standard environment (EE and SE) for 8 weeks. The most pronounced alterations in the expression of PNNs and synaptic markers occurred in the dentate girus (DG) and CA2 hipocampal regions. In the DG, TnC -/- mice in SE showed ultrastructural changes toward PNN reduction and an increased density of inhibitory terminals, compared to wild-type in the same environment. Contrary, EE in TnC+/+ mice increased the intensity of PNNs around PV- neurons and increased the density of the inhibitory terminals, compared with the wild-type in SE, while upon EE in TnC -/- mice the PNN ultrastructure shifted towards the condensation and increased excitation in the DG, compared to the same genotype in SE. The CA2 region of TnC -/- mice housed in SE, showed an increase in the number of PNNs and in the intensity of inhibitory terminals, compared to TnC+/+ mice. Both subfields CA2 and CA3 were found to have an increased density of inhibitory synapses in TnC+/+ after EE, which is found reduced in TnC-/- mice. Notably, TnC deficiency and EE had no significant effect on the number and intensity of PNNs, on the number of PV neurons or on the synaptic expression in the CA1 region. In conclusion, our findings indicate that TnC is involved in modulating structural plasticity of the hippocampus, especially in DG and CA2 regions which emerged as focal points of alterations in perineuronal nets and synaptic terminals due to TnC deficiency and environmental enrichment.

Pulse propagation and pulse revival in Doppler broadened four wave mixing in hot alkali vapor

Marija Ćurčić, Dušan Arsenović and Brana Jelenković

Institute of Physics, Pregrevica 118, 11080 Belgradey, Serbia

Contact: M. Ćurčić (marijac@ipb.ac.rs)

Abstract. The four-wave mixing (FWM) plays important role in both high order nonlinear processes (parametric gain) and quantum processes (squeezing and entanglement). Common atomic scheme for generating FWM is a doubleΛ, in which pump and seed probe photons mix to generate quantum correlated pairs of photons, new probe and FWM signal photons. We use this scheme to study the dynamics of FWM after a weak seed pulse enters the potassium vapor, while cw probe is on. The change of the shapes of probe and signal pulses as they propagate through Doppler broadened FWM media is not thoroughly investigated. These investigations are important for practical purposes, like all optical switching, and for contribution to development of quantum information and communications.

As our experiment shows, for some FWM parameters, the 80 ns probe Gaussian pulse at the input results in similar, but broadened, probe and signal pulses at the exit from FWM medium. Likewise, for other values of the same parameters, both probe and signal pulses are distorted or split.

We have used model to explain different behavior of pulsed FWM at different FWM parameters, and to find out what is the origin of a multiple probe and signal pulses at the exit of FWM media, occurring at time after the seed pulse had passed the FWM medium. To analyze transient probe and signal behavior in FWM, and to calculate propagation equations, optical coherences between levels coupled by the probe and the signal, have to be calculated first.

From time development of calculated phases and amplitudes of optical coherences for atoms in different velocity groups, and for all atoms under the Maxwell-Boltzmann distribution, we find that the additional probe and signal peaks are motion induced pulse revival, that the revived peaks are results of constructive interference of coherences for atoms in different velocity groups.

REFERENCES

Rajitha K.V. et al., *Phys. Rev. A* 92, 023840 (2015),

B. Huber et al., *Phys. Rev. A* 90, 053806 (2014).

R. Fleischhaker et al., Phys. Rev. A 77, 043805 (2008).

Hemocompatibility evaluation of N-doped carbon quantum dots

Biljana Ristić[1], Đorđe Trpkov[2], Ivana Drvenica[1], Radovan Dojčilović[2], Tamara Đukić[3], Dragana Tošić[2], Jelena Pajović[4], Dušan K. Božanić[2], Drenka Trivanović[1], Tamara Matić[5], Dušan Sredojević[2], Vesna Ilić[1], Vladimir Đoković[2]

(1) Institute for Medical Research National - Institute of the Republic of Serbia, University of Belgrade, Dr Subotića 4, PO Box 39, 11000 Belgrade, Serbia

(2) Vinča Institute of Nuclear Sciences - National Institute of the Republic of Serbia, University of Belgrade, PO Box 522, 11001 Belgrade, Serbia

(3) Innovation center of the Faculty of Technology and Metallurgy, University of Belgrade, Karnegijeva 4, 11000 Belgrade, Serbia

(4) Faculty of Physics, University of Belgrade, PO Box 368, 11001 Belgrade, Serbia

(5) Faculty of Technology and Metallurgy, University of Belgrade, Karnegijeva 4, 11000 Belgrade, Serbia

Contact: B. Ristić (biljana.ristic@imi.bg.ac.rs)

Abstract. Nitrogen-doped carbon quantum dots (N-CQDs) are promising next generation nanomaterials for potential biomedical applications such as bioimaging, biosensing, and drug/gene delivery. However, N-CQDs biocompatibility has not been extensively investigated. Here, we report physico-chemical characteristics of newly synthetized N-CQDs and their effects on red blood cells (RBC), by analyzing their hemolytic activity, impact on RBC rheology/morphology, and oxidative stress induction. N-CQDs were prepared by hydrothermal method using citric acid and urea as precursors. Structural analyses of as prepared N-GQDs, observed by HRTEM/EDS, showed that the lateral dimensions of the particles are in the 10 to 20 nm range, as well as that the carbon, oxygen, and nitrogen are present in the nanosystem. Based on AFM measurements, the average height of N-CQDs was 3.9±0.08 Å. Photoluminescence emission (PLE) spectrum demonstrated that N-CQDs exhibit stable and strong fluorescence in green (520 nm) region, upon 410 nm excitation. FTIR spectroscopy indicated vibrational bands, characteristic for carbon structures and primary amines (N-doping). N-CQDs were negatively charged with an average Zeta potential of -15.3 mV as confirmed by DLS. To investigate hemocompatibility of N-CQDs, the RBC, the most abundant cells in blood, were treated with different concentration of N-CQDs (10-400 ug/ml) for 2h. Obtained results showed that there was no hemolytic activity. Moreover, ektacytometry analysis demonstrated that N-CQDs did not affect deformability of RBC. Fluorescent microscopy analyses revealed that treatment with N-CQDs did not induce significant morphological aberrant forms of RBC which was also confirmed by SEM analyses. Flow cytometry confirmed only slight RBC morphological changes based on FSC/SSC analysis. Furthermore, using ROS sensitive dye flow cytometry analyses suggested that N-CQDs did not induce oxidative stress in RBC. Taken together, our findings highlighted that exposure of RBC to N-CQDs only led to the attachment of N-CQDs on RBC membranes, but there is no other evidence of their nanotoxicity. These findings suggested that N-CQDs synthetized from eco-friendly precursors are potentially biocompatible and safe for biomedical application.

