BULGARIAN ACADEMY OF SCIENCES

GEORGI NADJAKOV
INSTITUTE OF SOLID STATE PHYSICS

ANNUAL RESEARCH REPORT
2020

Compiled and Edited by J. Genova

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Foreword

To commemorate the 48th anniversary of the Institute of Solid State Physics an exhibition "Liquid crystals and bionanocomposites: fundamental and applied achievements of IFTT-BAS with national and world recognition" was held in the period October 19-23, 2020 at the central lobby of administrative building of the Bulgarian Academy of Sciences. The exhibition included 18 poster presentations demonstrating the scientific achievements of the Institute on the behavior of biomembranes under the influence of changes in the composition of the environment and various effects of the use of nanoparticles, composite and biocomposite materials, as well as the developed methods for using aquatic plants as a resource of valuable chemicals, sugars and phenols. In the focus of the exhibition was also the phenomenon of bioflexoelectricity, which is of fundamental importance for the physics of living matter, as well as the development of the molecular theory of the elasticity of a lipid monolayer.

During 2020, the realization of the project BG05M2OP001-1.001-0008 continued. This project is funded by the Operational Programme "Science and Education for Smart Growth" of the Ministry of Education and Science co-financed by the European Union through European structural and investment funds. The ultimate goal of the project is to build a National Center of Excellence for Mechatronics and Clean Technologies. ISSP is a one of the main partners in this project. Important equipment was purchased and installed in the Institute in the frames of the project during the year.

In 2020, the Institute was the beneficiary of several scientific projects financed by Ministry of Education and Science. Another project was awarded in the framework of the National Scientific Program" Petar Beron & NIE" (P. Beron) – AuLip "Influence of hydrophobic gold nanoparticles on bending elasticity, stability, phase transition and fluidity of SOPC lipid model systems".

During 2020, the 21st edition of the traditional International School on Condensed Matter Physics devoted to "Progress and Perspectives in Functional Materials" was organized. The event was held from 31st August to 3rd September 2020 in Varna, Bulgaria. This year, due to the specific situation with the Covid-19 pandemic, in order to ensure all measures for social distancing, the conference provided an opportunity for online participation. Once again, the school was supported by the Ministry of Education of Bulgaria through the Research Fund within the frames of the "Procedure for Supporting International Scientific Forums in Bulgaria". The project allowed 10 young scientists to be seconded to the school to present their scientific results.

The Institute organized the traditional 23rd Winter Seminar "Interdisciplinary Physics" for doctoral students and young scientists from the Bulgarian Academy of Sciences during the winter of 2020. Furthermore, the organization of the 22nd edition of the traditional International School on Condensed Matter Physics devoted to "State of the Art in Functional Materials& Technologies" has started. The event will be held from August 29th to September 2nd 2022 in Varna, Bulgaria.

During the last year, the scientific personnel of the Institute published 115 papers. 85 articles have been published in internationally recognized high impact journals indexed in Web of Science and/or SCOPUS. The total number of citations in 2020 exceeds 1207. ISSP currently holds 22 BG patents and 4 applications for patents are in procedure.

During 2020 eight patents were approved: Method of creating a mobile electronic copy of printed or handwritten material; Composite material and method for its preparation; Method and device for determination of kinematic viscosity and mass density of aerosols; Method for characterization of nanostructured nematic liquid crystals; Device for extraction of atmospheric electricity; Contactless determination of the number and diameter of fog drops by gravity separation and measurement of electrical signals; Detection of the emergence of impurities in

the composition of mists and aerosols by surface photo - charge effect by measuring an electrical signal; Contactless detection of phase transitions in liquid crystal media by laser-induced surface photo-charge effect through measurement of electric.

The scientific teams, led by Assist. Prof. Kaloyan Zlatanov and Assoc. Prof. Dimiter Dimitrov were awarded the prize for their scientific achievements for the year 2020 in ISSP.

Hassan Chamati

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Mission: The Institute is committed to generating, disseminating and preserving fundamental knowledge in the fields of condensed matter physics, optics, spectroscopy and laser physics, and application of this knowledge for the creation of novel materials, devices and analytical methods for micro- and nano-technologies, and to working with others to bring this knowledge to bear on Bulgaria's great challenges.

Every second year since 1980, ISSP organizes at the Black Sea coast an International School-Symposium on contemporary problems in condensed matter physics (ISCMP).

EQUIPMENT, METHODS AND TECHNOLOGIES

ISSP has at his disposal a rich variety of equipment, precise methods and technologies:

- Equipment and methods for electron microscopy and electron diffraction investigations, atomic, electric and magnetic force microscopy, X-ray diffraction with topographic, diffractometric and spectrometric facilities, ellipsometric measurements, spectroscopy from VUV to IR spectral regions, time-resolved spectroscopy, EPR spectroscopy;
- Equipment and know-how for single crystal growth from oxide materials for laser techniques and photorefractive effect applications, techniques and technology for thin layer deposition for microelectronic, optoelectronic and acoustoelectronic sensors and laser technology, cleanroom facility, complex equipment for molecular beam epitaxy, equipment for synthesis and investigation of high temperature superconducting materials;
- Equipment for polarization measurements in mesophases and polymer liquid crystals for display techniques, equipment for stroboscopic videomicroscopy and micromanipulation of lipid membranes;
- Various laser systems: gas discharge metal vapour and solid state (ns and fs) lasers, oscillating in UV, visible and IR spectral range, for plasma physics applications, laser analysis and material processing, for application in nanotechnology, medicine, archaeology, ecology, etc.;
- Equipment (Physical Properties Measurement System produced by Quantum Design, USA) for studies of electrical, magnetic and thermal properties of materials, surfaces and structures;
- Scanning probe microscope (VEECO, Multimode, USA) for precise surface characterization at the nanoscale.

HISTORICAL REFERENCE: *ISSP at BAS was created by Decree No 362 / October16, 1972, of the Ministry Council of Bulgaria. This Decree splits the existing Institute of Physics with Atomic Scientific Experimental Center (IP with ASEC) at BAS, founded by Academician G. Nadjakov in 1946, into ISSP and INRNE (Institute of Nuclear Research and Nuclear Energy), starting January 1, 1973. Since February 16, 1982, the Institute of Solid State Physics was named after Academician Georgi Nadjakov. The first Director (1973-1991) of the Institute of Solid State Physics was Academician Milko Borissov. The second Director (1991-1999) was Professor Nikolay Kirov. The third Director (1999-2015) of the Institute of Solid State Physics was Academician Alexander G. Petrov.*

ORGANIZATION OF THE INSTITUTE OF SOLID STATE PHISICS

DIRECTORATE

Director:	Prof. H. Chamati, D.Sc.
Deputy Director:	Prof. A. Paskaleva, D.Sc.
Scientific Secretary:	Assoc. Prof. J. Genova, Ph.D.

DEPARTMENTS

Theory	Head: Prof. H. Chamati, D.Sc.
Functional Materials and Nanostructures	Head: Prof. A. Paskaleva, D.Sc.
Nanophysics	Head: Prof. D. Nesheva, D.Sc.
Physical Optics and Optical Methods	Head: Assoc. Prof. T. Tenev, Ph.D.
Soft Matter Physics	Head: Prof. V. Vitkova, Ph.D.
Laser, Atomic, Molecular and Plasma Physics	Head: Assoc. Prof. V. Mihaylov, Ph.D.
Innovation Department:	Head: Assoc. Prof. D. Spassov, Ph.D.
Education Department:	Head: Prof. A. Paskaleva, D.Sc.
Center for Investigation of the Physical Properties of Materials, Surfaces and Structures:	Head: Prof. P. Rafailov, Ph.D.

SCIENTIFIC COUNCIL

Chairman: Assoc. Prof. E. Dimova, Ph.D.
Deputy Chairman: Assoc. Prof. Y. Marinov, D.Sc.
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12. Assoc. Prof. B. Katranchev, Ph.D.
13. Assoc. Prof. V. Mihailov, Ph.D.
14. Assoc. Prof. A. Stoyanova-Ivanova, Ph.D.,
15. Assoc. Prof. T. Tenev, Ph.D.

LABORATORY

ELECTROMAGNETIC SENSORS

HEAD: **Assoc. Prof. Ognyan Ivanov, Ph.D.**
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TOTAL STAFF: **8**
RESEARCH SCIENTISTS: **4**
ASSOC. MEMBERS: **1**

Assist. Prof. L. Mihailov, Ph.D.; Assist. P. Todorov, Ph.D. student – Mechanical engineer; Assist. Zh. Stoyanov, Ph.D. student; N. Mihaylov – Mechanical engineer, Master student; V. Altunova, B.Sc. student – Laboratory technical assistant; N. Ilieva, B.Sc. student – Laboratory technical assistant; N. Nikolova, B.Sc. student – Laboratory technical assistant;;

Associated member: Assoc. Prof. Katya Hristova, Ph.D.

1. Department topic:

The department caries experimental and theoretical research in the field of electromagnetic field-matter interaction. Sensors and devices on the basis of Electromagnetic echo effect / EMEE / are developed. This is a laser-induced Charge Effect which previous working title was Surface Photo Charge Effect. These sensors are designed for various fields of the industry, security, scientific experiments and others. Our aim is to adhere to activities that are of national interest. In 2020, we worked on improving a series of sensors and devices designed to improve European security and civilian applications. These sensors will work together with fluid generation systems set up by colleagues from several institutions in Europe.

The resulting pandemic following the advent of the Covid - 19 coronavirus has shifted much of our capacity to creating virus sensors. In this regard, many efforts were made, including the submission of several projects in search of funding on this topic.

The theoretical studies of the interaction electromagnetic field – matter are continuing. They are currently aimed at applying the obtained results to describe magnetars. These are a class of neutron stars characterized by huge magnetic fields

We also participate in national operational activities. Such as maintain the projects Optimal Allocation of Locomotives and Dynamic Traction Integrator (used by the National railways company) that are important for the functioning of the railways.

2. RESULTS FROM THE RESEARCH ACTIVITY IN 2020:

Contactless detection of phase transitions in liquid crystal media by means of the electromagnetic echo effect

A method for contactless determination of the phase transition in a liquid crystal by measuring the electrical signal induced by the electromagnet echo effect (EMEE) was developed. Liquid crystals are an intermediate state of matter between a solid and an isotropic liquid. In addition to their significant physical anisotropy, they also have polymorphism. From this point of view, they are an interesting field for studying phase transitions and critical phenomena in partially ordered systems. In order to improve the unambiguous determination of the presence of a phase transition in such polymorphic systems as liquid crystals, we created a non-contact method in which a modulated laser radiation induces an electrical signal with a constant amplitude until a phase transition is induced in the studied liquid crystal. The measured value of the EMEE signal depends on the structure, order and dynamics of these thermodynamic systems. When a phase transition occurs, a sharp change in the measured signal is observed.

Equation of state of magnetars.

Magnetars are a class of neutron stars characterized by huge magnetic fields on their surface. According to the numerical simulations the magnetic fields in the interior are even stronger. They are so extreme that the structure of the neutron star can change. The effects of quantization of the electron motion on the equation of state and the equilibrium composition of the neutron star crust are studied in a wide range of magnetic field strength. The effects on the outer and inner part of the crust are considered in a uniform and consistent way within the nuclear energy density functional theory.

Experimental study on the changes, occurring in a fog in the occurrence of additives with different composition.

The influence of aerosols on the formation of fog in laboratory conditions was studied. The physical and chemical properties of aerosols affect the formation of droplets. The fog is an interesting phenomenon because it affects visibility, air quality, climate and human health. The fog is also used in some industrial processes. Mists with appropriate additives are used as a cleaning agent by the military, in peacetime to protect against terrorist attacks, accidents, natural disasters and more. To achieve our goals, automated fog generation systems have been developed, including mists with controlled additives. The obtained results showed that the spectrum of distribution of the diameters of the mist droplets changes with the change of the concentration of the additive to the mist. This is an original scientific result that has serious practical significance, taking into account the important functions of the fog, some of which were mentioned above.

Detection of impurities in the composition of mists and aerosols by means of laser-induced charge effect

A method has been developed to detect the presence of impurities in the composition of mists and aerosols by measuring an electrical signal induced by EMEE, which depends on the type and concentration of impurities. This is done by inducing an electrical signal with modulated

radiation, the amplitude of which remains constant in pure fog, but changes when an impurity appears. For this purpose, a method for detecting the presence of impurities in the mists by laser generated electromagnetic echo effect, characterized in that the used working structure represents electrode and a plate of semiconductor material on which is formed a solid-liquid border. The liquid is situated inside the sensor, the mist in the environment reacts and dissolves in this layer of liquid. The surface of the structure is irradiated with modulated laser radiation, which induces an electrical signal from EMEE, which is measured with a voltmeter, and this signal changes in the presence of impurities in the condensed mist. This happens, because the impurity changes the interface between the solid body and the liquid and hence the measured signal.

Contactless determination of the number and diameter of fog droplets by means of gravity separation and measurement of electrical signals

The existing on the market devices are expensive and complicated to operate. Our development offers a simple and inexpensive method for contactless determine the number and diameter of the droplets in a stream of fog, through gravity separation and measuring electrical signals from Electromagnetic echo effect at several points of the jet. For this purpose, a non-contact method has been created in which the fog is irradiated with modulated laser radiation, which induces an electrical signal in a receiver. The measured signal value depends on the fog parameters (number and sizes of droplets). This signal is measured at several points in the jet, and the droplets need to be in laminar flow. After measuring the signal at the first point, the signals at the previous points are subtracted from its value at each subsequent point so that the read signal at each point can be separated and the fog parameters determined. It has been found experimentally that in the generation of fog, at a certain distance from the nozzle, the flow of droplets is turbulent, after which distance the flow passes into laminar flow. It is from this moment on that gravitational separation of the droplets by size is observed. The largest drops of the stream fall to the ground first, and the rest move forward. Then the next largest drops fall, reaching only the finest drops. After appropriate calibration and electronic processing of the signal the results of the distribution of droplets in diameter and number are received.

Ability to create a coronavirus sensor using the Electromagnetic Echo Effect

Our studies have shown that EMEE signal is highly sensitive to even small changes in the composition and properties of the tested fluid. The method is fast and contactless and provides real-time analysis. On this basis, a sensor can be created to detect COVID-19 in three cases - in the air, on solid surfaces and in liquids from the human body. The approach involves detection of specific reactions to the virus, even if they are invisible without special equipment. Previous results show that the EMEE signal is very sensitive to weak or virtually unnoticeable reactions. The idea is to work with a structure in which a specific reaction will take place when the virus appears on it. For this purpose, antibodies or other substances can be

used in which a reaction is excited only when the desired virus appears. We already have initial experimental results for animal viruses.

National and operational activities serving the state: Scientific-applied systems.

Our developments are "Optimal Distribution of Locomotives" and "Dynamic Traction Integrator", authored by Dr. Mihailov. They are implemented in the railways with great efficiency. The developed algorithms are included in scientific-applied systems of national importance, for which we provide constant assistance. A system for long-term planning of train schedules, based on these developments, is provided in the form of a training version of VTU "T. Kableshkov" and the Kazakh Academy of Transport and Communications.

3. INTERNATIONAL SCIENTIFIC COOPERATION:

Within the *COUNTERFOG* project we worked with participants in the consortium implementing the project, which are a total of nine. With members of the consortium we submitted a proposal for a new European project - acronym: PILOT COUNTERFOG RIA-IA PartB section1-3 – EoI. The topic is on implementing the results of the COUNTERFOG project. We also worked on a project submitted in 2018 to the *European Space Agency* with approximately the same participants with similar topic. There is still no answer for this project.

We applied some of the results obtained by COUNTERFOG with:

- I. Gultepe *: Faculty of Engineering and Applied Science, University of Ontario Institute of Technology* , Ontario. Canada;

- Sevinc Sirdas, *Istanbul Technical University*, Vice Dean of *Faculty of Aeronautics and Astronautics, Department of Meteorological Engineering,* Istanbul, Turkey;

- Ashok Vaseashta, International Clean Water Institute, Manassas, VA 20112, USA;

- Richard Ding, EU-China Environmental Technology Collaboration Platform;

For the theoretical studies of the interaction electromagnetic field - matter with application in astrophysics, we worked with:

- N. Chamel: *Institute of Astronomy and Astrophysics, Libre University of Brussels*, Brussels, Belgium;

- JM Pearson: *Department of Physics, University of Montreal*, Montreal, Canada.

4. PARTICIPATION OF THE DEPARTMENT IN THE TRAINING OF SPECIALISTS

In Department *Electromagnetic sensors* work two PhD students and three students who improve their knowledge and skills in the field of experimental and theoretical scientific and applied research.

Ognyan Ivanov is the supervisor of PhD student Petar Todorov, topic of the dissertation Research of Fluid Environments and Development of Sensors, at the Institute of Mechanics, BAS.

5. INNOVATION ACTIVITY OF THE DEPARTMENT AND ANALYSIS OF ITS EFFICIENCY

In 2020, we assisted the patent office in reviewing our five patent applications. Three of them were adopted in 2020. These patent applications are the result of joint innovation with organizations from abroad. They are funded by a contract with the *Research Executive Agency* of the European Commission. We worked with *GIS Transfer Center*, BAS on applying these scientific results. We also actively cooperate with state, private and public institutions. This fact gives us reason to believe that the patents they will quickly find their real, practical applications.