The Enigma of Changing Look Active Galactic Nuclei

Edi Bon[1], Nataša Bon[1], Miroslava Savković[1] and Paola Marziani[2]

(1) *Astronomical Observatory, Volgina 7, 11000 Belgrade, Serbia*

(2) *Padua Astronomical Observatory, National Institute for Astrophysics (INAF), Padua, Italy*

Contact: E. Bon (ebon@aob.rs)

Abstract. Active Galactic Nuclei (AGN) stand out as the most luminous entities in the universe. Categorized into two primary types based on emission line widths, type-1 AGN exhibits both broad and narrow emission lines, whereas type-2 AGN exclusively features narrow emission lines. The extensive observation and monitoring of Type 1 objects over extended periods have unveiled that some of them show intriguing extreme variability undergoing transition cases, and therefore these objects are named "changing look" AGN (or CL AGN). This review delves into the various transition types observed in these enigmatic objects, shedding light on their characteristics, transitions, and the intriguing questions they pose.

Photonics pathways in higher education

Goran Z. Mashanovich [1,2]

(1) *Optoelectronics Research Centre, University of Southampton, Southampton, SO17 1BJ, UK*

(2) *School of Electrical Engineering, University of Belgrade, 11070 Belgrade, Serbia*

Contact: G. Z. Mashanovich (g.mashanovich@soton.ac.uk)

Abstract. Due to an increasing importance of silicon photonics, there is a need to educate engineers and technicians at both undergraduate (UG) and postgraduate (PG) levels such they can acquire new skills required by both industry and academia. To achieve this, we have established a silicon photonics pathway consisting of three modules in undergraduate and postgraduate courses at the University of Southampton. An additional motivation for this project was to utilise the extensive cleanroom complex and exceptional laboratory facilities in a world leading Optoelectronics Research Centre (ORC) and in the best electronics department in the UK. To achieve this, we have introduced the following modules: 'Photonics I' in year 2, 'Photonics II' year 3, and 'Silicon photonics' at MSc level. In 'Photonics I,' optical fibres and passive silicon photonic devices (waveguides, couplers, splitters, ring resonators, and interferometers) are taught, whilst in 'Photonics II' active devices (detectors, modulators and lasers) are covered. In the 'Silicon Photonics' module more advanced topics (multiplexers, heterogeneous modulators, modulation formats, detectors, fabrication, and sensors) are taught.

We start to teach Silicon Photonics in year 2, in the 'Photonics I' module. Our students first complete a simulation lab in which they learn how to design waveguides, bends, directional couplers and Mach-Zehnder interferometers using the software Lumerical MODE Solutions [1]. They are also given their main coursework assignment to simulate and draw a layout mask design of a silicon photonic circuit using Tanner Tools L-edit [2], which is then combined with the other students' designs, and fabricated in the University of Southampton cleanroom, through the CORNERSTONE foundry service [3]. The fabrication process is carried out on the 220 nm silicon-on-insulator (SOI) platform with a single etch depth of 120 nm. Standard devices such as grating couplers for a wavelength of 1550 nm are provided to the students. This simple process enables devices to be fabricated within two weeks of the design submission. Students then measure their own devices and circuits in the characterisation lab session. Recognising the importance of silicon photonics education and the fact that many departments in the UK and abroad do not have facilities suitable for the fabrication of large number of SOI samples we offer this chip fabrication to external students and universities as a service strictly for teaching purposes at the modest cost of £100 per student [3].

In the 'Photonics II' module our students move onto more complex photonics devices such as modulators. In the simulation lab they design a carrier injection modulator which utilises the well-known plasma-dispersion effect. The simulation model is built using the Lumerical DEVICE software package [1]. The teaching laboratories include experimental setups for measuring near-infrared light transmission through photonic integrated circuits, and for simultaneously applying low frequency electrical signals to the chips. Each setup includes a tuneable laser, detector, fibres, polarisation controller, stages for manipulating the fibre positions, and magnifying cameras for viewing the chip during alignment. The students work in pairs, with each lab session taking 3 hours.

In the 'Photonics I' module the students characterise passive devices and circuits that they have designed during their coursework. They learn how to align fibres to grating couplers and how to run wavelength versus transmission sweeps, and analyse the results.

In the 'Photonics II' module the students go a step further and measure the low frequency behaviour of thermo-optic modulators and switches, implemented using silicon Mach-Zehnder interferometers with metal heaters above one interferometer arm, to which electrical signals are applied. In the 'Silicon Photonics' MSc module we start with basics concepts and silicon photonics devices, primarily for direct entrants who have not attended Photonics I and II UG modules and we later teach more advanced topics: multiplexers, heterogeneous modulators, modulation formats, fabrication techniques, detectors and sensors.

Due to challenges in timetabling of laboratories, only one 3-hour long characterisation lab session can be organised per module. In order to enhance the laboratory experience and enable students to achieve more during the session, in collaboration with the Digital Learning Team in Southampton we have developed a virtual lab environment. It enables students to familiarise themselves with the equipment prior to the lab session. The Virtual Silicon Photonics Experimental Lab (V-SPELL) has been developed using Articulate Storyline (Figure 1).

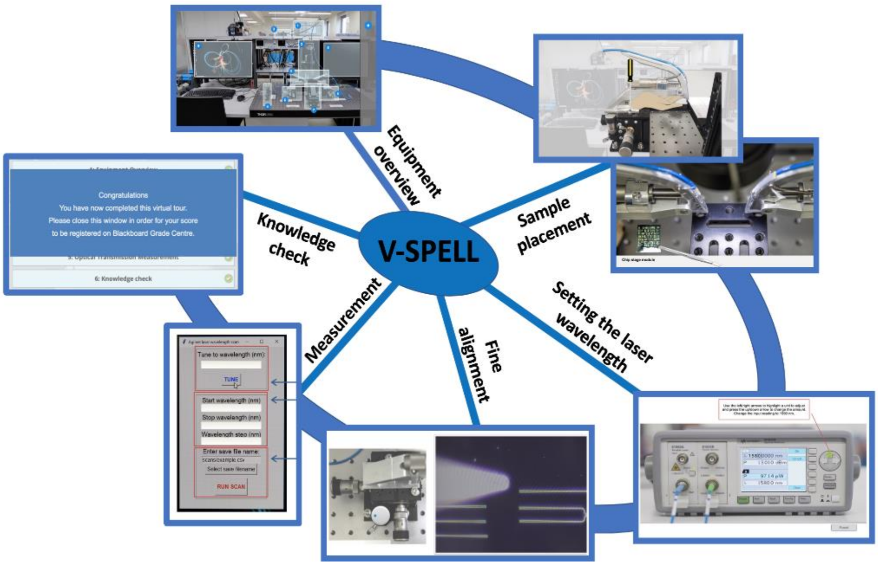

Figure 1. Virtual Silicon Photonics Experimental Lab (V-SPELL)

One of the most important topics in education is how to effectively assess student progress and provide useful feedback that can point to areas for improvement [4]. We have applied several methods such as: conceptual questions, peer learning, just in time teaching, electronic voting during lectures, and assessment workshops to address this. many students, particularly year 1 students, are not usually familiar with university assessments. To better prepare them for final assessment and to improve their self-assessment skills we have introduced so-called assessment workshops [5]. In these 2-hour sessions students are first given previous exam questions and they work in groups of three producing solutions. We then discuss solutions in class. In the second hour, they are given exemplar answers and the actual marking scheme, and they have to mark the example. Several groups are then chosen to present their marks and to give assessment feedback, which are then discussed in class.