8. PUBLISHING AND INFORMATION ACTIVITY OF THE DEPARTMENT

Ognyan Ivanov is a member of 6 publishing boards of international scientific journals and conferences. In 2020 he took part in the jury for the defense of the dissertation of Francisco José Llerena Aguilar from the *Universidad de Alcalá, Department of Teoría de la Señal y Comunicaciones*, Madrid, Spain. He has written two reviews for *Boundary - Layer Meteorology (BOUN)* , Springer : A /BOUN-D-20-00120, A review of Coastal Fog Microphysics during C - FOG ". B/ BOUN-D-20-0061R1, "Coastal Fog Microphysics Using In-Situ Observations and GOES-R Retrievals ". He is a member of the Scientific Committee 3rd International Conference on Photonics Research - *Interphotonics 2020*, Lykia.

List of projects in which the department participates:

- Petar Todorov - National Program "Young Scientists and Postdoctoral Fellows", № RMS № 577 / 17.08.2018, "Research of fluid environments and development of sensors".
- FP7-SECURITY Program, Device for Large Scale Fog Decontamination, acronym COUNTERFOG, number 312804

In 2020, we submitted two projects to the National Research Fund, Bulgaria and four to international institutions in Germany, Italy and the European Commission. We participated indirectly in two other submitted projects in the USA and Canada, as they were only for organizations from the respective countries. We had no success. We have not received a response only from the project submitted to *the European Space Agency* in January together with several partners from Europe. There two competing consortia are ranked and it remains to be decided which of them will be selected for funding.

In 2020 we have published 3 patents, 5 papers and presented 1 report at a conference. We have sent 3 papers to journals for review. Also, we are working on technical adjustments in the text of two other patents, for which a letter from experts of the Patent Office confirming the requisite novelty has been received but need refining according the requirements for registering patents. The observed citations for 2020 are 19.

Patents:

- Invention 112488 / 13.04.2017, Contactless detection of phase transitions in liquid-crystal media by means of laser-induced surface photo-charge effect by measuring an electrical signal, Ognyan Ivanov, Harityun Naradikyan, Jose Louise Perez Diaz, approved in 2020
- Invention 112588 / 29.09.2017, Detection of the appearance of impurities in the composition of mists and aerosols by means of Surface photo-charge effect by measuring an electrical signal, Ognyan Ivanov, Jose Louise Perez Diaz, approved in 2020
- Invention 112602 / 20.10.2017, Non-contact determination of the number and diameter of fog droplets by means of gravity separation and measurement of electrical signals, Ognyan Ivanov, Petar Todorov, Jose Louise Perez Diaz, approved in 2020, issued on 10.12.2020 with № 67164 B1.

Publications:

- **Ivanov O.**, **Todorov P.**, **Nikolova N.**. Application of Electromagnetic Charge Effect for Development of Optical Sensors. *Acta Materialia Turcica*, 4, 3, 2020, ISSN:1359-6454, 8-15
- **Ivanov O.**, **Todorov P.**, **Stoyanov Zh.**. Possibility to create a coronavirus sensor using an optically excited electrical signal. *arXiv:2010.01965* [physics.app-ph], 2020
- **Ivanov O.**, **Todorov P.**, Gultepe I.. Investigations on the Influence of Chemical Compounds on Fog Microphysical Parameters. *Atmosphere*, 11, 3, 2020, 225. JCR-IF (Web of Science):2.046 Q3 (Web of Science)
- Mutafchieva Y. D., Stoyanov Zh. K., Chamel N., Pearson J. M., **Mihailov L. M.**. Unified equation of state for the outer and inner crusts of magnetars. 1555, *Journal of Physics*, 2020, DOI:10.1088/1742-6596/1555/1/012015, SJR (Scopus):0.227 Q4 (Scopus)
- **Ivanov, O**.; Simeonov, K.; **Todorov, P**.; Antonova, D.; Pulis, V. Registration of Reactions Occurring From the Emergence of a Virus by Using an Electromagnetic Charge Effect. Preprints 2020, 2020120114 (doi: 10.20944/preprints 202012.0114.v1).

THEORY

LABORATORY

THEORY GROUP

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ASSOC. MEMBERS: **1**

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Associated members: Assoc. Prof. M. Primatarowa, Ph.D.

RESEARCH ACTIVITIES:

A theoretical framework has been developed to characterize the magnetic properties of a class of molecular magnets with non-trivial bridging structure between the magnetic metal centers. The theoretical background is based on the molecular orbital theory in conjunction with the multi-configurational self-consistent field method and results in a post-Hartree-Fock scheme for constructing the corresponding energy spectrum. Furthermore, we construct a bilinear spin-like Hamiltonian involving a set of discrete coupling parameters accounting for the relevant spectroscopic magnetic excitations, magnetization and magnetic susceptibility.

In order to demonstrate the efficiency of the method, the spectral properties of a spin-one magnetic dimer are computed. Moreover, the devised method and the constructed Hamiltonian are further employed to characterize the magnetic properties of the molecular magnet Ni_4Mo_{12}. The obtained results reproduce both quantitatively and qualitatively the main features of the magnetic spectrum. Furthermore, the theoretical results for the magnetization and the low-field susceptibility are in very good agreement with their experimental counterparts. In this respect, they improve upon the results obtained with conventional Heisenberg models. The present approach may be applied to a variety of magnetic units based on transition metals and rare earth elements.

The possibility to apply phenomenological approach to the description of magnetic transitions in UGe_2 with the help of Landau free energy expanded up to 8-th order in magnetization is studied. The analysis shows that for certain values of the parameters in the coefficient of M^4 and M^6 terms in the free energy there is possibility for the appearance of two successive phase transitions between the low-magnetization and high-magnetization phases with the same structure. We establish the relation of the parameters in Landau energy, for which the phase transition from the disordered to low-magnetization phase is of second order as the

experimental data shows. Within our approximation the transition between two magnetically ordered phases is of first order.

The quantum phase diagram of the mixed-spin (1,1/2) was studied theoretically using strong-coupling expansion as well as numerically applying exact-diagonalization (Lanczos method). Since the unit cell contains 4 spin-1/2 and one S=1 variables, it occurred that the Langzos method was not enough effective, so that we had to apply the DMRG method for larger systems containing up to 20 unit cells (PBC). The first results concerning the ground-state energy are already available.

The $J_1 - J_3$ Heisenberg spin models with nearest-neighbor (J_1) and additional isotropic three-site (J_3) spin interactions remain relatively less explored, although such types of competing exchange terms can naturally emerge from different sources. A short survey of the recently published research in this field, the emphasis being on the characteristics of the variety of quantum phases supported by a few generic uniform- and alternating-spin J_1–J_3 Heisenberg chains was presented. The dimer phases in spin-S J_1–J_3 Heisenberg chains ($S > 1$) serve as complete analogues of the famous gapped Majumdar-Ghosh dimer phase in the spin-1/2 Heisenberg chain with next-nearest-neighbor couplings. The same dimerizations appears in the alternating-spin (S, σ) J_1–J_3 chains ($S > \sigma$)–provided that the cell spin $S + \sigma$ is an integer, whereas for a half-integer cell spin the local dimer formation produces gapless spin-liquid ground states. The alternating-spin J_1-J_3 chains also provide some typical examples of spin models supporting the so-called non-Lieb-Mattis magnetic phases.

Two cases of interaction between a quantized electromagnetic field and two different XY spin molecules; one with spins ½, and the other with spins 1 were studied. Both models interact with a quantized electromagnetic field, with one of the spins in the chain interacting with the electromagnetic field. The interaction between the field mode and the spin chain with spins 1 is described by the one- and two-photon Jaynes-Cummings model (JC model). On the other hand, the interaction between the spins ½ and the electromagnetic field is described only by the one-photon Jaynes-Cummings model. Analytical and numerical calculations were peformed for the case of a different number of photons in the field mode, a different number of spins, and a different position of spin, interacting with the electromagnetic field. The invariant and block structures of such a chain are shown with a comparison made between the evolution of the magnetic moment and the number of photons in both cases.

It has been shown that the entanglement between two atomic spins, coupled via XY interaction, can be achieved with the aid of a single photon in a controllable manner. Assuming a constant spin-photon coupling, two distinct cases are considered - excitation with a constant and with a linear time-dependent photon frequency. We demonstrated that these problems reduce to the study of the well known Jaynes-Cummings and Jaynes-Cummings – Landau-Zener models, respectively, where the two-level system is formed by the zero-momentum mode states of the dimer. Owing to the exact solubility of both models, by tuning the relevant parameters, one can design and coherently control the dynamics of the excitation process. For instance, one can adiabatically switch from an atomic spin system initialized in a state with both spins down to the maximally entangled triplet state.

Solitons provide a promising means to control the state of a spin-qubit in quantum information technology. The anisotropic interaction between a soliton, propagating in a ferromagnetic Heisenberg spin chain and a spin-1/2 particle (qubit) is considered. The spin chain exhibits an on-site anisotropy and spin-spin nearest-neighbor and next-nearest-neighbor interactions. The Bloch sphere picture is employed to investigate the spin- 1/2 dynamics. It was found that increasing the anisotropic and the second neighbor interactions leads to an increase of the deviation of the spin- 1/2 particle from its initial state.

The interaction of a soliton with an impurity spin in a discrete anisotropic ferromagnetic chain is studied. The defect spin in the model is characterized by a modification of the exchange interaction with its neighbors. A perturbed nonlinear Schrödinger (NLS) equation for the spin amplitude is derived on the basis of a semiclassical and a continuum approximation. A specific feature of this type of defect is that it leads to perturbations to all terms of the NLS equation. Localized soliton-defect spin solutions are obtained for the case of dark and bright solitons and their stability is analyzed.

The numerical simulations showed that the single minima/maxima soliton - defect spin solutions are stable while the double minima/maxima solutions are quite unstable. The spin with modified exchange interaction affects the two adjacent sites and hence this type of defect is effectively larger in size than a single on-site linear or nonlinear defect. This imposes more stringent restrictions on the width of the double minima/maxima soliton-defect spin solutions compared to point defects.

Residential segregation is analyzed via the Schelling model, in which two types of agents attempt to optimize their situation according to certain preferences and tolerance levels. Several variants of this work are focused on urban or social aspects. Whereas these models consider fixed values for wealth or tolerance, here we consider how sudden changes in the economic environment or the tolerance level affect the urban structure both in the closed city and open city frameworks, i.e. depending on whether migration processes are relevant or not. In the closed city framework, agents tend to group into clusters, whose boundary can be characterized using tools from kinetic roughening. On the other hand, in the open city approximation agents of a certain type may enter or leave the city in a series of avalanches, whose statistical properties are discussed.

We consider random walkers that deform the medium as they move, enabling a faster motion in regions which have been recently visited. This induces an effective interaction between walkers mediated by the medium, which can be regarded as the space metric. This gives rise to a statistical mechanics toy model either for gravity, motion through deformable matter or adaptable geometry. In the strong-deformability regime, we find that diffusion is ruled by the porous medium equation, thus yielding subdiffusive behavior of an initially localized cloud of particles, whose global width will grow like $\sigma \sim t1^{/3}$, though the width of each sample will sustain a $t^{1/2}$ growth, which can be accounted for through ergodicity breaking. Indeed, random walkers present strong correlation effects, which we explore indirectly through the fluctuations of the center of mass of the cloud.

Motion of substance in a channel of network in presence of possibility for inflow of substance to nodes of the channel was studied. Stationary state of motion of substance can exist in this case and we discuss conditions for existence of such state. The probability distribution connected to distribution of substance in nodes of channel was obtained. Flow of substance in a channel of network which consists of nodes of network and edges that connect these nodes and form ways for motion of substance was investigated. The channel can have arbitrary number of arms and each arm can contain arbitrary number of nodes. The flow of substance is modeled by a system of ordinary differential equations. We discuss first a model for a channel which arms contain infinite number of nodes each. For stationary regime of motion of substance in such a channel we obtain probability distributions connected to distribution of substance in any of channel's arms and in entire channel. Obtained distributions are not discussed by other authors and can be connected to Waring distribution. Next, we discuss a model for flow of substance in a channel which arms contain finite number of nodes each. We obtain probability distributions connected to distribution of substance in the nodes of the

channel for stationary regime of flow of substance. These distributions are also new and we calculate corresponding information measure and Shannon information measure for studied kind of flow of substance.
The Simple Equations Method (SEsM) for obtaining exact solutions of nonlinear partial differential equations was discussed. It was shown that the Hirota method is a particular case of SEsM for a specific form of the function from the Step. 2 of SEsM and for simple equations from the kind of differential equation for an exponential function. The methodology was illustrated by obtaining the three- soliton solution of the Korteweg - de Vries equation, two soliton solution of the nonlinear Schrödinger equation, and the soliton solution of the Ishimori equation for the spin dynamics of ferromagnetic materials. It was shown that the Hirota method is a particular case of SEsM for specific form of the function from the Step. 2 of SEsM and for simple equations from the kind of differential equation for exponential function. The methodology was illustrated by obtaining the three- soliton solution of the Korteweg - de Vries equation, two soliton solution of the nonlinear Schrödinger equation, and the soliton solution of the Ishimori equation for the spin dynamics of ferromagnetic materials.
As a continuation of the research of the solar corona, a numerical analysis was performed, on the base of the Wynn's identity for the compass, which have been shown that it gives the long-sought criterion, the minimal criterion, for the choice of the optimal Padé approximant. The work of this method is illustrated by calculation of multipoint Padé approximation by a new formula for calculation of this best rational approximation. The calculation of the optimal Padé approximant by this criterion is demonstrated in calculation of series summation – frequently encountered problem in theoretical physics. This study originates from a magneto-hydrodynamic problem of heating of solar corona by Alfvén waves, where the present method is used for a predictor in solution of differential equations.

A new mechanism for damping of slow magnetosonic waves (SMWs) by pressure induced oscillations of the ionization degree is proposed. An explicit formula for the damping rate is quantitatively derived. Physical conditions where the new mechanism will dominate are briefly discussed. For high frequencies, the ionization–recombination damping is frequency independent according to the Mandelstam–Leontovich theory. The derived damping rate is proportional to the square of the sine between the constant magnetic field and the wave-vector.

A new effect in condensed matter surface magnetization of the vortex phase of a superconductor induced by electric field has been predicted. The magnetized superconductor should be one of the plates of a plane capacitor on which a voltage has to be applied. Applying alternating voltage to the capacitor, electrostatic induction leads to oscillations of the magnetic moment which has to be measured by electromotive force inducted in a detector coil. The derived explicit formula for the magnetization contains the effective mass of Cooper pairs and a systematic investigation of the predicted magnetization will lead to a creation of an effective Cooper pair mass spectroscopy. For cleaved superconductors this effective mass is a property of the bulk material. Cooper pair mass spectroscopy is actually a tool for normalization of the Ginzburg-Landau wave function.

An alternative for creation of Cooper pair mass spectroscopy studying changes of the electron work-function of a superconductor proportional to the square of the current density are known as Bernoulli effect in superconductors or current induced Contact Potential Difference (CPD) was analyzed. The temperature dependent coefficient $\beta(T;m^*)$ is parametrized by the effective mass of Cooper pairs m^*. In such a way the study of the Bernoulli effect leads to creation of Cooper pair mass-spectroscopy. A short review on the Bernoulli effect in superconductors is given and a proposed experimental set-up for its measurement is described in detail. As the quality of the superconductor surface is crucial for the proposed experiment the research is better to start with crystals used for angle-resolved photo-emission spectroscopy; all those

samples have excellent quality guarantying success even for the first experiment.

PUBLICATIONS:

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Karaaslan, G.I. Georgiev, Effect of high intense electron beam irradiation on structural and Raman properties of boron carbide micro powder, International Journal of Modern Physics B, 34, World Scientific, 2020, DOI:10.1142/S0217979220500083, 2050008.

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ONGOING RESEARCH PROJECTS:

- Quantum effects in low-dimensional and nanostructured magnetic systems
- Phases and excited states of highly frustrated magnetic systems – Bulgarian National Science Fund
- Liquid crystal approach for model lipid membrane functions optimization by nanoparticles insertion – Bulgarian National Science Fund
- Synthesis and theoretical studies of graphene nanostructures – Ministry of Sciences – Bulgaria & JINR Dubna - Russia
- Magnetic quantum effects in low-dimensional and nanostuctured spin systems – Bulgarian National Science Fund
- Dynamics of low dimensional spin systems – Post doctoral
- Exchange interactions in nanomagnetic systems

INTERNATIONAL COLLABORATION:
University of Bielefeld, Germany
JINR Dubna, Russia

TEACHING ACTIVITIES:
Latex Basics
Computer modeling of complex systems

DEPARTMENT FUNCTIONAL MATERIALS AND NANOSTRUCTURES

LABORATORY

PHYSICS OF MATERIALS AND LOW TEMPERATURES

HEAD: **Prof. Peter Rafailov, PhD**
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TOTAL STAFF: **17**
RESEARCH SCIENTISTS: **12**
*HONORARY MEMBERS:***1**
ASSOC. MEMBERS: **1**

Assoc. Prof. E.K. Nazarova, DSc; Assoc. Prof. D.Z. Dimitrov, PhD; Assoc. Prof. B.S. Blagoev, PhD; Assoc. Prof. K.M. Buchkov, PhD; Assist. Prof. L.K. Yankova; Assist. Prof. V.T. Tomov, PhD; Assist. Prof. K. Pavlov, PhD; P.K. Sveshtarov, PhD; V. B. Mehandjiev, MSc; S. Boyadjiev, PhD; E. Milanov, MSc; S. Petrov, M.Sc.
Technicians: O. Mihailov, L. Nikova, S. Simeonov, P. Zashev

Honorary member: Prof. N.S. Tonchev, D.Sc.
Associated member: Prof. M.M. Gospodinov, D.Sc.

RESEARCH ACTIVITIES:

- *Growth and characterization of crystals and thin layers with optical, X-ray, electron-microscopic and other methods*

Applications of Al-doped transparent conductive ZnO oxide layers in liquid crystal displays and devices with polymer dispersed liquid crystals are demonstrated. Such layers deposited on flexible PET substrate retain their sheet resistance even after 1000 bending cycles.

The magnetocaloric effect in TbVO4 single crystals was investigated using magnetic and Raman measurements. A phase transition from tetragonal to orthorhombic symmetry was established at 33 K, leading to strong magnetic anisotropy and the corresponding presence of a rotational magnetocaloric effect in TbVO4. LuVO4 single crystals were examined by polarization Raman spectroscopy and the refinement of the first order Raman-active phonons was completed.

Two-dimensional layers of platinum diselenide - a graphene-like material with potential applications in spintronics and sensor technology - were synthesized. The production of the material was confirmed by polarized Raman spectra and electrical measurements with values of sheet resistance ~ 103Ω / sq.

Layers of AlN were deposited on Si substrates in an ALD reactor. In both half-cycles of the ALD process, TMA (tri-methyl aluminum) and ammonia were used as precursors and purge nitrogen and as carrier gas. To optimize the deposition mode, the pulse duration and purge, deposition temperature, number of cycles and substrate type were changed. The layers are characterized by XRD, XPS, AFM and ellipsometry. The average roughness obtained from the AFM analysis of the AlN layer on Si / SiO2 substrates is of the order of 0.33 nm, which is suitable for devices operating with surface acoustic waves.

The surface of biopolymer and biopolymer-ceramic composites was textured with a femtosecond laser. A layer of ZnO was deposited on the textured samples using low-temperature ALD at 50 ° C. In order to optimize the samples, the parameters of the laser pulses

and the parameters of the ALD deposition were varied. The morphology and chemical properties of the samples were studied with SEM, EDX and XPS. This approach significantly improves the bioactive properties of the samples when used as substrates for bone growth, which is an important result for tissue engineering.

- *Carbon-nanostructure research*

A heterostructure was created from CVD grown graphene transferred on a cycloolefin polymer substrate. The properties of the obtained samples were systematically examined using micro-Raman, terahertz and infrared spectroscopy. High transmittance and high conductivity were established, demonstrating the suitability of the obtained structures as materials for the production of a new class of transparent and flexible electrodes operating in the terahertz spectrum.

- *High-temperature superconductors*

The research of superconducting samples of the type FeSe and FeSeTe continued. In FeSe addition of silver improves the properties of the material (critical parameters, pinning, transition width) and reduces the magnetic impurity phases. It was found that for FeSeAg samples the critical current and the field of irreversibility are larger than those for FeSe samples. The energy of pinning as a function of the magnetic field shows a transition from single to collective pinning for both types of samples. The transition field as well as the pinning energy are higher for FeSeAg samples, which suggests that silver increases the number of pinning centers and their efficiency.

The fluctuation superconductivity in polycrystalline FeSeAg and FeSe-samples obtained by partial melting and solid phase synthesis was studied. Unlike cuprates, little is known about fluctuation superconductivity, fluctuating Cooper pairs over Tc, and their effect on FeSe properties. The dependence $\Delta^*(T)$ is obtained, which in cuprates is associated with a pseudo-gap. Maximum density of local Cooper pairs was found in the FeSeAg sample due to the presence of Ag. It is shown that the fluctuation superconductivity in FeSe obeys the classical fluctuation theories, and fluctuating Cooper pairs also exist at temperatures exceeding $2T_c$.

The hysteresis curves of FeSe0.5Te0.5 crystals at different rates of change of the constant magnetic field were studied. It was found that with an increase from 5 Oe / s to 200 Oe / s the hysteresis curve expands and the second peak in the magnetization shifts to higher fields. The critical current increases at temperatures in the range 2.5K - 10 K, and the ratio Jc (@ 200 Oe/s) / Jc (@ 5 Oe/s) reaches a value of 6 at T = 10 K and H ~ 8 T. These effects are achieved, because the high rate of change of the magnetic field reduces the induced dissipative electric field in the sample, shortens the relaxation time of the fluxoids and limits the dynamic processes, which is extremely important in practical application.

The fluxoid dynamics in these crystals was also studied in an alternating magnetic field by means of a harmonic analysis of the magnetic susceptibility. The dependence of the field of irreversibility on temperature, Hirr (T), at different frequencies of the alternating magnetic field was determined, reaching the maximum values reported in the literature, which is evidence of the high quality of the studied material obtained in our Institute.

AWARDS:

The work reported in Publication 2 of the following list was chosen by the Scientific Council of the Institute of Solid State Physics as the best science-application research achievement of the Institute for the year 2020.

PUBLICATIONS:

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ONGOING RESEARCH PROJECTS:

- National Scientific Research Fund: Projects КП-06-Н38/10, Н28/8;

- M-ERA project 2D-SPIN-MEM; COST Actions: DCOST 01/2 and KP-06-COST/13;

- Inter-academic cooperation with:

(i) Polish Academy of Sciences, Institute of Low Temperature and structure research, Wroclaw, Poland: "Investigation of non-conventional superconductors and magnetic biogenic nanoparticle materials"

(ii) University of Salerno, Italy

"Investigation of superconducting and multiferroic materials"

INTERNATIONAL COLLABORATION:

- Institute of Low Temperature and Structure Research, PAS, Wroclaw, Poland;

- National Ciao Tung University, Hsinchu, Taiwan;

- Department of Physics 'E.R. Caianiello', University of Salerno, Salerno, Italy

- CNR-SPIN Salerno, via Giovanni Paolo II, 132, Fisciano (SALERNO), I-84084, Italy

DEPARTMENT FUNCTIONAL MATERIALS AND NANOSTRUCTURES

LABORATORY

PHYSICAL PROBLEMS OF MICROELECTRONICS

HEAD: **Assoc. Prof. Dencho Spassov, Ph.D.**
tel:029795731; e-mail: d.spassov@issp.bas.bg

TOTAL STAFF: **10**
RESEARCH SCIENTISTS: **5**
ASSOC. MEMBERS: **0**

Prof. D.Sc. A. Paskaleva, Assoc. Prof. Ph.D. D. Spassov, Assoc. Prof. Ph.D. E. Manolov, Assoc. Prof. Ph.D. Ts. Ivanov, assist. T. Stanchev, physicis E.Gajdarzhieva, technologist S. Tsvetanov, technologist M. Stoicheva, technologist Ch. Petkanov, technologist M. Atan.

RESEARCH ACTIVITIES:

The research activities of the Laboratory in the recent years have been focused on nanoelectronics and cover the investigations of thin and ultra-thin nanolaminated and doped high-*k* dielectrics and semiconducting oxides for advanced non-volatile memories. During the year 2020 the conducted reaserch work can be summarized as follows:

The effect of blocking and tunnel layers on the electrical characteristics and charge trapping properties of MIS (metal-dielectric-semiconductor) capacitors with HfO_2/Al_2O_3 nanolaminates deposited by ALD were studied (fig. 1). As blocking and tunnel oxide layers were investigated respectively: 20 nm Al_2O_3 and 3 nm tunnel layers of Al_2O_3 and SiO_2. It has been established that the type of tunnel oxide affects the density of the interface states of the dielectric/Si interface, the sign of the initial oxide charge in the structure and the leakage currents. The use of SiO_2 as a tunnel layer provides the lowest density of interface states and the lowest leakage current. The initial charge of the structures with an Al_2O_3 tunnel layer and structures without tunnel film is positive as its density in the first case is higher. Capacitors with a SiO_2 tunnel layer have a negative initial charge, which is interpreted by a dipole formation at the interface between the tunnel SiO_2 and the first Al_2O_3 sublayer of HfO_2/Al_2O_3 nanolaminate. The comparison of the charge-trapping characteristics of the investigated structures shows that the realization of a capacitor structure with separate blocking and tunnel layers significantly increases the density of the charged charge, as the capacitors with SiO_2 tunnel layer demonstrate the largest memory windows (fig.2).

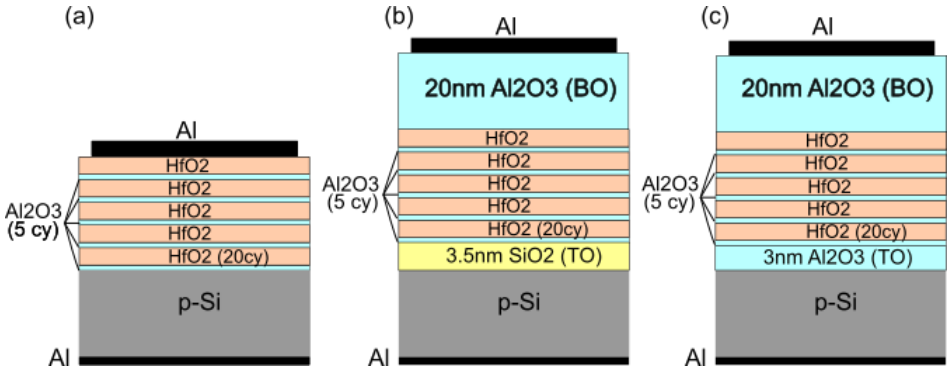

Fig. 1. Schematics of the investigated MIS strictures. (a) type 1 capacitor without BO and TO layers; (b) type 2 capacitor with SiO_2 and Al_2O_3 as TO and BO, respectively; and (c) type-3 capacitor with TO and BO of Al_2O_3.

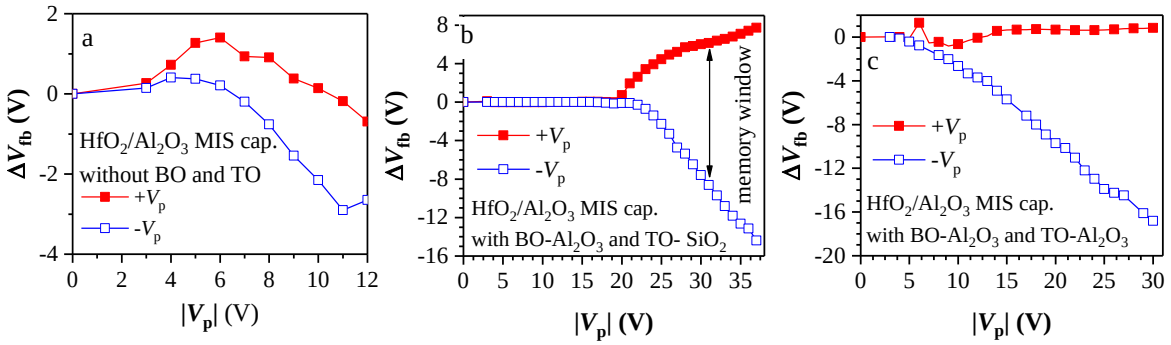

Fig. 2. An illustration of the charge-trapping in the MIS capacitors presented in Fig. 1 under voltage pulses V_p with different amplitudes. The figure shows the obtained flat-band voltage shifts (ΔV_{fb}) in respect to the initial V_{fb} value.

The radiation hardness of HfO_2/Al_2O_3 nanolaminates annealed in nitrogen to gamma radiation (^{60}Co, 1 and 10Mrad) was evaluated. It was found that, unlike the HfO_2/Al_2O_3 nanolaminates that did not received any post-deposition treatment and those annealed in oxygen, an increase in electron traps after irradiation was not observed. The influence of gamma radiation on the electrical and interface properties of the multilayered HfO_2/Al_2O_3 dielectrics annealed in nitrogen strongly depends on the dose. For example, irradiation with 1 Mrad generates a negative charge and increases the density of the interface states of the (HfO_2/Al_2O_3)/Si boundary, but at the same time reduces the leakage current. At higher radiation doses (10 Mrad), the electrical characteristics of the annealed in nitrogen structures revert close to the corresponding characteristics of non-irradiated samples.

Smooth uniform thin films of pure and transition metal (Co, Ni or Fe) doped ZnO have been prepared by atomic layer deposition. The effect of dopant on the structure, morphology and optical properties of films have been investigated by a number of various techniques: X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS), ellipsometry, UV-Visible spectroscopy, Fourier transformed infrared spectroscopy (FTIR). The effect of substrate (glass, Si with different conductivity type and orientation) on the morphology of layers has also been studied. All layers have hexagonal wurtzite structure but the preferential orientation of crystallites depend strongly on the dopant. The doping changes preferential orientation of crystallites from (002) for pure ZnO to (100) for Co- and Ni-doped films. For Fe-doped ZnO films deposited on Si both orientations are present with a slight predominance of (002) orientation. For a given dopant, the preferred orientation is preserved when films are deposited on different substrates. In the case of Ni-doping the results unambiguously reveal incorporation of Ni in ZnO lattice. NiO clusters are also possibly formed in Ni:ZnO layers which can explain the observed significant decrease of their transparency. The observed structural changes, increased concentration of oxygen vacancies and changes in transmittance and FTIR spectra of Co- and Fe-doped ZnO films imply that these dopants are also incorporated, though in a very small amount, in ZnO. Co-doping improves the transparency of ZnO films which could find practical application of these films as functional electrodes in energy control smart windows or as photocatalytic material. The possibility to deposit thin homogeneous films of transition metal (Ni-, Co- or Fe-) doped ZnO by ALD method opens-up new frontiers for implementation of these materials in advanced electronic, magnetic or optical applications.

PUBLICATIONS:

1. Simeonov, S., Szekeres, A., Covei, M., Spassov, D., Kitin, G.,, Predoana, L., Calderon-Moreno, J.M., Nicolesku, M., Preda, S., Stroescu, H., Gartner, M., Zaharescu, M.. Inter-trap tunneling in vanadium doped TiO_2 sol-gel fims. Materials Research Bulletin, 127, Elsevier, 2020, 110854.
2. Paz, J., Nedev, N., Nesheva, D., Curiel, M., Manolov, E., Valdez, B., Perez, O., Mateos, D., Nedev, R., Arias, A., Ramirez, M., Dzhurkov, V.. Selective Photosensitivity of Metal-Oxide-Semiconductor Structures with SiOx layer annealed at high temperature. Journal of Materials Science: Materials in Electronics, 2020, 31, 17412-21.
3. Hadjichristov, G. B., Marinov, Y. G., Ivanov,Tz. E., Koduru, H. K., Scaramuzza, N. PEO/E8 Polymer-Liquid Crystal Flexible Complex Blend Electrolyte System for Na Ions. In: Liquid and Single Crystals: Properties, Manufacturing and Uses, Nova Science Publ., 2020, ISBN:978-1-53616-541-8, 1-64.
4. Boyadjiev, S.I., Georgieva, V., Szilágyi, I.M., Vergov, L., Georgieva, B., Paskaleva, A. Comparison of ALD-grown thin ZnO films with various thicknesses for NO2 sensing. Journal of Physics: Conference Series, 2020, 1492, 012052.
5. Blagoev, B., Terziyska, P., Mehandzhiev, V., Tzvetkov, P., Kovacheva, D., Avramova, I., Ivanova, T., Gesheva, K., Paskaleva, A. Optimization of ALD grown Ni-, Co- and Fe-doped ZnO films. Journal of Physics: Conference Series, 2020, 1492, 012053.

ONGOING RESEARCH PROJECTS:

Funded by Bulgarian Science foundation:

1. Resistive switching and magnetorsistanse effects in ZnO layers doped with transition metals (Co, Ni, Fe) for multifunctional applications
2. Atomic layer deposition of dielectric nanolayers on two-dimensional materials as active components for multifunctional devices.
3. Multilayered high-*k* dielectric structures for application in non-volatile flash memories
4. Investigation of crystallization mechanism of graphene and carbon nanotubes on catalytic surfaces.

Funded by Bulgarian Academy of Sciences:

1. Reliability aspects and radiation hardness of HfO_2-based multilayer stacks for non-volatile flash memories.
2. Al_2O_3/HfO_2 multilayer high-k dielectric stacks for charge trapping flash memories.

INTERNATIONAL COLLABORATION:

1. Fraunhofer Inst. of Integrated Systems and Device Technology, Erlangen, Germany.

2. Institute of Electronic Engineering, Slovak Academy of Sci., Bratislava, Slovakia.

3. Insitute of Physics, St.St. Cyril and Methodius Universty, Skopie, Macedonia.

4. University of Nish, Serbia.

5. Institute of Physics, Polish Academy of Sci. Warsaw, Poland.

6. Universidad Autonoma de Baja California, Mexicale, Mexico.

DEPARTMENT FUNCTIONAL MATERIALS AND NANOSTRUCTURES

LABORATORY

ACOUSTOELECTRONICS

HEAD: **Assoc. Prof. Ekaterina Radeva**
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TOTAL STAFF: **7**
RESEARCH SCIENTISTS: 4
ASSOC. MEMBERS: 1

Prof. DSc. Ivan Avramov., Assoc. Prof. Ekaterina Radeva Ph.D., Assoc. Prof. Karekin D. Esmeryan Ph.D., Senior Res.Assist. Julian Lazarov Ph.D., eng. Lazar Vergov, Stefan Staykov, technician, Vladimir Kabakchiev, technician

Associated members: Cor. Mem. Lozan Spassov

RESEARCH ACTIVITIES:

Langmuir-Blodgett (LB) monolayer films grown from a Dipalmytoyl Phosphatidyl Ethanolamine head, labelled with Nitrbenzoxadiazole (DPPE-NBD) and dissolved in chlorophorm , have been studied for their ability to be used as sensing layers for Rayleigh surface acoustic wave (RSAW) based volatile organic compound (VOC) sensors. Such layers can serve as a matrix for immobilization of proteins, enzymes, aptamers, while preserving their function for selective reaction with certain organic analytes. This function has been confirmed by probing the RSAW resonant sensors, coated with such sensing layers, with vapors of 6 different VOCs including chlorophorm. The highest sensor sensitivity, measured as 225 kHz, (equal to a total of 11,42 ng of sorbed vapor mass), was observed with the vapors of chlorophorm which was the active substance in the process of LB film deposition. In this way, we observe a highly selective strong sensor response to chlorophorm. In addition, the sorbtion/desorption process was very fast and reproducible and the frequency returned within just a few second to its base line value after the chlorophorm vapors were removed. We believe that the RSAW sensors described could be competitive in systems for selective detection of VOC vapors.