REFERENCES

[1] https://www.lumerical.com
[2] https://www.eda-solutions.com
[3] https://www.cornerstone.sotonfab.co.uk
[4] C. Evans, G. Mashanovich, et al., "Developing students' ability to self-monitor and self-evaluate their own work," *ESLTIS17 Conference*, University of Sheffield, Sheffield, UK, 20-21 July 2017.
[5] G. Z. Mashanovich, M. Nedeljkovic, C. G. Littlejohns, and M. M. Milosevic, "A photonics playground," *Optics and Photonics News*, July/August 2020 issue, pp. 16-18, 2020.

Non-covalent interactions of nitrogen-doped carbon quantum dots and aromatic amino acids, an experimental and DFT study

Djordje Trpkov[1], Dušan Sredojević[1], Danijela Danilović[1], Jelena Pajović[2], Dragana Tošić[1], Radovan Dojčilović[1], Dušan K. Božanić[1], Vladimir Djoković[1*]

(1) *Vinča Institute of Nuclear Sciences, National Institute of the Republic of Serbia, University of Belgrade, P.O. Box 522, 11001 Belgrade, Serbia*

(2) *University of Belgrade, Faculty of Physics, P. O. Box 368, 11001 Belgrade, Serbia*

Contact: Djordje Trpkov (djordjet@vinca.rs)

Abstract

Nitrogen doped carbon quantum dots (NCQDs) were non-covalently conjugated by phenylalanine (Phe) and tryptophan (Trp). HR-TEM showed amorphous nanoparticles with 10-20 nm diameter. Chemical mapping confirmed N-doping of carbon nanostructures. Atomic force microscopy revealed NCQDs average height of ~0.4 nm. After the conjugation, the height of the particles increased up to ~3 nm. UV-vis spectroscopy analysis confirmed that the amino acids were conjugated to NGQD nanostructures. DFT numerical calculations based on three differently N-doped clusters were additionally performed in order to elucidate the nature of non-covalent interactions of NGQDs with corresponding amino acids. Photoluminescent spectra showed stable and strong fluorescence signal of both hybrids in the UV region. The most pronounced changes were observed in the case of Trp-conjugation. Contrary to phenylalanine, non-covalent bonding of tryptophan to NGQD quenches visible emission (~500 nm) coming from surface states of the dots.

Optical Properties of Natural Anthocyanin Dyes Encapsulated in Biopolymers

Dragana Tosic[1], Radovan Dojcilovic[2], Dusan Bozanic[2], Vladimir Djokovic[2]

(1) *Vinča Institute of Nuclear Sciences – National Institute of the Republic of Serbia, University of Belgrade, Mike Petrovića Alasa 12-14, 11351 Belgrade, Serbia*

(2) *Center of Excellence for Photoconversion, VINČA Institute of Nuclear Sciences, University of Belgrade, Mike Petrovića Alasa 12-14, 11351 Belgrade, Serbia*

Contact: D. Tosic (draganica@vin.bg.ac.rs)

Abstract. Anthocyanins represent natural intrinsically fluorescent phytopigments that provide the purple, blue, and red colors of many plants. One of the most interesting features of anthocyanins is their natural ability to change colors in different environments. The color variation of anthocyanins is associated with the structural changes in their chemical forms that are a direct consequence of pH changes in solution [1]. In this study, anthocyanins were extracted from black chokeberry (*Aronia melanocarpa*) powder using a solvent extraction method. Aronia extracts show high sensitivity to the pH of the environment manifested by changes in the color of the solutions. The optical properties of aronia extracts were investigated by UV-Vis and photoluminescence (PL) spectroscopies. It was observed that the absorption peak shifts to a longer wavelength with the increase in pH values. PL spectroscopy reveals clear differences between the optical properties of the samples in acidic and alkaline environments.

Chitosan, a natural and biodegradable polysaccharide, can be considered as an ideal carrier for anthocyanins. Chitosan macromolecules contain a large number of polar OH and NH_2 groups that can entrap the pigments via interactions with phenolic components of the anthocyanin molecules [2]. In the present study, we investigated two types of chitosan-anthocyanin systems. We have fabricated indicator films that change the color with changes in the pH of the environment. Specifically, we exploited the fact that the chitosan biopolymer is soluble in the mild acidic solvents. In the case when the pH of the environment drops, the chitosan films release anthocyanins, which results in fast colorimetric response. This type of research is part of the ongoing efforts that aim towards replacement of traditional plastic packaging with smart biodegradable packaging biomaterials. Also, we have encapsulated anthocyanins into core-shell chitosan-alginate nanoparticles, which can be used in cell bioimaging [3]. Fluorescence microscopy images of aronia extract encapsulated in the nanoparticles show the highest fluorescence at the excitation of 575 nm in the emission range of 600-700 nm. The obtained nanoparticles can be employed for monitoring the subcellular localization of anthocyanins.

REFERENCES

[1] A. Houghton, I. Appelhagen, C. Martin, *Plants*. **10** (2021), 726.
[2] K. Halász, L. Csóka, *Food Packag. Shelf Life*. **16** (2018), 185-193.
[3] P. Mukhopadhyay, S. Chakraborty, S. Bhattacharya, R. Mishra, P.P. Kundu, *Int. J. Biol. Macromol.* **72** (2015), 640-648.