In a separate study we investigated the mass sensitivity of RSAW based resonant devices in the 400 MHz range to multiple layer depositions of amorphous carbon over the active resonance area. We deposited a total of 15 carbon layers of 10 nm thickness each subsequently on top of each other and recorded the resonant frequency and insertion loss after each deposition. In this process we observed a cyclic shift of the resonant frequency with the number of depositions – first downwards and then upwards until after deposition 10, the frequency increased more than its initial value. To the best of our knowledge, this phenomenon has been observed for the first time and indicates that subsequent deposition of very thin carbon layers can change the properties of the waveguide, transferring a significant amount of the wave energy from the piezoelectric quartz substrate in the layered structure which results in a substantial increase in propagation velocity. Further studies are on the way.

The method of plasma polymerization was applied for obtaining boron containing polymer films. The experiments with triethilborate as precursor were carried out. By varying the process parameters- current density and time duration- the layers with different thisckness and structure

were obtained.The thin filmsobtained on glass, Si and Al were characterized by XPS analysis. The results showed the presence of boron-carbon bonds. This way the synthesized new boron containing polymer was proved.

Within 2020, a thorough literature review on the operation principles of extremely water-repellent coatings for passive icing protection was performed. The contemporary scientific trends, challenges and innovative application aspects of these coatings for preventing the ice formation at subzero temperatures were considered. Also, in 2020, a unique (without analogue in the scientific literature) method for cryopreservation of human cells and tissues (tested on human sperm) was developed using an ultra-nonwettable carbon soot-based surface. The non-polar chemical composition of the soot, together with the formation of a rough surface profile, minimizes the solid-liquid contact area, resulting in delayed heat transfer rate, inhibition of the intracellular crystallization, lack of osmotic shocks, smooth freezing and thawing, and recovery of up to ~ 80% of the initial vital signs of the preserved biological object (for the case of human sperm, motility and vitality). Finally, 2020 marked the beginning of a productive collaboration with colleagues from Tianjin University, China, -
the physicochemical surface profile of the Cicada insect.

PUBLICATIONS:

1. G. R. Ivanov, I. D. Avramov, V J Strijkova, Y G Marinov, T E Vlakhov, E Bogdanova and G B Hadjichristov, "Langmuir – Blodgett Films from Fluorescently Labeled Phospholipids on Surface Acoustic Wave Devices", 21st International School on Condensed Matter Physics, Sept. 2020, Varna, Bulgaria, (in press) *Journal of Physics*: Conference Series (JPCS), IOP Conference Series;
2. K. D. Esmeryan, Y. Lazarov, G. S. Stamenov, T. A. Chaushev, When condensed matter physics meets biology: Does superhydrophobicity benefiting the cryopreservation of human spermatoza?, *Cryobiol*ogy 92 (2020) 263-266.
3. K. D. Esmeryan, From extremely water-repellent coatings to passive icing protection – principles, limitations and innovative application aspects, *Coatings* 10 (2020) 66.
4. X. Ge, J. Zhao, K. D. Esmeryan, X. Lu, Z. Li, K. Wang, F. Ren, Q. Wang, M. Wang, B. Qian, Cicada-inspired fluoridated hydroxyapatite nanostructured surfaces synthesized by electrochemical additive manufacturing, *Materials & Design* 193 (2020) 108790.
5. Boyadjiev, S.I., Georgieva, V., Szilágyi, I.M., Vergov, L., Georgieva, B., Paskaleva, A.. Comparison of ALD-grown thin ZnO films with various thicknesses for NO2 sensing. Journal of Physics: Conference Series, Volume 1492, Issue 1

PATENTS:

(1) K. D. Esmeryan, T. A. Chaushev, Superhudrophobic quartz microbalance as biosensor for analysis of of human urine, filed on 15.05.2020, Sofia, Bulgaria, №113134

ONGOING RESEARCH PROJECTS:

Study of the influence of physicochemical characteristics on the superhydrophobic coatings from corbon soot on its aisphobic properties, ФНИ 2019-2022г
Research Center Karlsrue, Germany for preparing SAW sensors on litium niobate for analysis of liquids.

INTERNATIONAL COLLABORATION:

- Chemical Engineering and Chemical Technology, Imperial College London, England
- Research Center - Carls Rue, Germany
- Department of Mechanical Engineering and Nuclear Engineering, Virginia Commonwealth University, USA
- Department of Mechanical Engineering, University of British Columbia, Canada
- Department of Engineering Mechanics, Tianjin University, China

DEPARTMENT NANOPHYSICS

LABORATORY
PHOTOELECTRICAL AND OPTICAL PHENOMENA IN WIDE BAND GAP SEMICONDUCTORS

HEAD: **Prof. Diana Nesheva, D.Sc.**
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TOTAL STAFF: ***8***
RESEARCH SCIENTISTS: ***5***
ASSOC. MEMBERS: 5

Assoc. Prof. Z. Levi, PhD; Assoc. Prof. I. Bineva, PhD; Assoc. Prof. P. Terziyska, PhD; Assoc. Prof. T. Vasileva, PhD; Eng. R. Dzhurkova; Eng. V. Dzhurkov;
Technologist E. Zaharincheva;

Honorary members: Prof. E. Vateva, D.Sc; Assoc. Prof. K. Kolentsov;
Associated members: Assoc.Prof. S. Simeonov, Ph.D.; Assoc.Prof. A. Szekeres, Ph.D.; Assoc.Prof. S. Alexandrova, Ph.D.

RESEARCH ACTIVITIES:

The influence of two types of treatments on the structure and electrical conductivity of sol-gel thin films of ZnO was studied. Hot air flow was applied as a first step in the film drying, and an infrared pulsed laser was used for postdeposition irradiation of the layers. It has been found that all layers (as-prepared, annealed at 400oC and laser irradiated) are crystalline with a wurtzite structure. The use of hot air causes reduction of the film thickness, which is similar to that caused by furnace annealing at 400 oC. It was concluded that each of the two treatments improves the crystallinity, which is associated with a reduction of both the films porosity and the amount of organic inclusions in the layers. Besides, each treatment, hot air drying and laser irradiation, causes a reduction in the electrical conductivity of the layers, which is associated with a decrease of the defects density (hydrogen, oxygen vacations, etc.). The non-irradiated and laser-irradiated layers, prepared by applying of a two-step drying (hot air flow and furnace drying at 140°C), showed a good reaction at room temperature to ethanol vapors.

Optical properties of topological insulators (WTe_2, $MoTe_2$, $TaTe_2$, WSe_2), quasi 2D layers of $PtSi_2$ 15-20 nm thick, deposited on SiO_2/Si, as well as of graphene layers deposited on SiO_2/Si by sublimation of amorphous carbon, were investigated by spectroscopic ellipsometry using Woollam M2000D spectroscopic ellipsometer. Spectroscopic ellipsometry measurements were also systematically performed on metal oxide layers (Al_2O_3, ZnO, AlZnO, TiO_2 etc.), deposited on Si or glass substrates by atomic layer deposition (ALD) for determination of their thickness. The thickness, optical constants and bandgap of ZnO layers doped with Fe, Co and Ni, deposited by ALD have been determined by spectroscopic ellipsometry. It was found that Ni doping of ZnO leads to NiO cluster formation, which reduces the optical transparency of the material.

The influence of the deposition rate (V_d = 0.2, 0.5 and 1.5 nm/s), film thickness (d = 30 and 50 nm) and annealing temperature (T_a) on the properties of thin ZnSe films deposited by thermal evaporation in vacuum, was investigated. During the films deposition the substrates

were rotated at a rate of 8 rpm and thus ZnSe vapors condensed on them during 1/12 part of the turn time. All as-deposited films were annealed in an inert atmosphere at 200°C for 60 min and a part of them were further annealed at 400°C for 60 min. The XRD and AFM results have revealed that the films are nanocrystalline, have cubic structure with preferred orientation (111) and the crystallites size increases with increasing both d and V_d. Absorption spectra have revealed band gap energies ~ 2.7 eV for all films and direct allowed transitions, which confirms their crystallinity. It has been observed that films porosity decreases with increasing both T_a and V_d. The obtained high value of dark current activation energy (~ 0.8 eV), which does not depend on preparation conditions, has been related to strong crystallite depletion. Room temperature sensitivity to ethanol vapors was investigated. Best sensing properties have been found for the films with thickness of 50 nm, deposited at the lowest rate and annealed at 200°C.

Selective sensitivity to ultraviolet (UV) light was observed in metal-oxide-semiconductor structures with SiO_x films (x = 1.15 and 1.3). Annealing at 700, 800 and 1000°C was carried out to grow amorphous or crystalline silicon nanoparticles in the SiO_x layers. It has been shown that in all structures the UV sensitivity is much higher than that to visible light. The sensitivity depends on the stoichiometric index x, the annealing temperature and the polarity of the applied gate voltage. The structures with x = 1.3 show higher selectivity to UV light, than those with x = 1.15 but the structures with x = 1.15 show higher sensitivity. The highest sensitivity was obtained at positive gate voltage applied to structures with x = 1.15 annealed at 1000°C. The observation has been related to effective injection into the SiO_x layer of carriers, photogenerated in the substrate. The carrier injection in the structures with x = 1.15 annealed at 700 and 800°C occurs at lower gate voltages than that in the 1000°C but they show lower sensitivity, as well.

AWARDS:

PUBLICATIONS:

1. Blagoev, B., **Terziyska, P.**, Mehandzhiev, V., Tzvetkov, P., Kovacheva, D., Avramova, I., Ivanova, T., Gesheva, K., Paskaleva, A. Optimization of ALD grown Ni-, Co- and Fe-doped ZnO films. Journal of Physics: Conference Series, 1492, 012053, IOP Publishing, 2020, DOI:10.1088/1742-6596/1492/1/012053. SJR (Scopus):0.23

https://doi.org/10.1088/1742-6596/1492/1/012053

2. **Simeonov, S.**, **Szekeres, A.**, Covei, M., Spassov, D., Kitin, G., Predoana, L., Calderon-Moreno, J.M., Nicolesku, M., Preda, S., Stroescu, H., Gartner, M., Zaharescu, M. Inter-trap tunneling in vanadium doped TiO_2 sol-gel fims. Materials Research Bulletin, 127, 110854, Elsevier, 2020. JCR-IF (Web of Science):3.355 Q2 (Web of Science)

https://doi.org/10.1016/j.materresbull.2020.110854

3. **Szekeres, A**, **Alexandrova, S**, **Terziyska, P**, Anastasescu, M, Stoica, M, Gartner, M. Study of silicon surface layers modified by hydrogen plasma immersion ion implantation and oxidation. Journal of Physics: Conference Series, 1492, 012056, IOP Publishing, 2020, ISSN: 1742-6588, 1742-6596, DOI: 10.1088/1742-6596/1492/1/012056. SJR (Scopus):0.23

https://doi.org/10.1088/1742-6596/1492/1/012056.

4. Angelova, L., Bliznakova, I., Daskalova, A., Blagoev, B., Trifonov, A., **Terziyska, P.**, Buchvarov, I. Femtosecond laser surface engineering of biopolymer ceramic scaffolds coated with ZnO by low temperature atomic layer deposition method. Optical and Quantum Electronics, 52, 173, Springer, 2020.

SJR (Scopus):0.37, JCR-IF (Web of Science):1.547 Q2 (Scopus)
https://doi.org/10.1007/s11082-020-02284-x

5. Paz, J., Nedev, N., **Nesheva, D.**, Curiel, M., Manolov, E., Valdez, B., Perez, O., Mateos, D., Nedev, R., Arias, A., Ramirez, M., **Dzhurkov, V.** Selective Photosensitivity of Metal-Oxide-Semiconductor Structures with SiO_x layer annealed at high temperature. Journal of Materials Science: Materials in Electronics, 31, 20, 17412-17421, Springer, 2020, ISSN: 0957-4522, DOI: 10.1007/s10854-020-04297-4.

SJR (Scopus):0.477, JCR-IF (Web of Science):2.22 Q2 (Web of Science)
https://doi.org/10.1007/s10854-020-04297-4

6. Beshkova, M., Blagoev, B.S.**,** Mehandzhiev, V., Yakimova, R., Georgieva, B., Avramova, I., **Terziyska, P.**, Kovacheva, D., Strijkova, V. Initial conditions for preparation of thin AlN films by atomic layer deposition. Journal of Physics: Conference Series, 1492, 012021, IOP Publishing, 2020, DOI: 10.1088/1742-6596/1492/1/012021.

SJR (Scopus):0.23 Q3 (Scopus)
https://doi.org/10.1088/1742-6596/1492/1/012021.

7. Guziewicz, E., Krajewski, T. A., Przezdziecka, E., Korona, K. P., Czechowski, N., Klopotowski, L., **Terziyska, P.** Zinc Oxide Grown by ALD – from Heavily n-type to p-type Material. Physica Status Solidi b, 257, 2, 1900472, John Wiley & Sons Ltd., 2020, ISSN: 2053-1591, DOI: 10.1002/pssb.201900472.

SJR (Scopus):0.519, JCR-IF (Web of Science):1.454 Q2 (Web of Science)
https://doi.org/10.1002/pssb.201900472

8. Milanova, M, Donchev, V, Arnaudov, B, Alonso-Álvarez, D, **Terziyska, P**. GaAsSbN-based p-i-n heterostructures for solar cell applications grown by liquid-phase epitaxy. Journal of Materials Science: Materials in Electronics volume, 31(3) 2073-2080, Springer, 2020, ISSN: 1573-482X, DOI: 10.1007/s10854-019-02728-5.

JCR-IF (Web of Science):2.22 Q2 (Scopus)
https://doi.org/10.1007/s10854-019-02728-5

9. Todorov R., Cernoskova E., Vlasova M., **Hristova-Vasileva T.**, Atanasova A., Katrova V., Cernosek Z. Spectroscopic ellipsometry investigation of electronic states and optical properties of thin films from $Ge_{30}As_xSe_{70-x}$ system. Journal of Non-Crystalline Solids, 538, 120048, Elsevier, 2020, ISSN: 0022-3093, DOI:10.1016/j.jnoncrysol.2020.120048.

SJR (Scopus):0.712, JCR-IF (Web of Science):2.929 Q1 (Web of Science)
https://doi.org/10.1016/j.jnoncrysol.2020.120048

Accepted for publication:

10. **Nesheva D.**, Fogarassy Z., Fabian M., **Hristova-Vasileva** T., Sulyok A., **Bineva I.**, Valcheva E., Antonova K., Petrik P., Influence of fast neutron irradiation on the phase composition and optical properties of homogeneous SiOx and composite Si–SiOx thin films.. J Mater Sci, 56, Springer Nature, 2021, ISSN:1573-4803, DOI:https://doi.org/10.1007/s10853-020-05338-3, 3197-3209. SJR (Scopus):0.8, JCR-IF (Web of Science):3.553, Q1.
11. **Dzhurkov, V., Levi, Z., Nesheva, D., Hristova-Vasileva, T., Terziyska, P.**, Properties of ZnSe nanocrystalline thin films prepared by thermal evaporation. Journal of Physics: Conference Series, Institute of Physics Publishing, 2021, ISSN:1742-6588, SJR (Scopus):0.227
12. **Gegova-Dzhurkova, R., Nesheva, D.**, Mihailov, V., **Dzhurkov, V., Terziyska**, **P.**, Manolov, E.. Effect of infrared laser irradiation on electrical conductivity and ethanol sensitivity of sol gel ZnO thin films. Journal of Physics: Conference Series, Institute of Physics Publishing, 2021, ISSN:1742-6588, SJR (Scopus):0.227

PATENTS:

1. Bulgarian Patent Office, Patent Application: 111032/15.09.2011, Patent No: 66556/30.11.2016. Pretender: ISSP-BAS
Inventors: Nedev N., Manolov E., Nesheva D., Krezhov K., Curiel M., Nedev R., Valdez B.
Invention: Metal-Insulator-Semiconductor structures for detectors of ionizing radiation, containing silicon nanocrystals, and method for their production.
2. Bulgarian Patent Office, Patent Application: 109759/01.12.2006, Patent No: 65971/09.09.2010. Pretender: ISSP-BAS
Inventors: Nesheva D., Nedev N, Manolov E., Brüggemann R., Meier S., Levi Z., Bineva I.
Invention: Metal-Insulator-Silicon structures, containing silicon nanoparticles, and method for their production.

ONGOING RESEARCH PROJECTS:

Financed by the Bulgarian Academy of Sciences :
Preparation, modification, properties and applications of nanostructured/amorphous oxide and chalcogenide thin films
Financed by the Bulgarian Ministry of Education and Science:

1. Preparation, characterization, and laser modification of nanocrystalline ZnO films, National program "Young scientists and postdoctoral researchers" approved by DCM N577, 17.08.2018, beneficient eng. Chem. Radka Dzhurkova, adviser Prof. D. Nesheva, DSci
2. Preparation and investigation of ZnSe thin films suitable for chemical sensors, National program "Young scientists and postdoctoral researchers" approved by DCM N577, 17.08.2018, beneficient Eng. Chem. Valeri Dzhurkov, adviser Assoc. Prof. Z. Levi, PhD.

INTERNATIONAL COLLABORATION:

Preparation and characterization of nanostructured semiconductor thin films for sensor application, bilateral project between BAS and SASA, Center for Solid State Physics and New Materials, Belgrade, Serbia 2020-2022, coordinator Assoc. Prof. I. Bineva, PhD.

DEPARTMENT SOFT MATTER PHYSICS

LABORATORY

LIQUID CRYSTALS AND BIOMOLECULAR LAYERS

HEAD: **Prof. Victoria Vitkova, Ph.D.**
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TOTAL STAFF: **15**
RESEARCH SCIENTISTS: **8**
HONORARY MEMBER: **2**
ASSOC. MEMBERS: **1**

Assoc. Prof. Yordan Marinov, D.Sc.; Assoc. Prof. Angelina Stoyanova-Ivanova, Ph.D.; Assoc. Prof. Julia Genova, Ph.D.; Assist. Prof. Lidia Popova, Ph.D.; Assist. Prof. Zdravka Slavkova, Ph.D.; Assist. Prof. Todor Vlakhov; Chem. Eng. Maria Dencheva-Zarkova; Chem. Eng. Peter Lilov; Chem. Eng. Violeta Petrova; Technol. Vasil Stanoev; Biol. Neli Drinova; Techn. Assist. Ognyan Petkov, B. Sc (part-time); Techn. Assist. Nevena Yotova (part-time); Dr. Hari Krishna Koduru, Postdoctoral Fellow

Honorary member: Academician Alexander G. Petrov, D.Sc. Fellow of the Bulgarian Academy of Sciences; Prof. Isak Bivas, D.Sc.
Associated members: P Assoc. Prof. Antonia Zheliaskova, Ph. D.

RESEARCH ACTIVITIES:

The structure, phase behaviour and mechanics of biomimetic archaeolipid nanostructures were characterized for recognizing the molecules, which render the membranes of archaeal single-cell microorganisms stable in harsh environments. Fluorescence microscopy, thermal shape fluctuation analysis and fluorescence spectroscopy were applied for revealing the molecular mechanisms, which underlie the cellular survival. The acquired knowledge about the structure and mechanical properties of tetraether lipid nanostructures is expected to be effectively exploited in biomedicine and bionanotechnology for the development of pharmaceutical and biomedical applications based on liposomes.

Thermal shape fluctuation analysis of nearly spherical giant lipid vesicles was carried out for probing the membrane mechanics in electrolyte solutions of sucrose. Quantitative phase measurements were performed in order to reconstitute the shape of flaccid unilamellar lipid vesicles. The bending elasticity modulus of synthetic lipid membranes was quantified in aqueous solutions of mono-, di- and polysaccharides. The obtained results indicate that the presence of sodium chloride modifies the effect of sucrose on the bending rigidity of lipid bilayers.

In cooperration with the Department of Biophysics and Radiobiology at the Faculty of Biology at Sofia University “St. Kliment Ohridski” we studied the electrokinetic and light scattering properties of higher plants’ thylakoid complexes in low ionic strength media containing the electrostatic polymer linker polylysine. Microelectrophoresis, actinic light scattering, millisecond-delayed fluorescence and free radical production of thylakoid membranes were measured to analyze the influence of the polycation on thylakoids’ surface electrical properties. Enhanced proton gradient in polylysine-treated membranes upon

illumination is reported as a result of alterations of the proton intake across the membrane. Lower rates of lipid peroxidation in the presence of polylysine were measured for thylakoids in salt-free medium. The effect of polycations on photosynthetic membranes provides potential for future developments of thylakoid-based approaches for energy transfer applications.

A series of cross-current nanofiltration experiments was carried out by a MaxiMem membrane filtration system (PS Prozesstechnik GmbH). Nanofiltration was successfully applied as a separation tool for fractionation of carbohydrates and phenolics derived from aquatic plant hydrolisate. Based on the obtained results mild hydrodynamic conditions are recommended for nanofiltration of aqueous extracts of Eurasian water milfoil – low pressure and cross-flow velocity. The fact that no or slight effect of the feed flow rate on flux and rejection is observed indicates that concentration polarization was not a limiting phenomenon. The separation efficiency of the membrane towards sugars is discussed based on the rejection difference between the components. Decreasing glucose and other reducing sugars rejections and higher rejection difference with the group of phenolics are observed for low cross-velocity rates. The latter can be recommended in view of extract separation into purer glucose solution (in permeate) and concentrated solution of other reducing sugars and polyphenols (in retentate). Further improvement of the separation is expected to be achieved by applying nanofiltration in a diafiltration mode.

Novel nanocomposites (NCs) from discotic liquid-crystalline (mesogen) tris(keto-hydrozone compound LTTH-6 and single wall carbon nanotubes (SWCNTs) at concentration of 1 wt.%, were studied. The NCs were produced from suspension in organic solvent (1-methyl-2-pyrrolidinone) and were formed as thin films with a thickness of 3 μm. The prepared NCs of SWCNTs/LTTH-6 were examined by combination of differential scanning calorimetry (DSC) and polarizing optical microscopy. As evidenced, at room temperature the columnar liquid-crystal phase of the discotic mesogen LTTH-6 can freeze into a glassy state. The same applies to SWCNT-6/LTTH-6 nanocomposite. For the latter, it was found that it exhibits photo-electrical response. Moreover, the photo-electrical response of the studied NCs at room temperature was probed in view of their possible applications for sensors and other devices.

The experimental investigation are focused on the ion-conducting and dielectric properties of nanocomposite ion-conductive polymer electrolytes based on two-polymer blend of poly(ethylene oxide) (PEO) and polyvinyl pyrrolidone (PVP), with added sodium metaperiodate ($NaIO_4$) at concentration of 10 wt%. The polymer-ion complexes PEO/PVP/$NaIO_4$ are doped with small amount (up to 3 wt%) TiO_2 nanoparticles of average size ~ 10 nm. The obtained results for ionic conductivity indicate that both the Na+-ion conductivity and the dielectric function of PEO/PVP/$NaIO_4$/TiO_2 nanocomposite electrolytes are enhanced upon addition of TiO2 nanoparticles. Thus, the produced $NaIO_4$ salt-complexed TiO_2-nanofilled ionic polymer electrolytes are attractive for use in sodium ion secondary batteries, electrochemical applications, as well as in organic electronics.

Detection of some pollutants in water requires high sensitive techniques or smart biosensors. In the biosensor development crucial is the active bioreceptor layer which interacts with the analyte. We propose thin organic nano- films of DPPE-NBD prepared by the Langmuir-Blodgett method from a fluorescently labelled phospholipid with well-developed 3D structure, which yield increased sensor sensitivity. The average thickness of the layer is 3 nm suggesting fast reaction times. The structure is tested by detecting Cd^{2+} ions dissolved in pure water. The transduction of the signal is performed in two ways: optically, by measuring fluorescence intensity; and with a newly developed bubble drop setup for electrochemical impedance spectroscopy. The results show that both optical and electrical methods are sensitive enough for the detection of presence of heavy metal ions (in particular Cd-ions) in the water subphase at concentrations lower or compatible to the allowable limits for drinking water.

In cooperation with the Department of Orthodontics at the Medical University of Sofia, we studied the structure, morphology, chemical composition, thermal behavior and mechanical properties of as-received or used in-vivo (clinical practice) TriTanium^{TM} orthodontic archwires with application in the dental practice in Bulgaria. By means of X-ray diffraction analysis, scanning electron microscopy, energy dispersion analysis, laser-induced emission spectroscopy, X-ray photoelectron spectroscopy, nanoindentation and statistical analysis we acquired important information, which is essential for optimization of the usage of orthodontic archwires in the clinical practice, and will be beneficial for the patient's health. We reported stability of the elemental composition of the archwires studied after their clinical application during orthodontic treatment. The comparative analysis of the mechanical properties exhibited by as-received and used TriTanium^{TM} archwires showed that their indentation hardness and indentation modulus decreased with increasing the time of application without any negative effect on patients' health. The obtained results are related to the assessment of the treatment duration and must be taken into account in clinical use.

High-temperature superconductivity has been widely studied due to its potential applications in the lossless transmission of electricity, magnetic levitation and others.In order to improve the properties of the Y134 system, as well as of $ReBa_2Cu_3O_{7-\beta}$ (Re = Y, Gd, Dy) cuprate ceramic materials, an additive of nano-Fe_3O_4 and Ag_2O, respectively, was introduced. The samples obtained by solid-phase synthesis are polycrystalline with inhomogeneous composition and homogeneous distribution on the surface of iron and silver, respectively.

In cooperation with the Institute of Electrochemistry at the Bulgarian Academy of Sciences we studied a nickel-zinc electrochemical system as a promising candidate for alkaline batteries with low toxicity, high energy densities and power. Its main disadvantage consists in the solubility of the zinc electrode and the formation of dendrites during operation. Our previous research revealed the possibility of B(Pb)SCCO superconducting ceramics to be used as additives to the active mass of the zinc electrode of Ni-Zn batteries. When treating ceramics in alkaline environment they are partially reduced to oxides and hydroxides, improving conductivity and thus leading to longer battery life. Conductive ceramics used as an additive in the zinc electrode of the nickel-zinc system were synthesized by solid phase synthesis. The influence of the mixing method of the active electrode mass of a zinc electrode with B(Pb)SCCO ceramic additives was studied for three types of electrodes with different chemical composition to improve the performance of zinc electrodes used in electrochemical energy storage systems. The phase behaviour and morphology of the samples were monitored by electron scanning microscopy and X-ray diffraction. The electrode conductivity was examined by potentiostatic electrochemical impedance spectroscopy in order to distinguish the best homogenization of the additive in the active mass, achieved by ultrasonic treatment. The obtained results could underlie future improvements of the chemical composition of Zn electrodes, containing ceramic additives, in view of optimizing the electrode performance.

Object of our scientific interest were systems of synthetic lipid (steroyl-oleoyl phosphatidylcholine) and carbon nanosized flakes, with thickness of less than three layers and a side size of 0.5-5 μm. Various concentrations of the nanoflakes, ranging from 0 to 5 mg, were added to the lipid in aqueous medium. The liquid samples were examined by differential scanning calorimetry in order to study the effect of the inclusions on the phase transition from gel to liquid-crystalline state of the phospholipid. Results established that the effect is not very pronounced. When compared to the analyses of previous measurements of amide-functionalized and pure carbon nanotubes, it could be concluded that their functionalisation is of great importance for their incorporation into the lipid matrix.

AWARD:

FEDERATION OF THE SCIENTIFIC ENGINEERING UNIONS (FNTS)
XVII National Conference for Young Researchers' 2020, Sofia
II Section: Chemical Sciences and Technologies

II Prize: Ognyan Petkov and Angelina Stoyanova-Ivanova "B(Pb)SCCO ceramic additives in alkaline Ni-Zn systems for energy storage applications"

PUBLICATIONS:

1. Vitkova, V., Mitkova, D., Yordanova, V., Bakowsky, U., Pohl, P., Staneva, G., Batishchev, O.. Elasticity and phase behaviour of biomimetic membrane systems containing archaeal lipids. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 601, Elsevier, 2020, DOI:10.1016/j.colsurfa.2020.124974, 124974. JCR-IF (Web of Science): 3.99, Q1 (Web of Science)
2. Doltchinkova, V., Vitkova, V. Polylysine effect on thylakoid membranes. Biophysical Chemistry, Elsevier, 2020, ISSN:0301-4622, DOI:10.1016/j.bpc.2020.106440, 106440. SJR (Scopus):0.61, JCR-IF (Web of Science):1.995, Q2 (Web of Science)
3. Vitkova, V., Minetti, Stoyanova-Ivanova, A., Bending rigidity of lipid bilayers in electrolyte solutions of sucrose, Bulgarian Chemical Communications, Volume 52E (pp. 35 - 40), 2020, ISSN: 0324-1130; SJR (Scopus):0.14, JCR-IF (Web of Science): 0.242, Q4 (Scopus)
4. Marinov, G. , G. B. Hadjichristov, T. E. Vlakhov, H. K. Koduru, N. Scaramuzza, Electrochemical impedance and dielectric spectroscopy study of TiO2-nanofilled PEO/PVP/NaIO4 ionic polymer electrolytes, Bulgarian Chemical Communications, 52E, (pp. 57 – 61), 2020, ISSN:0324-1130; SJR (Scopus): 0.14, JCR-IF (Web of Science): 0.242, Q4 (Scopus)
5. Ivanova, G. D., Petrova, V. P., Petkov, O. K., Minchev, B. A., Lilov, P. A., Stoyanova-Ivanova, A., Stoyanova, A. E., Effect of ball milling treatment on the Zn electrode properties in Ni- Zn battery, Bulgarian Chemical Communicationsolume 52E (pp. 79 - 83), 2020, ISSN: 0324-1130; ; SJR (Scopus): 0.14, JCR-IF (Web of Science): 242; Q4 (Scopus)
6. Yordanova, V., G. Staneva, V. Vitkova, M. Angelova, A. Kostadinova, D. Benkova, R. Veleva, A. Nesheva, R. Hazarosova, Biomimetic vesicles as a tool to reveal the physico-chemical membrane changes induced by oxidized lipids, Oxidation Communications 43 (4), 2020, ISSN:0209-4541, SJR (Scopus):0.22, Q3 (Scopus)
7. Tonova, K., M. Lazarova, M. Dencheva-Zarkova, S. Paniovska, I. Tsibranska, Vasil Stanoev, D. Dzhonova, J. Genova, Separation of glucose, other reducing sugars and phenolics from natural extract by nanofiltration: Effect of pressure and cross-flow velocity, Chemical Engineering Research and Design, Volume 162, October 2020, Elsevier, 2020, ISSN:0 8247 0070 8, 107-116. SJR (Scopus):0.83, JCR-IF (Web of Science):3.35, Q1 (Scopus)
8. Dencheva-Zarkova M., Hadjichristov G. B., Marinov Y. G., Maslyanitsyn I. A., Petrov A. G., Popova L., Shigorin V. D., Torgova S. I.. Effect of Inhomogeneous Electric Field in a Cell with Side Electrodes: Nematic Liquid Crystal 5CB. Physics of Wave Phenomena, 28, 3, Allerton Press, Inc., 2020, ISSN:1541-308X, 250-254. SJR (Scopus):0.31, JCR-IF (Web of Science):0.745, Q3 (Scopus)

9. Dencheva-Zarkova, M., Genova, J.. Influence of amphotericin B on the physicochemical properties of model lipid membranes. Bulg. Chem. Commun., 52, 4, 2020, DOI:10.34049/bcc.52.4.MP08, 549-553. SJR (Scopus):0.14; Q4 (Web of Science)

10. Hadjichristov, G. B., Y. G. Marinov, Tz. E. Ivanov, H. K. Koduru, N. Scaramuzza. PEO/E8 Polymer-Liquid Crystal Flexible Complex Blend Electrolyte System for Na Ions. In: Liquid and Single Crystals: Properties, Manufacturing and Uses, Nova Science Publ., 2020, ISBN:978-1-53616-541-8, 1-64

11. Genova, J., Chamati, H., Petrov, M.. Study of SOPC with embedded pristine and amide-functionalized single wall carbon nanotubes by DSC and FTIR spectroscopy. Coll. Surf. A, 603, Elsevier, 2020, DOI:10.1016/j.colsurfa.2020.125261, 125261. JCR-IF (Web of Science): 3.99, Q1 (Web of Science)

12. Genova, J., Chamati, H, Petrov, M. Physico-chemical characterizations of lipid membranes in presence of cholesterol. Advances in Biomembranes and Lipid Self-Assembly, 31, Elsevier, 2020, DOI:10.1016/bs.abl.2020.02.003, 1-42. SJR (Scopus): 0.23, Q4 (Web of Science)

13. Slavkova, Z., Genova, J., Chamati, H., Koroleva, M., Yancheva, D.. Influence of hydrophobic Au nanoparticles on SOPC lipid model systems. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 603, Elsevier, 2020, DOI:10.1016/j.colsurfa.2020.125090, 125090. SJR (Scopus):0.79, JCR-IF (Web of Science):3.99, Q1 (Web of Science)

14. Stoyanova-Ivanova A., Lilov P., Vasev A., Stoyanova A., Ivanova G., Karashanova D., Mikli V.. Studies of structural and morphological properties of cuprate conductive ceramics after electrochemical treatment in alkaline electrolyte. Materials Chemistry and Physics, 39, 239, 2020, DOI:https://doi.org/10.1016/j.matchemphys.2019.121934, SJR (Scopus): 0.71, JCR-IF (Web of Science): 3.409, Q2 (Web of Science)

15. Stoyanova-Ivanova, A., Cherneva, S., Petrunov, V., Petrova, V., Ilievska, I., Mikli, V., Yankov, R.. Investigation of mechanical and physicochemical properties of clinically retrieved titanium-niobium orthodontic archwires. 22, 1, Acta of Bioengineering and Biomechanics, 2020, DOI:DOI: 10.37190/ABB-01486-2019-03, JCR-IF (Web of Science):0.968, Q4 (Web of Science)

16. Marinov, Y. G., G. B. Hadjichristov, T. E. Vlakhov, H. K. Koduru, N. Scaramuzza. Electrochemical impedance and dielectric spectroscopy study of TiO2-nanofilled PEO/PVP/NaIO4 ionic polymer electrolytes. Bulgarian Chemical Communications, 52(E), 2020, ISSN:0324-1130, 57-61. SJR (Scopus):0.14, JCR-IF (Web of Science): 0.24, Q4 (Scopus)