Quantum-limited localization and resolution of optical sources

Ben Wang[1], Chenyu Hu[1], Lin Zhou[1], Liang Xu[1], Lijian Zhang[1]

(1) *College of Engineering and Applied Science, Nanjing University, 163 Xianlin Road, 210023 Nanjing, China*

Contact: Lijian Zhang (lijian.zhang@nju.edu.cn)

Abstract. Locating an emitter and resolving different emitters, i.e. estimating their relative positions, are key tasks in imaging problems and determine the ultimate resolution. It was widely accepted that Rayleigh's criterion sets the limit of the resolving power of an imaging system. Recently there have been efforts to formulate imaging as a parameter estimation problem and analyze its performance using the tools developed in quantum metrology. This formulation allows to identify the fundamental limit of resolution and methods to overcome Rayleigh's criterion [1]. In this talk I will present our recent works along this direction. With the applications of multiple-parameter estimation quantum metrology, we derive the fundamental quantum limit of locating a single emitter and resolving two emitters with different brightness in three-dimensional space [2-4]. The effects of the point spread functions and coherence of the source on location precision and resolution are also analyzed. I will also talk about the experimental demonstrations of the imaging schemes to achieve the quantum limit. Our results may find wide applications from microscopy to astrometry.

REFERENCES

[1] M. Tsang, R. Nair, and X.-M. Lu, *Phys. Rev. X* 6, 031033 (2016).
[2] Ben Wang, Liang Xu et al., *Photon. Res.* 9, 1522 (2021).
[3] Ben Wang, Liang Xu et al., *Chin. Opt. Lett.* 21, 042601 (2023).
[4] Chenyu Hu, Liang Xu et al., *Quant. Frontiers* 2, 20 (2023).

Precision cw-spectroscopy of Rydberg states of nitric-oxide molecules

Robert Loew

Universität Stuttgart Fachbereich Physik 5. Physikalisches Institut Pfaffenwaldring 57 70569 Stuttgart, Germany

Contact: r.loew@physik.uni-stuttgart.de

Abstract. Abstract: High-resolution CW laser spectroscopy of nitric oxide (NO) molecules has been performed to study the energy-level structure, decay dynamics, collisional effects and effects of electric fields on high lying Rydberg states with unprecedented precision. The experiments were performed with molecules flowing through a room temperature gas cell. Rydberg-state photoexcitation was carried out using a three-photon excitation scheme, with the excited molecules detected by high-sensitivity opto-galvanic methods. The motivation for these studies is twofold: 1) The availability of narrow-band cw-lasers in the UV region allows for highly resolved sub-Doppler spectroscopy of molecules. This is from broad interest as many molecules so far were only accessible with pulsed laser sources. 2) Nitric-oxide is a tracer gas for inflammatory diseases and highly sensitive and large bandwidth trace gas sensor for NO opens new pathways for clinical studies.

The Urban Observatory of Belgrade

D.V. Lukić[1], S. Samurović[2]

[1] *Photonic Center, Institute of Physics Belgrade, University of Belgrade, Pregrevica 118, 11080 Belgrade, Serbia*

[2] *Astronomical Observatory, Volgina 7, 11000 Belgrade, Serbia*

Contact: D.V. Lukic (lukic@ipb.ac.rs)

Abstract. Under the banner of the Urban Observatory project, focused on tackling light pollution, we are initiating the establishment of the facility within the renowned Astronomical Observatory of Belgrade and the first of its kind in the country. Given the escalating spread of artificial lighting worldwide, there's a growing need to assess night sky brightness. Light pollution remains a poorly understood yet impactful form of environmental degradation. Our primary objective is to employ established astronomical methodologies to investigate light pollution and dynamic processes within Belgrade, the Serbian capital. Our observations will yield crucial insights into energy consumption patterns, with significant implications for the environment and ecosystems. To achieve this, we plan to deploy multiple observational instruments spanning the visible (400 nm) to the infrared (13 micron) spectrum, including broadband and hyperspectral imaging systems for comprehensive analysis. In addition to urban dynamics, our instruments will focus on assessing sky brightness and identifying sources of pollution, such as streetlights. The facility will not only generate high-quality observational data but also serve as a hub for training and knowledge dissemination. Our approach involves long-term monitoring complemented by periodic validation, with all collected data made publicly accessible and linked to relevant databases. Furthermore, we aim to promote widespread awareness of our facility, measurements, and findings. By implementing a cost-effective, replicable model, our three-year project aims to establish an Urban Observatory that can serve as a blueprint for similar initiatives in other Serbian cities, ultimately enhancing the quality of life for their residents.

ACKNOWLEDGMENT

This research was supported by the Science Fund of the Republic of Serbia, grant no. 6775, Urban Observatory of Belgrade - UrbObsBel.

BioQantSense - Twinning for excellence of the Serbian Research Center for quantum biophotonics

Classical microscope interference-objectives for quantum holography

Dejan V. Pantelic

Senzor INFIZ, Pregrevica 118, 11080 Zemun, Belgrade, Serbia

Contact: dejanvpantelic@gmail.com

Abstract. Quantum holography emerged as a promising method for NIR and thermal IR imaging. Its main advantage is a possibility to interact with the specimen at infrared, while signal detection is performed at visible wavelengths (using ubiquitous visible cameras). So far, little attention was paid to microscopy and resolution limits imposed by objective lens design and associated aberrations. Here we show that slight modifications of Linnick and Mirau [1] interferometers can be used for diffraction limited quantum holographic microscopy.

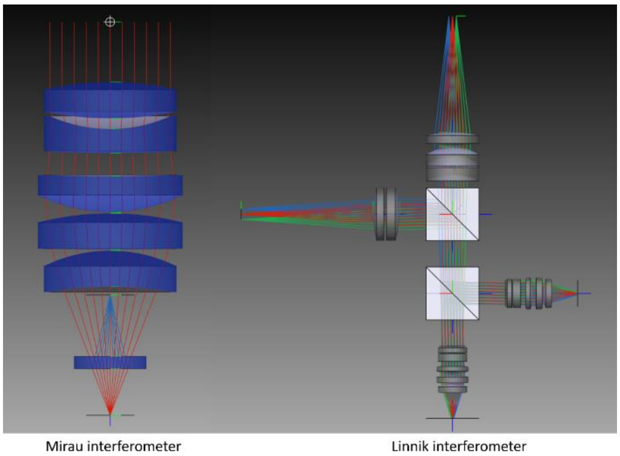

Figure 1. Mirau and Linnik interferometers

REFERENCES

[1] Peter J. de Groot, James F. Biegen, "Interference microscope objectives for wide-field areal surface topography measurements", Opt. Eng. 55 (7), 074110

Evaluating abnormal levels of intracellular cholesterol through Raman and Surface-enhanced Raman spectroscopy

Caterina Dallari[1,2], Enrico Baria[2,3], Claudia Capitini[1,2], Francesco Mattii[1,2,3], Francesco Saverio Pavone[1,2,3], Riccardo Cicchi[1,2], Caterina Credi[1,2] and Martino Calamai[1,2]

[1]*National Institute of Optics (INO), National Research Council (CNR), Sesto Fiorentino, Italy*
[2]*European Laboratory for Non-Linear Spectroscopy (LENS), University of Florence, Sesto Fiorentino, Italy*
[3]*Department of Physics, University of Florence, Sesto Fiorentino, Italy*

Contact: dallari@lens.unifi.it **;** caterina.dallari@ino.cnr.it

Abstract. The quantification of intracellular cholesterol is crucial for disease detection and understanding cellular physiology. Cholesterol is crucial for cell membrane integrity and various cellular processes, and deviations from normal levels are linked to diseases, including metabolic disorders, neurodegenerative conditions, and certain cancers. Timely and precise measurement is essential for tempestive interventions, be it lifestyle adjustments, pharmacological interventions, or targeted treatments, to mitigate disease risk and optimize overall health. While fluorescence microscopy is commonly used, it has limitations, such as auto-fluorescence interference and sensitivity to environmental factors. The need for sensitive and rapid methods led to the exploration of Raman spectroscopy (RS), proposed as an alternative due to its nondestructive, label-free nature. Despite weaknesses, RS can be enhanced by surface-enhanced Raman scattering (SERS), overcoming limitations. The study focuses on using Raman and SERS spectroscopies to detect cholesterol in wild-type fibroblasts and cells affected by Niemann-Pick disease, a genetic disorder impacting cellular fat metabolism. The findings highlight the potential of RS and SERS as fast, label-free methods for inspecting cellular cholesterol content, particularly near lysosomal structures, suggesting their potential adoption in diagnostics and therapeutics as alternatives to fluorescence microscopy. Based on successful results, within the BQS project, the same biological target has been exploited to prepare samples for imaging through quantum holography. Cholesterol enriched cells were cultured on different substrate materials chosen for microfluidic fabrication, with the aim of developing a cell-analyzer device that can easily interface with microscopy. The concept is to use quantum holography to analyze the chemical and morphological alterations induced by varied cholesterol content, associated with pathological conditions.

Nonlinear interferometers for quantum imaging with undetected light

Sebastian Töpfer[1], Sergio A. Tovar Pèrez[1], Jorge Fuenzalida[1], Marta Gilaberte Basset[2,3], Josué R. León Torres[2,3], Juan P. Torres[4], and Markus Gräfe[1,2]

(1) Institute of Applied Physics, Technical University of Darmstadt, Schloßgartenstraße 7, 64289Darmstadt, Germany

(2) Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Albert-Einstein-Str. 7,07745 Jena, Germany

(3) Friedrich Schiller University Jena, Abbe Center of Photonics, Albert-Einstein-Str. 6, 07745 Jena, Germany

(4)ICFO-Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, 08860Castelldefels, Spain, and Dept. Signal Theory and Communications, Universitat Politecnica de Catalunya, 08034 Barcelona, Spain

Contact: M. Gräfe (markus.graefe@tu-darmstadt.de)

Abstract. Exploiting nonclassical states of light allows new imaging and sensing approaches. In particular, nonlinear interferometers enable quantum imaging with undetected light [1]. Here, based on the effect of induced coherence [2], samples can be probed with lightthat is not detected at all. Instead, its quantum-correlated partner light is recorded and yields the information of the sample, although it never interacted with it. An experimental setup to perform such »spooky« quantum imaging with undetected light is depicted in Fig. 1 below. Photon pairs are generated via spontaneous parametric down-conversion in a nonlinear crystal(here, ppKTP). Three nonlinear interferometer arms are matched. While inserting an object into the idler arm (green), the image of the object is recorded on a camera with signal light (red) only. The talk will outline the fundamental concept, recent progress, limits, and perspectives for biomedical applications of nonlinear interferometers.

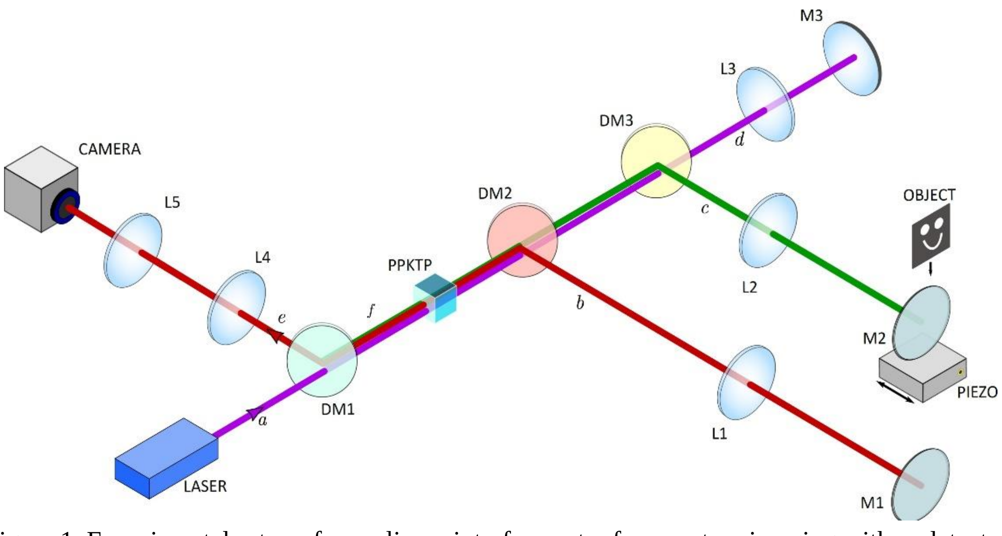

Figure 1. Experimental setup of a nonlinear interferometer for quantum imaging with undetected light.

REFERENCES

[1] G. B. Lemos, V. Borish , G. D. Cole, S. Ramelow, R. Lapkiewicz, and A. Zeilinger, “Quantum imagingwith undetected photons,” Nature 512, 409 (2014).

[2] X. Y.Zou, L. J. Wang, and L. Mandel, “Induced coherence and indistinguishability in optical interference,”Phys. Rev. Lett. 67, 318 (1991).

Mid-Infrared Quantum Scanning Microscopy with Visible Light

Josué Ricardo León-Torres[1,2,3], Jorge Fuenzalida[1], Marta Gilaberte[1], Valerio Gili[1], Markus Gräfe[4]

[1]*Fraunhofer Institute of Applied Optics and Precision Engineering IOF, Albert-Einstein-Straße 7, D-07745 Jena, Germany*

[2]*Friedrich-Schiller-Universität Jena, Abbe Center of Photonics, Max-Wien-Platz 1, D-07745 Jena, Germany*

[3]*Cluster of Excellence Balance of the Microverse, Friedrich Schiller University Jena, Jena, Germany*

[4]*Institute of Applied Physics, Technische Universität Darmstadt, Schloßgartenstraße 6, D-64289 Darmstadt, Germany*

Contact: josue.ricardo.leon.torres@iof.fraunhofer.de

Abstract. A label-free quantum scanning imaging system is presented, capable of detecting in the visible regime, while illuminating with undetected light in the Mid-IR region by exploiting the phenomenon of induced coherence [1] and the quantum correlations of photon-pairs generated by Spontaneous Parametric Down Conversion (SPDC) Laser scanning microscopy (LSM) is the workhorse for modern life-science, it allows to get new insights into a variety of biological processes. LSM together with illumination in the mid infrared region (Mid-IR) permits to map the chemical composition of samples to a space frame. However, low-light observations in the Mid-IR spectrum are still challenging and a limiting factor for a faster development.