17. Marinov, Y. G., G. B. Hadjichristov. Electro-optical characteristics of thin films of aerosil-7CB nematic gel nanocomposites doped with photoresponsive liquid crystalline azo-compounds. Compt. Rend. Acad. Bulg. Sci, 73, 10, 2020, ISSN:1310–1331, 1368-1375. SJR (Scopus):0.218, JCR-IF (Web of Science): 0.343, Q2 (Scopus)

18. Cherneva, S., Stoyanova-Ivanova, A., Georgieva, M., Andreeva, L., Petkov, A., Petrov, V., Petrova, V., Mikli, V.. Nanoindentation and surface characterization of clinically retrieved multi-force NiTi orthodontic archwires. Russian Journal of Biomechanics, 2020, SJR (Scopus):0.35 Q4

19. Ivanov, G., Y. Marinov, G. Hadjichristov, T. Vlakhov. Detection of Heavy Metal Ions by Newly Designed Biosensor with Well-Formed 3D Nano-Structure. 2019 XXIX International Scientific Symposium "Metrology and Metrology Assurance" (MMA), IEEE, 2020, DOI:10.1109/MMA.2019.8935987 Международно неакадемично издателство (IEEE Xplore)

20. Exner, G. K., Y. G. Marinov, G. B. Hadjichristov. Novel nanocomposites of single wall carbon nanotubes and discotic mesogen with tris(keto-hydrozone) core. Compt. Rend. Acad. Bulg. Sci., 73, 9, 2020, ISSN:1310–1331, DOI:10.7546/CRABS.2020.09.04, 1217-1224. SJR (Scopus):0.22, JCR-IF (Web of Science):0.343 Q2 (Scopus)

21. Goršak, T., Drab, M., Križaj, D., Jeran, M., Genova, J., Kralj, S., Lisjak, D., Kralj Iglič, V., Iglič, A., Makovec, D. Magneto-mechanical actuation of barium-hexaferrite nanoplatelets for the disruption of phospholipid membranes. Journal of Colloid and Interface Science, 579, Elsevier, 2020, DOI:10.1016/j.jcis.2020.06.079, 508-519. JCR-IF (Web of Science):7.489 Q1 - оглавява ранглистата (Web of Science)

22. Ivanova, G. D., Petrova, V. P., Petkov, O. K., Minchev, B. A., Lilov, P. A., Stoyanova-Ivanova, A., Stoyanova, A. E.. Effect of ball milling treatment on the Zn electrode properties in Ni- Zn battery. 52, Bulgarian Chemical Communications, 2020, 87-92. JCR-IF (Web of Science): 0.242 Q4 (Web of Science)

23. Santhosh, P., Genova, J., Iglič, A., Kralj Iglič, V., Poklar Ulrih, N.. Influence of cholesterol on bilayer fluidity and size distribution of liposomes. Compt Rend Acad Bulg Sci, 73(7), 2020, DOI:10.7546/CRABS.2020.07.07, 947-956. JCR-IF (Web of Science): 0.321 Q2 (Web of Science)

24. Иванова, Г., Стоянова, А., Стоянова-Иванова, А., Петрова, В., Петков, О., Карашанова, Д.. ВЛИЯНИЕ СЪДЪРЖАНИЕТО НА B(Pb)SCCO 2212 КАТО ДОБАВКА КЪМ АКТИВНАТА МАСА ВЪРХУ РАБОТНИТЕ ХАРАКТЕРИСТИКИ НА ЦИНКОВИЯ ЕЛЕКТРОД. 2020, ISBN:978-619-245-072-4, 146-147, National Academic Publishing House

25. Петков, О., Стоянова-Иванова, А., Колев, С., Петрова, В., Ковачева, Д., Tran, L-M., Babij, M., Zaleski, A., Mikli, V.. ИЗСЛЕДВАНЕ НА ВЛИЯНИЕТО НА ДОБАВКИ (нано-Fe3O4, Ag2O) ВЪРХУ ФАЗООБРАЗУВАНЕТО В СВРЪХПРОВОДИМА КЕРАМИКА С НОМИНАЛЕН СЪСТАВ YBa3Cu4O7-x. 2020, ISBN:978-619-245-072-4, 144-145, National Academic Publishing House

26. Петков, О., Стоянова-Иванова, А.. B(Pb)SCCO КЕРАМИКИ С ПОТЕНЦИАЛНО ПРИЛОЖЕНИЕ КАТО ДОБАВКИ В АЛКАЛНИ Ni-Zn СИСТЕМИ. 2020, ISBN:1314-8931, 106-111, National Academic Publishing House

PATENTS:

BG Reg. № 67044B1 / 15.04.2020
“Method for characterization of nanostructured nematic liquid crystals“
Patent Applicants: ISSP-BAS
Contact person: Lidia T. Popova

BG Reg. № 67053B1 / 15.04.2020
“Method and device for determination of the kinematic viscosity and mass density of aerosols“
Patent Applicants: ISSP-BAS

Contact person: Yordan G. Marinov

BG Reg. № 67066B1 / 01.06.2020
“Composite material and method for its production”
Patent Applicants: ISSP-BAS
Contact person: Angelina K. Stoyanova-Ivanova

ACADEMIC DEVELOPMENT:

Assoc. Prof. Dr. Yordan G. Marinov, Dissertation entitled "Flexoelectricity of nematic liquid crystal systems" successfully defended on November 04, 2020 for the acquisition of the scientific degree **“Doctor of Sciences“**

ONGOING RESEARCH PROJECTS:

1. Research Project “New effects in nano-thin ordered organic films (Langmuir and Langmuir-Blodgett) and their use for conceptual development of a new generation of biosensors for working in a fluid environment at ambient conditions and real-time monitoring of hard-to-find water pollutants (anti-terrorism) or early diagnosis by tumor markers (acronym NanoBioSensors)” (contract № KP-06-OPR 03/9) by the Ministry of Education and Science, through the National Science Fund of Bulgaria (2019 – 2021), ISSP-coordinator Assoc. Prof. Y. Marinov.
2. Research Project “Advanced Nanocomposite Polymer Membranes for Na-, Mg-ions conductive electrolytes, Proton-Exchange, and Chromogenic Applications”, under National Scientific Program “Petar Beron i NIE” (P. Beron), BNSF project ANAPOM (2020-2022), contract № KP-06-DB-1/16.12.2019, Dr. Koduru, ISSP-coordinator Assoc. Prof. Y. Marinov.
3. Research Project “Obtaining and study of nanostructured materials by optical methods and impedance spectroscopy (2018-2021), Bulgarian Ministry of Education and Science under the National, Research Programme “Young scientists and postdoctoral students” approved by DCM #577 / 17.08.2018, coordinator Assist. Prof. T. Vlakhov
4. Research Project “Liquid crystal approach for model lipid membrane functions optimization by nanoparticles insertion” (National Science Fund, Bulgaria – Grant DN08-2/13.12.2016), coordinator Assoc. Prof. Dr. J. Genova
5. Research Project “A mechanistic approach to revealing the molecular mechanism of how oxidized lipids alter the 2D and 3D lipid organization in model membranes” National Science Fund, Bulgaria – Grant DN18-15/15.12.2017), Coordinator, principal investigator: Professor Dr G. Staneva, IBPBME-BAS; ISSP-BAS /partner organization/ Coordinator: Prof. Dr V. Vitkova
6. Research Project “Investigation of the influence of nanoparticles on the properties of biologically relevant systems” THEME04-4-1133-2018/2020 – JINR, Cooperation project between the Institute of Solid State Physics (ISSP) of the Bulgarian Academy of Sciences, Sofia, Bulgaria and the Joint Institute for Nuclear Research (JINR), Dubna, Russian Federation, coordinator from ISSP-BAS Assoc. Prof. Dr. J. Genova
7. Research Project “Model membrane systems in the presence of biologically active macromolecules: physical and physicochemical parameters in norm and pathology” National Science Fund, Bulgaria – Grant KP-06-N38/14/2019), Coordinator, principal investigator: Assoc. Prof. Dr V. Doltchinkova, Sofia University “St. Kliment Ohridski”; Coordinator from ISSP-BAS /partner organization/: Prof. Dr V. Vitkova

8. Bilateral Research Project /ISSP-BAS and Tallinn University of Technology, Estonian Academy of Science (Estonian projects TAR16016 and IUT-T4)/ coordinator Assoc. Prof. Dr Angelina Stoyanova-Ivanova

INTERNATIONAL COLLABORATION:

BELGIUM: Dr. Christophe Minetti, Faculté des Sciences Appliquées, Université libre de Bruxelles

ESTONIA: DSc Valdek Mikli, Senior Scientist, Tallinn University of Technology, Estonian Academy of Science

FRANCE: Prof. Miglena Angelova, Université Paris VI: Pierre and Marie Curie and Paris VII: Diderot; Dr Thomas PODGORSKI, Laboratoire Interdisciplinaire de Physique, UMR 5588 (CNRS – Université Grenoble-Alpes)

GERMANY: Dr. habil. PD Rumiana Dimova, Department of Theory and Bio-Systems, Max Planck Institute of Colloids and Interfaces

ITALY: Prof. Nicola Scaramuzza, Dr. Marco Castriota, University of Calabria, Department of Physics and Department of Chemistry and Chemical Technologies

INDIA: Prof. Krishna Prasad, Centre for Nano and Soft Matter Sciences (CeNS)

POLAND: Prof. Andrzej Zaleski, Institute of Low Temperature and Structure Research, Polish Academy of Sciences, Wroclaw

RUSSIA: Prof. Evgeny V. Yurtov, Prof. Marina Koroleva, Dmitry Mendeleev University of Chemical Technology of Russia

Prof. Grygory Arzumanyan, Joint Institute for Nuclear Research (JINR), Dubna, Russian Federation

Prof. Yury Ermakov, Dr Oleg Batishchev, Frumkin Institute of Physical Chemistry and Electrochemistry, Russian Academy of Sciences

SLOVENIA: Prof. Ales Iglic, Dr. Samo Penic, University of Ljubljana

TEACHING ACTIVITIES:

BSc Thesis, Faculty of Physics, Sofia University "St Kliment Ohridski":
Ognyan Petkov "Lipid structures studied by electrochemical impedance spectroscopy", September 2020; Supervisors: Prof. Dr. Victoria Vitkova (ISSP-BAS) and Assoc. Prof. Dr Katerina Stoichkova (SU)

PhD Student Mirela Georgieva, MD (Medical University – Sofia); ISSP-BAS Supervisor: Assoc. Prof. Dr Angelina Stoyanova-Ivanova

PhD Student Eng. Peter Lilov (ISSP-BAS); Supervisor: Assoc. Prof. Dr Angelina Stoyanova-Ivanova

DEPARTMENT PHYSICAL OPTICS AND OPTICAL METHODS

LABORATORY

OPTICS AND SPECTROSCOPY

HEAD: **Assoc. Prof. Tihomir Tenev, Ph.D.**
tel: 979 5752; e-mail: tenev@issp.bas.bg

TOTAL STAFF: **16**
RESEARCH SCIENTISTS: **11**
ASSOC. MEMBERS: ***5***

Prof. K. Panayotov D.Sc.; Prof. G. Hadjihristov, Ph.D.; Assoc. Prof. L. Tsonev, Ph.D.; Assoc. Prof. S. Tonchev, Ph.D.; Assoc Prof. K. Antonova, Ph.D.; Assoc. Prof. M. Kuneva, Ph.D; Assoc. Prof. B. Katranchev, Ph.D.; Assoc.Prof. E. Karakoleva, Ph.D.; Assoc. Prof. H. Naradikian Ph.D.; Assist. Prof. I. Milushev, Ph.D.; Physicist E. Stoyanova; Physicist M. Molerova; Engineer O. Avramov; Technologist Y. Velkova; Technician Y. Sarafov.

Associated members: Prof. M. Petrov, D.Sc.; Prof. S. Rashev, D.Sc.; Assoc. Prof. T. Tsvetkova, Ph.D.; Assoc. Prof. R. Peeva, Ph.D.; Assoc. Prof. A. Andreev, Ph.D.

RESEARCH ACTIVITIES:

Novel electrolytic systems composed from polymer polyethylene oxide (PEO), the mesogenic liquid crystal (LC) mixture E8 and the salt sodium metaperiodate ($NaIO_4$) as ions dopant, were studied by electrical measurements upon temperature variation. Free-standing films (thickness from 0.1 to 0.25 mm) of flexible composite electrolytes were produced by solution casting technique from PEO and E8LC at a ratio PEO:E8LC 70:30 wt.%, with addition of $NaIO_4$ at weight percentage ranging from 2 to 10 wt.%. Being of importance for electrochemical and other applications, the complex electrical impedance spectra and current-voltage characteristics of sodium ion-conductive PEO/E8LC/$NaIO_4$ electrolyte films were analyzed and interrelated to their structural properties and thermal behaviors. The PEO/E8LC/$NaIO_4$ complexes involve metal-organic complex formations of the Na^+ cations from the salt $NaIO_4$ with the ether oxygen atoms in the polymer backbone. The effect from the inclusion of $NaIO_4$ ionic compound in the PEO/E8NLC composite electrolyte was inspected by means of complex electrical impedance studies in the frequency range from 1 Hz to 1 MHz. By increase of $NaIO_4$ concentration, the ionic conductivity (σ) of the produced PEO/E8LC/$NaIO_4$ electrolytes is increased. The enhancement of σ occurs by Na^+–polymer interactions. At ambient temperature, PEO/E8LC electrolyte with 10 wt.% of $NaIO_4$ demonstrated a fairly good ionic conductivity of ca. 10^{-7} S/cm, almost two orders of magnitude higher with respect to salt-free PEO/E8LC. Basically these effects are due to the enhanced flexibility of the polymer backbone and the ions movement resulting from the LC embedding, and are assisted by the high interfacial polymer-LC interaction. In PEO/E8LC composite electrolytes, both components, PEO and mesogenic LCs, provide effective ion conduction through interactions between PEO oxygen and LC molecules. By that, anchoring effect being induced by interfaces of both PEO and LCs, plays a significant role. Compared to another advanced Na^+-conducting solid polymer-blend electrolyte, namely $NaIO_4$-complexed

PEO/PVP/$NaIO_4$ at equal concentration of the salt, the studied PEO/E8LC/$NaIO_4$ polymer-LC electrolytes exhibit similar value of ionic conductivity. Such flexible composites incorporating LC soft matter are ionic conductors that can combine the advantages of solid polymer electrolytes with the unique properties of the LC soft matter included in plastic materials. They are promising polymer-LC combination and are attractive for sensorics, mechatronics and soft electronics applications.

We have experimentally investigated the ion-conducting and dielectric properties of nanocomposite ion-conductive polymer electrolytes based on two-polymer blend of poly(ethylene oxide) (PEO) and polyvinyl pyrrolidone (PVP), with added sodium metaperiodate ($NaIO_4$) at concentration of 10 wt%. The polymer-ion complexes PEO/PVP/$NaIO_4$ are doped with small amount (up to 3 wt%) TiO_2 nanoparticles of average size ~ 10 nm. Chemically-stable free-standing thin films (150 μm) of the synthesized PEO/PVP/$NaIO_4$/TiO_2 solid-state polymer electrolyte material are formed by using conventional solution-cast technique. The electrical and dielectric properties of these nanocomposites are studied by complex electrical impedance and dielectric spectroscopy over the frequency range 1 Hz – 1 MHz. The ionic conductivity of TiO_2-nanofilled PEO/PVP/$NaIO_4$/TiO_2 is determined as dependent on the concentration of the included TiO_2 nanoparticles. The obtained results indicate that both the Na^+-ion conductivity and the dielectric function of PEO/PVP/$NaIO_4$/TiO_2 nanocomposite electrolytes are enhanced upon addition of TiO_2 nanoparticles, as a result from high interfacial interactions between polymer chains and the surface of TiO_2 nanoparticles. Thus, the produced $NaIO_4$ salt-complexed TiO_2-nanofilled ionic polymer electrolytes are promising ionic conductors attractive for use in sodium ion secondary batteries, electrochemical applications, as well as in organic electronics.

We investigated laser beam reflection by optically-transparent hydrocarbon polymeric material subjected to low-energy ion implantation. In our study were measured 5 mm-thick plates of polymethylmethacrylate (PMMA) implanted with silicon ions (Si^+) accelerated to a relatively low energy of 50 keV at Si^+ fluence of 10^{16} ions/cm^2. Due to ion-produced destruction of the polymer network and reorganization of the organic structure in a depth of PMMA plate, a buried ion-modified layer with ~ 80 nm thickness is formed within the PMMA. The material in this ultra-thin nano-sized layer beneath the top surface of PMMA (in a depth of ~ 100 nm) is organized in carbon nanoclusters with a mean size of about 2–3 nm. The nonlinear gradual in-depth distribution of the complex refractive index in the nanostructured region of the polymer results in a significant modification of the reflection of coherent light by the formed structure. So, the reflected beam undergoes a strong laser-induced photothermal interface lensing (PTIL) upon irradiation with non-focused continuous-wave laser (λ = 532 nm) with an optical power above 30 mW. The obtained results indicate that PTIL in Si^+-implanted PMMA is due to the structural modification of the subsurface region of the polymer by the ion implantation and the formation of buried ion-implanted layer, and subsequently laser-induced change in the refractive index of the Si^+-implanted PMMA. As such, PTIL effect can be used to characterize both the interface at the ion-implanted layer, as well as the laser-induced change of the refractive index of Si^+-implanted PMMA. Such thermo-optical laser-induced nonlocal nonlinear effect is related to the laser-induced optical phase change. Being of importance for photonic applications in integrated and adaptive optics (waveguiding, refractive, reflective and diffractive structures, or beam splitters), PTIL was studied as dependent on both incident laser power and incidence angle of the laser beam. The characteristic properties of laser-induced PTIL were correlated to the structure formed in this optically-transparent ion-implanted plastic. Relevant to both ion-produced subsurface interface and the in-depth profile of the complex refractive index of the formed organic material, the PTIL increases with the increasing incident laser power, thus imposing limitations on the real applicability of ion-implanted optically-transparent plastics, even at a relatively low laser intensity. The elucidation of the observed

laser-induced PTIL effect controlled through the complex refractive index of the studied organic nanostructure configuration is of importance, because the presence of thermo-lenses can limit the optical and photonic applications of transparent ion-implanted polymers (e.g., for ultra-thin reflection-type laser beam splitters, diffractive-optic elements and micro-components for integrated optical circuits, as well as light-responsive sensors based on ion-implanted PMMA).