In this work a highly non-degenerated entangled photon-pair is created through SPDC when a pump photon interacts with a PPKTP non-linear crystal. The SPDC process can take place in the forward or backward direction, creating two probability amplitudes of photon-pair generation. In the forward direction, the idler photon (λ_i=2400 nm) is reflected by a dichroic mirror and directed towards the sample [2] The MIR photon illuminates the sample, while the VIS photon is used for reconstructing the object, by using a single pixel detector.

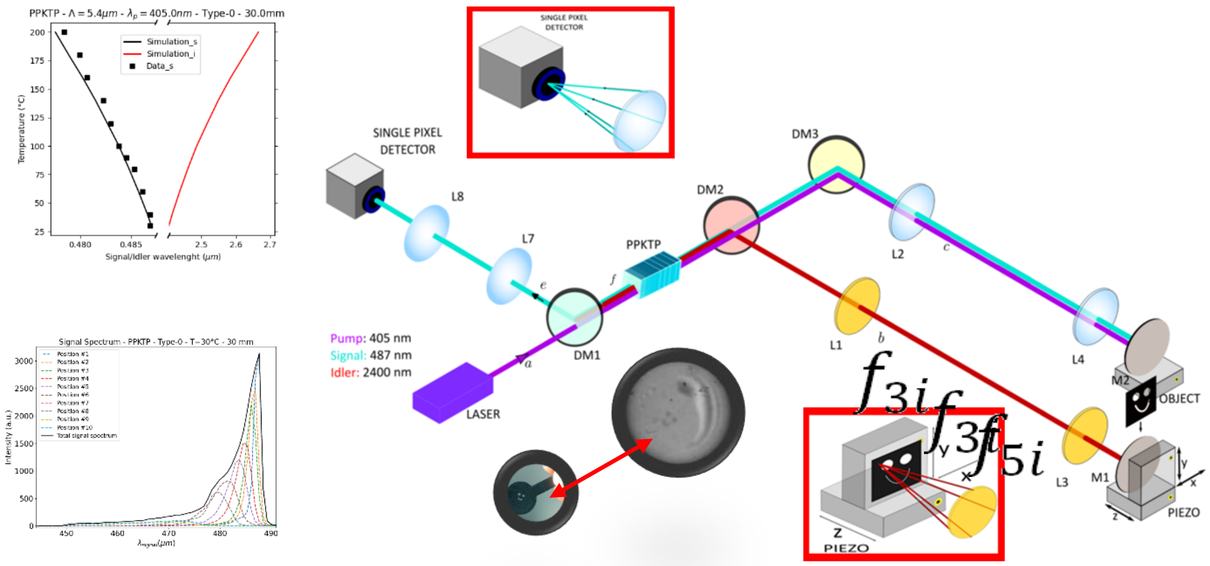

Figure 1. - Experimental setup, quantum imaging with undetected photons. Pump and signal photons in the VIS spectrum and idler in the Mid-IR spectrum. Idler photon is used to probe the sample, different functional groups in the fingerprint region (2.5- 12 μm) will absorb the illumination light, while the signal photon is detected.

[1] X. Y. Zou, L. J. Wang, L. Mandel, "Induced coherence and indistinguishability in optical interference," Phys. Rev. Lett., 67, 318 (1991).

[2] M. G. Basset, A. Hochrainer, S. Töpfer, F. Riexinger, P. Bickert, J. R. León-Torres, F. Steinlechner, M. Gräfe, "Video-Rate Imaging with Undetected Photons," Laser Photonics Rev. 15 202000327 (2021).

Entanglement generation at the nanoscale

Frank Setzpfandt[1,2]

(1) *Institute of Applied Physics, Abbe Center of Photonics, Friedrich Schiller University Jena, 07745 Jena, Germany*

(2) *Fraunhofer Institute of Applied Optics and Precision Engineering IOF, 07745 Jena, Germany*

Contact: Frank Setzpfandt (f.setzpfandt@uni-jena.de)

Abstract. Photon-pairs have evolved as a critical resource for quantum technologies, and many applications in quantum communication, imaging, sensing and computing are based on using such quantum states with judiciously designed properties. For many applications, sources of photon pairs are still based on bulk nonlinear crystals, which due to the need for phase matching enable efficient generation only in limited parameter ranges. In the last years, it was demonstrated that also nanoscale films of second-order nonlinear materials can serve as sources of photons pairs by spontaneous parametric down conversion (SPDC), without the need to achieve phase matching [1]. Structuring these films into resonant nanostructures enhances the generation efficiency while providing a large number of degrees of freedom for controlling the properties of the generated pairs through the geometry of the nanoresonators [2, 3].

However, a full understanding of how nanostructures can be employed for entanglement generation is still missing. We developed a general model to describe SPDC in open resonators, which allows us to fully predict the properties of the generated pairs. Using this to analyze a single nanoresonator from a III-V semiconductor material, we find that already such a simple structure can generate different maximally entangled states [4].

Alternatively, to using nanostructured resonators to control the polarization properties of photon pairs and generate entangled states, one can also use materials with specifically chosen nonlinear tensor structures to achieve entanglement. One material class with very peculiar nonlinear properties are transition metal dichalcogenides (TMDC), which tensor structure only couples the two in-plane polarization due to the two-dimensional nature of the layered material. Recently, TMDCs became available that conserve the second-order nonlinearity also for crystals with thicknesses in the range of several tens of nm, such that efficient nonlinear interactions can be achieved [5]. I will discuss our progress towards photon-pair generation in such materials and show, that I can generate maximally entangled Bell states which can be controlled by the direction of the pump polarization.

REFERENCES

[1] C. Okoth et al., Physical Review Letters 123, 263602 (2019).
[2] T. Santiago-Cruz et al., Nano Lett. 21, 4423 (2021).
[3] T. Santiago-Cruz et al, Science 377, 991 (2022).
[4] M. A. Weissflog et al., Appl. Phys. Rev. 11, 011403 (2024).
[5] X. Xu et al., Nature Photonics 16, 698 (2022).

The hidden value of responsive materials

Sara Nocentini[1,2], Simone Donato[2], Daniele Martella[1,2], Camilla Parmeggiani[2,3], Diederik S. Wiersma[1,2,4], Francesco Riboli[2,5]

(1) Istituto Nazionale di Ricerca Metrologica (INRiM), Strada delle Cacce 91, Turin, 10135 Italy
(2) European Laboratory for non-linear Spectroscopy (LENS), Via Nello Carrara 1, 50019, Sesto Fiorentino (FI), Italy
(3) University of Florence, Department of Chemistry, Via della Lastruccia 13, 50019, Sesto Fiorentino (FI), Italy
(4) University of Florence, Department of Physics and Astronomy, Via G. Sansone 1, 50019, Sesto Fiorentino (FI), Italy
(5) Istituto Nazionale di Ottica – Centro Nazionale delle Ricerche (CNR-INO), Via Nello Carrara 1, 50019, Sesto Fiorentino (FI), Italy

Contact: Sara Nocentini (nocentini@lens.unifi.it; s.nocentini@inrim.it)

Abstract. Responsive polymers are a class of materials that when trigger by external stimuli such as light illumination or temperature alter their chemical and/or physical properties, enabling microdevices capable of selective autonomous operation. Among them, liquid crystal based polymers offer a reversible shape change and birefringence variation in the millisecond time scale that can foster new applications in robotics [1], photonics [2], cryptography [3] and microfluidics.

In this contribution, I will highlight the role of responsive materials to encode and reveal information using light. Liquid crystalline network patterned at the microscale in an array of identical pixels with different responsiveness can encode information to the observer that can revealed only upon application of a specific stimulus. The reading mechanism is based on the shape-change of each pixel under stimuli and their color that combine together in a two-level encryption label. Once the stimulus is removed, the pixels recover their original shape and the message remains completely hidden. In this way, we demonstrate a mechanical “invisible ink” at the microscale [4].

On the other hand, when liquid crystals are dispersed in a polymer matric, they form a disordered ensemble of micro droplets that scatters light differently depending on their alignment. Taking advantage of the spatial control of the birefringence of the disordered media, we demonstrate a multilevel and multiuser generator of cryptographic password by means of light.[3]

The control of optical and mechanical properties of liquid crystal based polymer and their fabrication strategy can be applied for creating microactuators, pumps and filters into microfluidic systems that will be developed along the BioQantSense project.

REFERENCES

[1] Martella, D., Nocentini, S., Nuzhdin, D., Parmeggiani, C., Wiersma, D.S., *Adv. Mater. 29* (2018), 1704047.
[2] Nocentini, S., Parmeggiani, C., Martella, D., Zanotto, S., Wiersma, D.S., *Adv. Opt. Mater.* 6 (2018),1800207.
[3] Nocentini, S., Rührmair, U., Barni, M., Wiersma, D.S. and Riboli, F., *Nature Materials* (2024), 1.
[4] Donato, S., Nocentini, S., Martella, D., Kolagatla, S., Wiersma, D.S., Parmeggiani, C., Delaney, C. and Florea, L., *Small* (2023), p.2306802.

The authors acknowledge the support funding HORIZON-WIDERA-2021-ACCESS-03-01 – Twinning, Grant agreement No 101079355

FRAPOPM - Free Alignment precession optically pumped magnetometer

On prospects of the free alignment precession based optically pumped magnetometer

Zoran D. Grujić[1], Marija Ćurčić[1], Aleksandra Kocić[1], Theo Scholtes[2]

(1) *Institute of Physics Belgrade, Pregrevica 118, 11080 Belgrade, Serbia*

(2) *Leibniz Institute of Photonic Technology, Albert-Einstein-Strasse 9, D-07745 Jena, Germany*

Contact: Zoran D. Grujić (zoran.grujic@ipb.ac.rs)

Abstract. The optically pumped magnetometers (OPMs) with respectable sensitivity, moderate dimensions and low maintenance costs have their niche as the preferred tools for a number of applications. We pay special attention to a sub niche of applications where high accuracy is the priority. For such applications we use Free Alignment Precession (FAP) in Cs cells with antirelaxation coating. The first step involves optical pumping with linearly polarized light, followed by the observation of a FAP signal in the intensity of a weak probe beam in the second step. The applied method is similar to the previously demonstrated free spin precession magnetometer [1].

We will present our current progress in study of the accuracy of a FAP magnetometer related to the light shift. We will also share our resent results on the proposal for an improved method of optical pumping by frequency modulated light that leads to the increased signal quality and, hopefully, improved accuracy too.

REFERENCES

Z.D. Grujić, P.A. Koss, G. Bison, A. Weis, *Eur. Phys. J. D* **69**, 135, (2015)

Experimental and theoretical study of the dynamic phase projection error of Mx magnetometer – Progress report

Marija Ćurčić[1], Aleksandra Kocić[1], Zoran D. Grujić[1], Theo Scholtes[2]

(1) *Institute of Physics Belgrade, Pregrevica 118, 11080 Belgrade, Serbia*

(2) *Leibniz Institute of Photonic Technology, Albert-Einstein-Strasse 9, D-07745 Jena, Germany*

Contact: Marija Ćurčić (marijac@ipb.ac.rs)

Abstract. We will present our recent results of the study of a true scalar optically pumped magnetometer M_x [1]. We will show the design of our experimental set-up, based on the sensing of the magnetic field by the means of the optically pumped Cs vapor, at room temperature. Specially, we have been interested in the response of our magnetometer to the fast modulating transversal magnetic field. The active medium is pumped with a circularly polarized light. The same laser beam is being used for both, optical pumping, and reading out the spin state of the Cs atom ensemble. The precessing spin, driven by oscillating magnetic rf field, imprints a variation in the light intensity of the transmitted light at the Larmor frequency. The phase of the signal is analyzed by the lock-in amplifier.

Alongside the experimental work, we have also performed a theoretical study of the effect of interest. The model is based on the Bloch equation. We have solved it both analytically and numerically. We will present the obtained results and compare them to the ones experimentally measured. The results of the analytical model will be presented in the case of the resonant magnetic field, while the numerical model has been applied in the case of the frequency detuned magnetic field. We will demonstrate a good agreement between the experimental and theoretical results in both cases. Finally, with the obtained observations and conclusions, we are able to point out to the limitations of this type of optically pumped magnetometer when it comes to particular applications.

REFERENCES

[1] A. Weis, G. Bison, Z.D. Grujic, *High Sensitivity Magnetometers* – Magnetic Resonance Based Atomic Magnetometers, Springer, pp 361-424 (2016).