The photo-induced change of electro-optical characteristics (voltage-dependent light transmittance) of photoactive nematic gel nanocomposites produced from nematic liquid crystal heptylcyanobiphenyl (7CB) filled with nano(aerosil) of size ~ 7 nm at concentration of 3 wt.%, and further doped with molecules of azobenzene-containing photoactive nematogenic liquid crystal EPH at concentration of 3 wt.%, was studied. By applying external alternating-current (AC) electric field, the photo-induced change of voltage-dependent light transmittance of thin (25 μm) aerosil/7CB/EPH nanocomposite films was rather strong, even by relatively weak illumination with continuous light. The photo-induced effect results from *trans-cis* photoisomerization of EPH azo-bonded molecules by UV light at the wavelength of 375 nm, as well as from the backward process (*cis*-to-*trans* photoisomerization of EPH by light in the blue spectral range). The physical mechanism of the photo-activating of the aerosil/7CB/EPH nematic gel nanocomposites and the impact on their electro-optical characteristics, were analyzed. The role of the photoisomerizable EPH molecules in the AC field-induced nematic reorientations and for UV-light-enhanced light transmittance upon AC electric field, was evidenced. Closely related to the voltage-dependent optical birefringence, the voltage-dependent light transmittance characteristics of EPH-doped aerosil/7CB nematic nanocomposites upon illumination with UV light, are indicative of a strong suppression of the confined Freedericksz transition that occurs in these nematic systems upon UV light, as a result of *trans*-to-*cis* conformation of EPH azo-compound. The established photo-stimulated and photo-controllable response of the studied aerosil/7CB/EPH thin films from three-component nematic nanocomposites is effective and of practical interest. This can be applied for developments of photo-controllable electro-optics, as well as for photonics and sensorics based on electro-optics.

In the group of "Optics and spectroscopy of thermotropic liquid crystals" a nanocomposite - liquid crystal / graphene nanoparticles was realized, in which a smectic S_G liquid crystal matrix with a high degree (S = 0.7) of volume orientation was obtained. The aim was to induce electro-optical memory in the smectic S_G phase ('remembering' the smectic structure in the higher temperature nematic phase). A high degree of ferroelectric polarization in the SG phase,) ≈150 nC/cm2, was obtained by embedding in an electro-optical cell, with temperature-stabilized electrodes from graphene monolayer and graphene nanoparticles, with an average size of 0.4 nm. At this level of ferroelectric polarization in the C_G phase, the activation energy of erasure of the electro-optical memory, Q=670 kJ mol^{-1}, was measured, with 200 kJ mol^{-1} greater than the activation energy in the conventional smectic C phase. This result is an indication for the implementation of efficient electro-optically controllable memory in a liquid crystal matrix of the smectic S_G type. This allows us to increase and control the encoded and stored information in the liquid crystal matrix, a basic requirement of modern micro and nanophotonics, as well as to model revealed, for the first time by us, 3D slope in ferroelectric smectic phase with the lowest possible symmetry C_1.

For the performance of this task, an appropriate selection of both the used liquid crystalline substances and the components of the electro-optical liquid crystal cell, such as electrodes and nanoparticles with optimized shape, size and concentration, has been performed. This will allow us to work also with functionalized nanoparticles, which we expect to improve the management of electro-optical memory at fast (within microseconds) relaxation processes

in smectic structures. Temperature stabilized graphene electrodes with optimized graphene nanoparticle size and two-smectic slope accounting will be constructed.

The temperature dependences of the optical and elastic constants of a thermotropic liquid crystal showing a nematic twist-bend phase, synthesized in the Department of Organic Chemistry and Biochemistry of the Ruder Bozkovic Institute, Zagreb, Croatia, were studied. The method of impedance spectroscopy was used. Abnormal behavior of the "bend" - the elastic constant K33 in the range of several degrees before the phase transition nematic - nematic twist-bend. Instead of the expected strong increase in the transition to the lower temperature phase, the values of K33 slightly decrease compared to those in the nematic phase. This leads to the conclusion that the nematic twist-bend phase has lower energy.

We experimentally and theoretically demonstrate the variety of the nonlinear dynamics exhibited by a single frequency semiconductor laser subjected to optical injection from a frequency comb. The injection parameters (the detuning and the injection strength) and the comb properties (comb spacing and the amplitude of the injected comb lines) are varied to unveil several dynamics such as injection locking, wave-mixing, chaotic dynamics, and unlocked time-periodic dynamics corresponding to new comb solutions. The asymmetry of the injected comb is shown to modify the size of the injection locking region in the parameter space, as well as the common properties between the new comb solutions observed and the injected comb.

Coupled-cavity VCSELs typically support two fundamental longitudinal modes. Their wavelengths as a function of the difference of the optical lengths of the two cavities display avoided wavelength crossing (or anticrosing). We numerically solve the set of Maxwell equations for a coupled-cavity VCSEL.We show that when brought closer spectrally higher transverse-order modes of different orders display not only wavelength crossing (as anticipated by the Helmholtz equation) but also avoided crossing.

We consider an integrated electro-absorption modulator within a coupled-cavity VCSEL structure (EAM-VCSEL).We derive expressions for the modulation transfer function (MTF) of the EAM-VCSEL for small-signal modulation of either VCSEL injection current or EAM losses. For current modulation, the cut-off frequency remains limited by relaxation oscillation frequency. For EAM loss modulation, the MTF curve is much flatter and its shape around the relaxation oscillation frequency displays either a well-pronounced maximum, both a maximum and a minimum or a sharp minimum only depending on the bias point of the EAM losses. Furthermore, the cut-off frequency remains beyond 100 GHz for moderate and week coupling between the VCSEL and EAM cavities. The three cases of strong, intermediate and weak coupling are also considered when carrying out the large-signal modulation response of the EAM-VCSEL and a clear open-eye diagram is demonstrated at 100 Gbs for an optimal EAM cavity length.

Rogue waves (RWs) are rare, extreme amplitude, localized wave packets, which have received much interest recently in different areas of physics. Fiber lasers with their abundant nonlinear dynamics provide an ideal platform to observe optical RW formation. We review recent research progress on rogue waves in fiber lasers. Basic concepts of RWs and the mechanisms of RW generation in fiber lasers are discussed, along with representative experimental and theoretical results. The measurement methods for RW identification in fiber lasers are presented and analyzed. Finally, prospects for future RW research in fiber lasers are summarized.

We investigate and review the formation of two-dimensional dissipative rogue waves in cavity nonlinear optics with transverse effects. Two spatially extended systems are considered for this purpose: the driven Kerr optical cavities subjected to optical injection and the broad-area surface-emitting lasers with a saturable absorber. We also consider a quasi-two - dimensional system (the two dimensions being space and time) of a fiber laser describing the

complex cubic–quintic Ginzburg–Landau equation. We show that rogue waves are controllable by means of time-delayed feedback and optical injection. We show that without delayed feedback, transverse structures are stationary or oscillating. However, when the strength of the delayed feedback is increased, all the systems generate giant two-dimensional pulses that appear with low probability and suddenly appear and disappear. We characterize their formation by computing the probability distribution, which shows a long tail. We show that for all systems, the distribution tails expand beyond two times the significant wave height.

We introduce a spin–flip model for a vertical external-cavity surface-emitting laser (VECSEL) with a saturable absorber. We demonstrate the possibility, due to the spin–flip dynamics, to generate two orthogonally linearly polarized frequency combs in the mode-locked regime. The two combs are shifted in wavelength due to the birefringence in the VECSEL gain and/or saturable absorption mirror.We show that the polarization degree of freedom may also lead to several pulses being generated per roundtrip in the two orthogonal linear polarizations and to more complicated dynamics with both linear polarizations excited.

We continued optimization of the optimal regimes of the technological process for the realization of films with the necessary characteristics (refractive index, density, strength, adhesion, etc.) with new optical materials with the vacuum deposition system Symphony 9 (Tecport Optics), purchased under Operational Program "Development of the Competitiveness of the Bulgarian Economy".

Coatings for the near and far UV area - anti-reflective and mirror - are tested. The first trials give encouraging results for low absorptin in such coatings in the range above 210 nm under appropriate regimes using stable oxides - Al_2O_3 and SiO_2. Mirrors at 220 nm with a reflection R> 90% were obtained. Regimes for low absorption of shorter wavelengths, possibly 193 nm, are being investigated.

At the request of colleagues from the labaratory “Metal vapor lasers” applied a mirror and anti-reflective coating (TiO2-SiO2) were manufactured, according to their specifications for experiments with a new powerful laser under their contract with NSF.

A large number of spectrophotometric studies have been performed in different spectral regions of colleagues from the ISSP, Institutes at the Bulgarian Academy of Sciences and other external users.

The Institute has signed framework agreements for cooperation and joint activities with companies in the industry engaged in the development or use of optical coatings - Optics AD, Kimcoop Holding Ltd., Milkotronic Ltd., Opteco and Partners Ltd.

The series of articles on various laser methods for conservation and restoration of easel paintings was continued. The methods of treatment of paintings are reviewed: cleaning, cutting and stratigraphy, as well as the documenting methods – 3D scanning for exact replicas of original artworks. The effects of laser irradiation on painting materials – varnishes, dyes and adhesives - are described; their main mechanisms of action, examples of experiments on cleaning actual paintings, and the main types of lasers used are shown. The possibilities for monitoring of the cleaning process are reviewed, using the currently available laser workstations; the most remarkable experiments with particular artworks are shown. The advantages and disadvantages of these methods, the possible combinations with other, supplementary methods, as well as the promising opportunities of their application are discussed.

A series of reference books and bibliographies dedicated to the history of Sofia University (SU), science and education in Bulgaria was completed. The last book of the series includes a short review of these publications, biographical data on the rectors of SU in 1888-1939 and their educational and scientific activity; a name index, chronological and alphabetic indices for the period 1888-1945, etc.

In 2020, the range of archaeological sites in Bulgaria was expanded, where the application of luminescent dating (OSL-dating) can be extremely useful. The adaptation and reinterpretation of some megalithic sites in Bulgaria after the adoption of Christianity was traced. It was proved that luminescent dating could be very useful in the analysis of early Christian sites: temples, rites, and tombstones. The results are summarized in a monograph.

AWARDS:

Prof. Krassimir Panayotov is among 25 scientists from the Bulgarian Academy of Sciences, who are ranked among the top two percent of the world's top scientists in their field (№ 667 in Optoelectronics and Photonics), according to Stanford University.

The ranking groups all researchers in 22 scientific fields and 176 sub-fields. It is compiled on the basis of a complex analysis, which includes information on the number of citations, H-index, corrected in co-authorship H_m-index, citations of articles in different positions of authorship and others.

PUBLICATIONS:

1. **Dencheva-Zarkova M.**, **Hadjichristov G. B.**, **Marinov Y. G.**, Maslyanitsyn I. A., Petrov A. G., **Popova L.**, Shigorin V. D., Torgova S. I., Effect of Inhomogeneous Electric Field in a Cell with Side Electrodes: Nematic Liquid Crystal 5CB. Physics of Wave Phenomena, 28, 3, Allerton Press, Inc., 2020, ISSN:1541-308X, 250-254
2. **G. B. Hadjichristov**, **Y. G. Marinov**, **Tz. E. Ivanov**, H. K. Koduru, N. Scaramuzza, PEO/E8 Polymer-Liquid Crystal Flexible Complex Blend Electrolyte System for Na Ions. In: Liquid and Single Crystals: Properties, Manufacturing and Uses, Nova Science Publ., 2020, ISBN:978-1-53616-541-8, 1-64.
3. **Panajotov K.**, Schatz R., Coupled-Cavity VCSEL with an Integrated Electro-Absorption Modulator: Small- and Large-Signal Modulation Analysis. Applied Sciences, 10, 6128, MDPI, 2020, ISSN:20763417, DOI:10.3390/app10176128.
4. **Panajotov K.**, Tlidi M., Song Y., Zhang H., Control of dissipative rogue waves in nonlinear cavity optics: Optical injection and time-delayed feedback. Chaos, 30, 053103, AIP, 2020, DOI:10.1063/5.0003225.
5. **Y. G. Marinov**, **G. B. Hadjichristov**, **T. E. Vlakhov**, H. K. Koduru, N. Scaramuzza, Electrochemical impedance and dielectric spectroscopy study of TiO2-nanofilled PEO/PVP/NaIO4 ionic polymer electrolytes. Bulgarian Chemical Communications, 52(E), 57-61, 2020, ISSN:0324-1130.
6. **Y. G. Marinov**, **G. B. Hadjichristov**, Electro-optical characteristics of thin films of aerosil-7CB nematic gel nanocomposites doped with photoresponsive liquid crystalline azo-compounds. Compt. Rend. Acad. Bulg. Sci, 73, 10, 2020, 1368-1375, ISSN:1310–1331
7. **Кънева, М.**, Лазерни методи при реставрация и консервация на кавалетна живопис (част III). Светът на физиката, XLIII, 1, 2020, ISSN:0861–4210, 15-30
8. **Кънева, М.**, Лазерни методи при реставрация и консервация на кавалетна живопис (част IV). XLIII, 2, 2020, ISSN:0861–4210, 114-123
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10. **Цонев Любомир Владимиров**, Някои старини в България в нов ракурс. Булга медиа, 2020, ISBN:ISBN 978-954-9670-49-3, 406
11. Angelina Pirovska, **Krassimira Antonova**, **Galina Malcheva**, **Vani Tankova**, **Kiril Blagoev**. Nature and physicochemical features of the incrusted white decoration on pottery from two sites in Bulgaria, dated to the chalcolithic period (IV mill BC). Journal of Archaeological Science: Reports, 29, 1-6, 2020, DOI:10.1016/j.jasrep.2019.102142.
12. Doumbia Y., Malica T., Wolfersberger D., **Panajotov K.**, Sciamanna M., Nonlinear dynamics of a laser diode with an injection of an optical frequency comb. Optics Express, 28(21), 30379-30390, 2020, DOI:10.1364/OE.402120.
13. Doumbia Y., Malica T., Wolfersberger D., **Panajotov K.**, Sciamanna M., Optical injection dynamics of frequency combs. Optics Letters, 45(2), 435-438 2020, DOI:10.1364/OL.381039.
14. Frasunkiewicz L., **Panajotov K.**, Thienpont H., Dems M., Czyszanowski T., Transverse mode mixing in a coupled-cavity VCSEL. Journal of Lightwave Technology 38(20), 5774-5782, 2020, DOI:10.1109/JLT.2020.3004454.
15. G. Ivanov, **Y. Marinov**, **G. Hadjichristov**, **T. Vlakhov**., Detection of Heavy Metal Ions by Newly Designed Biosensor with Well-Formed 3D Nano-Structure. 2019 XXIX International Scientific Symposium "Metrology and Metrology Assurance" (MMA), IEEE, 2020, DOI:10.1109/MMA.2019.8935987
16. G. K. Exner, **Y. G. Marinov**, **G. B. Hadjichristov**., Novel nanocomposites of single wall carbon nanotubes and discotic mesogen with tris(keto-hydrozone) core. Compt. Rend. Acad. Bulg. Sci., 73(9), 1217-1224, 2020, DOI:10.7546/CRABS.2020.09.04.
17. Song Y., Wang Z., Wang C., **Panajotov K.**, Zhang H. Recent progress on optical rogue waves in fiber lasers: status, challenges, and perspectives. Advanced Photonics, 2, 2, SPIE, 2020, ISSN:2577-5421, DOI:10.1117/1.AP.2.2.024001, 024001-1-024001-15
18. Vladimirov A., **Panajotov K.**, Tlidi M. Orthogonally polarized frequency combs in a mode-locked VECSEL. Optics Letters, 45(1) 252-255, 2020, DOI: 10.1364/OL.45.000252,
19. **Diana Nesheva**, Zsolt Fogarassy, Margit Fabian, **Temenuga Hristova-Vasileva**, Attila Sulyok, **Irina Bineva**, Evgenia Valcheva, **Krassimira Antonova**, Peter Petrik., Influence of fast neutron irradiation on the phase composition and optical properties of homogeneous SiOx and composite Si–SiOx thin films. J Mater Sci, 56, Springer Nature, Published online 26 October 2020, 3197-3209, ISSN:1573-4803, DOI:10.1007/s10853-020-05338-3.

CITATIONS FOR 2020: 191

PATENTS:

"Method for non-contact detection of phase transitions in liquid crystal media by means of a laser-induced surface photo-charge effect by measuring an electrical signal and a device according to the method."
Inventor (s)
Naritun Markar Naradikyan, BG, Sofia.
Jose Perez Diaz Luis, ES, Alcala de Henares
Ognyan Dinev Ivanov, BG, Sofia.