Structured indium tin oxide heating layers on microfabricated alkali vapor cells for optical magnetometry

T. Kügler, F. Wittkämper, T. Scholtes, H. Schneidewind, R. Stolz

Leibniz Institute of Photonic Technology, Albert-Einstein-Straße 9, 07745 Jena, Germany

Contact: Tim.kuegler@leibniz-ipht.de

Abstract. Common optically pumped magnetometers (OPMs) employ optical detection of the interaction between an atomic (alkali) vapor and the magnetic field. The vapor is held in hermetically sealed cells and is optically pumped and probed by resonant (laser) light beams through the cells' optical windows [1]. Miniaturized state-of-the art OPMs use hot atomic vapors in heated microfabricated cells, requiring tailored thermal cell design to avoid (re-)condensation of atoms in the optical windows [2]. Here, electrical heating of the cell windows using thin layers of transparent conducting oxides (TCO) is a promising approach [3]. The structural design of those heating layers has an influence on several properties such as total electrical resistance, light transmission, resulting eddy current distributions potentially leading to excess magnetic field noise, and the resulting temperature distribution across the vapor cell.

We study the use of TCO thin films from indium tin oxide (ITO) as a material for electrical heaters. In detail, our investigation focuses on tailoring properties of the ITO films via thermal treatment and evaluation of various heater designs with respect to their performance and fabrication complexity.

REFERENCES

[1] D. Budker, M. Romalis, Nat. Phys. **3**, 227–234 (2007).
[2] J. Kitching, Applied Physics Reviews **5**, 031302 (2018).
[3] Z. Liu et al., IEEE Sensors Journal **21**, 16554-16559 (2021).

Lock-in Frequency Estimation Algorithm for Optically Pumped Magnetometer

Miloš Subotić[1,2], Zoran D. Grujić[2]

(1) *Faculty of Technical Sciences, Trg Dositeja Obradovića 6, 21102 Novi Sad, Serbia*

(2) *Institute of Physics Belgrade, Pregrevica 118, 11080 Belgrade, Serbia*

Contact: M. Subotić (milos.subotic@uns.ac.rs)

Abstract. In previous work [1], device for estimation of Larmor frequency f_L (which is proportional to magnetic field) was proposed. That device was based on least-squares curve fitting algorithm [2]. In this work, lock-in method based on unwrapped phase φ fitting for frequency estimation is implemented. Algorithm diagram of frequency estimating is shown in Fig. 1. First step to calculate phase difference φ between f_{est} and input signal. If frequencies of the signals are not equal, the phase difference φ is linear function with deviations only due to noise. The φ is further fitted to linear model and f_{est} is incremented by line slope φ'. Process is iterated until φ' drops below threshold i.e. phase difference become close to zero, i.e. f_{est} and f_L are almost equal.

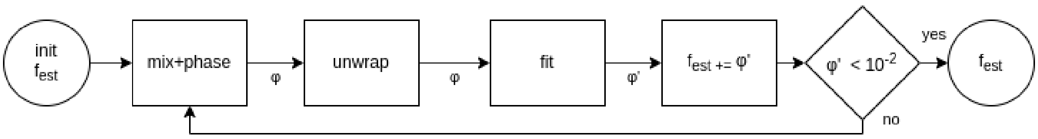

Figure 1. Lock-in frequency estimation algorithm.

Fig. 2. shows in detail calculation of phase difference φ by mixing sine and cosine of estimated frequency f_{est} with input signal, band-pass FIR filtering and argument extraction [3]. Due to use of band-pass filter, exponential decay and offset are also filtered.

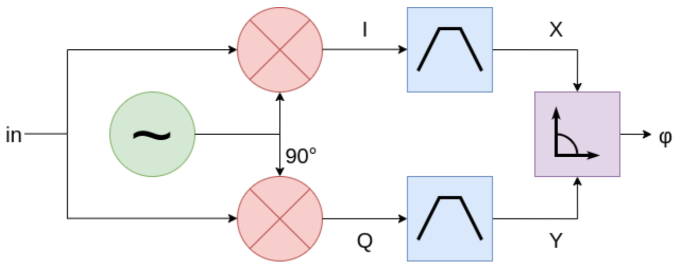

Figure 2. Mixing and phase calculation.

This algorithm is currently implemented as PC program and has similar accuracy and precision below Cramer-Rao Lower Bound as previous work [1]. Implementation of computationly most intensive part of this algorithm (which is mixing, especially FIR filtering) in a FPGA accelerator is a work in progrss.

REFERENCES

[1] Subotic, Milos, et al. "Frequency Estimating Device for Optically Pumped Magnetometer". *16th Photonics Workshop* (2023).

[2] Visschers, Jim C., et al. "Rapid parameter determination of discrete damped sinusoidal oscillations". *Optics Express* 29.5 (2021): 6863-6878.

[3] Macias-Bobadilla, Gonzalo, et al. "Dual-phase lock-in amplifier based on FPGA for low-frequencies experiments." Sensors 16.3 (2016): 379.

Recent developments in optical magnetometry

Theo Scholtes[1]

(1) *Leibniz Institute of Photonic Technology (IPHT), Albert-Einstein-Strasse 9, 07745 Jena, Germany*

Contact: T. Scholtes (theo.scholtes@leibniz-ipht.de, at present theo.scholtes@uni-jena.de)

Optically pumped magnetometers represent today's most sensitive non-cryogenic sensor class for the detection of magnetic fields. In such devices, ensembles of atomic spins are optically prepared and their interaction with the magnetic field is read-out by optical means [1]. Here, typically thermal atomic (alkali) vapors, held in sealed cells, are interrogated by resonant laser radiation, and, e.g., the change in intensity of the transmitted light in dependence on the magnetic field is monitored.

After a short introduction into optical magnetometry, I will review a selection of recent developments in the field with the focus on work towards applications within the geomagnetic field. In such scenarios, where magnetic shielding is not permissible, the sensor needs to resolve extremely tiny signals (pT to fT) within the large geomagnetic background field in the tens of µT range [2]. Moreover, besides calling for ultimative sensitivity and dynamic range, other sensor properties turn out to be crucial, e.g., rotation and vibration invariance of the measurement, simplicity, and robustness of implementation. These requirements become even more essential when the sensor is to be employed on a moving platform.

I will discuss promising approaches for unshielded and mobile operation and briefly summarize our own on-going work in this direction.

REFERENCES

[1] A. Grosz, M. J. Haji-Sheikh and S. C. Mukhopadhyay (eds), *High Sensitivity Magnetometers*, Springer International Publishing, Cham (2017).

[2] G. Oelsner, R. IJsselsteijn, T. Scholtes, A. Kr üger, V. Schultze, G. Seyffert, G. Werner, M. Jäger, A. Chwala, and R. Stolz, *Phys. Rev. Applied 17*, 024034 (2022).

Acknowledgements

I gratefully acknowledge financial support from the Federal Ministry of Education and Research (BMBF) of Germany under Grant No. 1DS21006 (FRAPOPM) and support within the project Rio-GNOME funded by the German research foundation (DFG) under grant number 439720477.