ONGOING RESEARCH PROJECTS:

Financed by the Bulgarian Academy of Sciences (budget subsidy)**:**

"Optics, electroptics and spectroscopy of new materials, surfaces, thin layers, liquid specimens and fiber optics", 2018/2020, budjet subsidy from the Bulgarian Academy of Sciences (BAS)

Financed by the Bulgarian Ministry of Education and Science:

Participation in three-year (2016-2020) project "Liquid crystal approach for model lipid membrane functions optimization by nanoparticles insertion" (FNI-DH08/48) head: Assoc. prof. J. Genova, ISSP-BAS (Assoc. Prof. B. Katranchev and Assoc. Prof. G. Hadjihristov – team members)

A three-year (2018-2020) research project on the 2018 NSF Thematic Contest, entitled: "New Effects in Nanoscale Organic Films (Langmuir and Langmuir-Blodgets) and their Use for Conceptual Development of a New Generation of Biosensors for field work in liquid environments and real-time monitoring of hard-to-detect water contaminants (anti-terrorism) or early diagnosis of tumor markers (NanobioSensors). " Funded by the NSF. Head: Assoc. Prof. Dr. Eng. Georgi Ivanov, University of Architecture, Civil Engineering and Geodesy (UACEG), Sofia. Contract DFI-KP-06-OPR 03/9 (Head of the Contract by IFTT-BAS: Assoc. Prof. Dr. Y. Marinov)

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3. Departamento de Fisica and Millennium Institute for Research in Optics, FCFM, Universidad de Chile, Casilla 487-3, Santiago, Chile
4. Shenzhen Engineering Laboratory of Phosphorene and Optoelectronics, Collaborative Innovation Center for Optoelectronic Science and Technology, Institute of Microscale Optoelectronics, Shenzhen University, Shenzhen 518060, China
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8. Université de Lorraine, LMOPS, 2 Rue Edouard Belin 57070 Metz, France
9. Institute of Physics, Technical University of Lodz, 90-924 Lodz, Poland
10. University of Perm, Russia

TEACHING ACTIVITIES:

Assoc. Prof. M. Kuneva, Ph.D - 120 hours Introductory course of physics for students on English, University of Architecture, Civil Engineering and Geodesy, Sofia, 2020

Assoc. Prof. M. Kuneva, Ph.D - 90 hours laboratory exercises in physics, bachelor program, Technical University, Sofia, 2020

LABORATORY

ATOMIC SPECTROSCOPY

HEAD: **Assoc. Prof. Valentin Mihailov, Ph.D.**
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TOTAL STAFF:**6**
RESEARCH SCIENTISTS: **6**

Assoc. Prof. Boian Torosov, Ph.D.; Assoc. Prof. Galina Malcheva, Ph.D.; Assist. Prof. Vasilka Steflekova, Ph.D.; Assist. Prof. Hristina Hristova Ph.D.; Assist. Prof. Vani Tankova

RESEARCH ACTIVITIES:

Optical methods for resolution of chiral molecules have been studied. For this purpose, two alternative methods were introduced, consisting a series of single or Raman pulses in a delta system of three states. A total of 12 series of pulses producing chiral resolution with maximum contrast were identified. These series of pulses allow direct generalization using composite pulses, which makes the method stable to errors in the parameters of interaction. A systematic approach has also been developed to derive composite pulses with a narrow and rectangular excitation profile that can produce an arbitrarily predetermined transition probability.

Composite pulses with a rectangular profile are constructed from a series of two narrow-profiles. Narrow profile series are used in metrology for the production of sensitive sensors, while rectangular ones can be used for precise selection of qubits at densely spaced atoms. A method for constructing stable and high-precision quantum gates in Raman qubits using composite pulses was also introduced during the year. For this purpose, two mathematical techniques were used: the Morris-Shore transformation and the decomposition of Majorana, which allowed the reduction of a three-state system to an equivalent two-state system. This allows a large set of composite series developed for two-state systems to be adapted for a three-state system. In this way we construct a NOT-gate, an Adamar gate, a rotation gate, as well as a phase gate. All of them demonstrate high precision and stability to experimental errors.

An optical isolator was realized using composite methods based on a Sanyak interferometer. A combination of a Faraday rotator and a half-wave plate is used, which acts as a rotator in one direction and a compensator in the opposite direction. The experimental prototype contains two such combinations, and in the laboratory instead of a half-wave plate we used its composite equivalent with two quarter-wave plates. The established insulation levels are between 41dB and 49 dB depending on the input polarization state.

Bronze artifacts dating to the Late Bronze Age and the Early Iron Age were analyzed by laser-induced plasma spectroscopy (LIBS) to determine the amount of antimony in the alloy. The method of the internal standard is used, based on the measurement of the intensities of the emitted spectral lines from the elements in the studied objects and determination of the electronic temperature and plasma density. The temperature was determined by the Boltzmann plot method and the concentration was determined by measuring the Stark broadening of the spectral lines. The results of the quantitative analysis showed an antimony content in the bronze

artifacts between 1.49 wt% and 3.13 wt%. These results help archaeologists to consider the origin and technology for the production of the studied artifacts.

The systematic investigation of archeological ceramic specimens has been started in order to identify the materials of the ceramic body and the decorative pigmentation, as well as to create a database. Analyzes were performed on five fragments of pottery dating to the 4th millennium BC. found during archeological excavations at two sites in Bulgaria: the village of Brenitsa, Pleven region and Stara Zagora mineral baths. The purpose of the study is to determine the mineral composition of the white paint. Three analytical methods are applied: laser-induced plasma spectroscopy, which determines the elemental composition of the material, X-ray diffraction, which identifies the phases and crystal structure of the minerals, and infrared spectroscopy, which gives the microstructure of the components. The results of the analyzes show that in three of the subjects the inlay is made of calcite, in one it is made of gypsum and in one - bioapatite (high temperature burnt bones). Based on the obtained results a conclusion about the technology of paint production is made.Of particular interest is the presence of bioapatite as burning bones and making white paste from them is one of the oldest technologies reported for artifacts from the 5th millennium BC. discovered on the territory of the Balkan Peninsula in antiquity and later reached other European territories

AWARDS:

Research team: Angelina Pirovska, Krasimira Antonova, **Galina Malcheva, Vani Tankova and Kiril Blagoev,** won second place in a competition for the best scientific achievement of the ISSP-BAS - *Investigation of the mineral composition of ceramic vessels dated to chalcolithic period (IV mill BC).*

PUBLICATIONS:

- *Chiral resolution by composite Raman pulses:* **BT Torosov**, M Drewsen, and NV Vitanov, **Physical Review Research,** vol.2, 043235, 2020
- *Efficient and robust chiral resolution by composite pulses*: **BT Torosov**, M Drewsen and NV Vitanov, **Physical Review A**, vol. 101, 063401, 2020
- *High-fidelity composite quantum gates for Raman qubits*: **BT Torosov** and NV Vitanov, **Physical Review Research**, vol. 2, 043194, 2020
- *Narrowband and passband composite pulses for variable rotations*: **BT Torosov**, SS Ivanov and NV Vitanov, **Physical Review A**, vol.102, 013105, 2020
- *Nature and physicochemical features of the incrusted white decoration on pottery from two sites in Bulgaria, dated to the chalcolithic period (IV mill BC).* Angelina Pirovska, Krassimira Antonova, **Galina Malcheva, Vani Tankova, Kiril Blagoev**. **Journal of Archaeological Science: Reports**, 29, Elsevier, 2020
- *Quantitative determination of antimony in archaeological bronze artefacts by laser induced breakdown spectroscopy"* **V. Tankova, V. Mihailov, G. Malcheva**, P. Penkova, L. Leshtakov, accepted for publication in ***J. Phys.: Conf. Ser.*** (online ISSN 1746-6596), 2020

- *Effect of infrared laser irradiation on electrical conductivity and ethanol sensitivity of sol gel ZnO thin films.* Gegova-Dzhurkova, R., Nesheva, D., **Mihailov, V**., Dzhurkov, V., Terziyska, P., Manolov, Journal of Physics: Conference Series, 2021 ***J. Phys.: Conf. Ser.*** 1762**,** 012037, 2021

PATENTS:

"Method for laser ablation threshold determination of solid materials"
O. Ivanov, **V. Mihailov**, S. Karatodorov, J. Perez Diaz №: BG/P/2017/ 112446

ONGOING RESEARCH PROJECTS:

- Atomic and Plasma Physics (funded by the budget subsidy of BAS),
- Composite and adiabatic methods for control in quantum and optical technologies. (National Science Fund). (funded by BSF DN 18/14 2017).
- Applications of laser ablation for the study of traditional materials in cultural heritage (under the Academy's bilateral agreements with National Institute for the Development of Optoelectronics - INOE 2000, Bucharest, Romania).
- Application of LIBS in archaeometry (Program of BAS to support young scientists),
- Adiabatic control and quantum-optical analogues – new techniques (Program of BAS to support young scientists)

INTERNATIONAL COLLABORATION:

- Faculty of Physics, Jagiellonian University, Krakow, Poland
- Faculty of Physics, University of Belgrade, Serbia,
- French National Research Center CNRS, Institute of Physics.
- New Technologies - Research Center (NTC), University of Western Bohemia, Pilsen, Czech Republic
- National Institute for Research and Development of Optoelectronics (INOE 2000), Magurele, Romania

DEPARTMENT - LASER, ATOMIC, MOLECULAR AND PLASMA PHYSICS

LABORATORY

METAL VAPOUR LASERS

HEAD: **Assoc. Prof. Krassimir Temelkov, PhD**
tel: 979 5708; e-mail: temelkov@issp.bas.bg

TOTAL STAFF: **19**
RESEARCH SCIENTISTS: **16**
HONORARY MEMBERS: **1**
ASSOC. MEMBERS: **1**

Assoc. Prof. Dimo Astadjov, PhD; Assoc. Prof. Ekaterina Iordanova, PhD; Assoc. Prof. Peter Zahariev, PhD; Assoc. Prof. Todor Petrov, PhD; Assist. Prof. Lubomir Stoychev, PhD; Assist. Prof. Stefka Slaveeva, PhD; Assist. Prof. Georgi Yankov, PhD; Assist. Prof. Stefan Karatodorov, PhD; Assist. Prof. Danka Iordanova, PhD; Assist. Prof. Ognian Sabotinov, PhD; Physicist Viktoria Atanassova, PhD; Physicist Klaoyan Zlatanov, PhD; Assist. Ivan Kostadinov; Assist. Krassimir Dimitrov; Assist. Yulian Fedchenko; Physicist Blagovela Blagoeva

Associated members: Margarita Grozeva, PhD;
Honorary members: Academician Nikola Sabotinov, DSc, PhD, member of BAS

RESEARCH ACTIVITIES:

High-power diffraction-limited (M^2 = 1) sealed-off master oscillator – power amplifier (MO–PA) strontium vapor system oscillating in the middle infrared (mid-IR) spectral range was developed and studied with the following substantial improvements: a new optical design of the MO to visualize the optical path through the entire optical scheme; a diffraction self-filtering of the laser radiation to the ultimate diffraction limit; considerable increase in the energy laser characteristics with the development and investigation of a new sealed-off laser tube with an enhanced active volume, which was used as a PA. Precise microprocessing of optical grade fused quartz was also accomplished.

High-beam-quality sealed-off MO–PA copper bromide vapor system oscillating on atomic copper (Cu) self-terminating transitions in the visible spectral region was also developed and investigated. A detailed study on the laser beam divergence was carried out with various characterizing methods demonstrating production of diffraction-limited laser beam with a superior beam quality (M^2 = 1.2) for the lasers oscillating at the atomic Cu 510.6- and 578.2-nm lines. It must be noted that only recently announced second-harmonic Nd:YAG laser systems produced by Spectra-Physics and Coherent yields single-transverse-mode TEM_{00} laser oscillation at the 532-nm wavelength with a beam propagation factor M^2 of about 1.1-1.3. Precise microprocessing of various materials, such as optical grade fused quartz, Si, stainless steel, was also realized. A maximal ratio of the hole depth to the hole diameter (so called aspect ratio) of about 100÷200, which was commensurable or two-time higher than the one achieved so far, was obtained. Enhancement of the hole length was attributed to the guiding effect induced by the high-quality hole walls, which propagated the radiation with limited losses and

intensity lowering. Precise microscribing in both Si and stainless steel samples was fulfilled at an average laser power of 0.7 mW, which corresponded to a laser pulse energy of 37 nJ.

The amplifier of a Cr:forsterite MO–PA system was modified and an output energy of 45 mJ was achieved with an extremely narrow linewidth of 0.39 pm (74 MHz) and a high beam quality of the laser radiation (M^2_x = 1.9, M^2_y = 1.7). A laser system based on the difference frequency generation (DFG) in different nonlinear crystals ($LiInS_2$, $LiInSe_2$ и $BaGa_4Se_7$), which produced tunable, narrow-linewidth (<30pm), and comparatively high-energy mid-IR radiation in the 6.8 μm region, was developed and studied. Single-frequency nanosecond-pulse Nd:YAG and Cr:forsterite lasers oscillating at 1064 nm and 1262 nm, respectively, were exploited as pumping sources. Performing double-pass through the nonlinear crystal, an output energy of 540 μJ was obtained with an extremely narrow linewidth ($\Delta\lambda$ < 30 pm и $\Delta\lambda/\lambda \leq 5.10^{-6}$). This linewidth corresponded to coherence length L_{coh} > 150 cm and coherence time τ_{coh} > 5 ns, which were above an order of magnitude higher than the ones reported in the scientific literature. Using appropriate nonlinear crystals, the DFG system could produce laser radiation in the spectral range from 5350 nm to 10800 nm with a tuning step of 34 pm that gave an opportunity of sensing extremely small amount (9.10^{-9}) of H_2O, O_3, N_2O, NO_x, NO_2, CH_4, C_2H_6, SO_x, NH_3, H_2S, HNO_3, etc.

Using a sequence of two adiabatic pulses split by a phase jump serving as a control parameter, a theoretical technique for the accurate, flexible, and robust generation of arbitrary preselected coherent superpositions of two quantum states was proposed. An experimental technique for strong enhancement (more than 3000 times compared to the conventional third harmonic signal from the same sample) of the signal yielded in the third harmonic generation by bias seeding the nonlinear sample with some intensity (less than 0.1% of the fundamental beam) at the third harmonic wavelength in addition to the driving fundamental beam was developed. An alternative way for the derivation of Morris-Shore transformation for decomposition of non-degenerate multistate quantum systems to a set of independent two-state systems and uncoupled single states was proposed. This technique was applied to the popular Λ three-state system, and the four-state tripod, double-Λ and diamond systems.

An investigation on the interaction of focused laser pulses with duration of 35 fs and repetition rate of 1 kHz, which were produced by Ti:Sapphire laser oscillating at the basic wavelength of 800 nm, with various biopolymer samples was accomplished. Structure, composition, and stability of the biopolymer samples were analyzed. Using a modified *z*-scan, nonlinear properties and effects of the polymers were experimentally determined through measurement of the nonlinear refractive index n2 and multiphoton absorption β. Microprocessing with the femtosecond laser radiation changed the properties of the biomaterial surface.

Using the PLASIMO platform, 2D nonstationary fluid model of a hollow cathode discharge with cathode sputtering in a new tube construction was developed. This discharge tube construction, which combined longitudinal and flute-type hollow cathode discharges, allowed us to produce independently active particles and to introduce them into the main longitudinal hollow cathode discharge, in which the gas discharge conditions were optimal for laser oscillation. Distributions of electric field potential and densities of electrons, copper atoms and ions were determined.

AWARDS:

1. Academician Nikola Vassilev Sabotinov was awarded with the Pythagoras Prize for Seminal Contribution to Advancement of Science.

2. Physicist Kaloyan Nikolaev Zlatanov, PhD and coauthors were awarded for the best scientific achievement of the Georgi Nadjakov Institute of Solid State Physics, Bulgarian Academy of Sciences.

PUBLICATIONS:

1. **L. I. Stoychev**, H. Cabrera, J. J. Suárez-Vargas, M. Baruzzo, K. S. Gadedjisso-Tossou, I. P. Nikolov, P. Sigalotti, A. A. Demidovich, E. Mocchiutti, C. Pizzolotto, J. Niemela, G. Toci, M. B. Danailov, A. Vacchi, "DFG-based mid-IR tunable source with 0.5 mJ energy and a 30 pm linewidth", *Optics Letters*, **45(19)**, pp. 5526-5529, 2020 **IF =3.714** & **Q1** in **Web of Science**, https://doi.org/10.1364/OL.405272;
2. **K. N. Zlatanov**, N. V. Vitanov, "Generation of arbitrary qubit states by adiabatic evolution split by a phase jump", *Physical Review **A***, **101(1)**, art. No. 013426, 2020 **IF = 2.777** & **Q1** in **Web of Science**, https://doi.org/10.1103/PhysRevA.101.013426;
3. **K. N. Zlatanov**, G. S. Vasilev and N. V. Vitanov, "Morris-Shore transformation for nondegenerate systems", *Physical Review **A***, **102**, art. No. 063113, 2020 **IF = 2.777** & **Q1** in **Web of Science,** https://doi.org/10.1103/PhysRevA.102.063113;
4. K. S. Gadedjisso-Tossou, **L. I. Stoychev**, M. A. Mohou, H. Cabrera, J. Niemela, M. B. Danailov, A. Vacchi, "Cavity Ring-Down Spectroscopy for Molecular Trace Gas Detection Using A Pulsed DFB QCL Emitting at 6.8 μm", *Photonics*, **7(3)**, art. No. 74, 2020 **IF =2.140** & **Q1** in **Web of Science**, https://doi.org/10.3390/photonics7030074;
5. C. Stock, **K. Zlatanov,** T. Halfmann, "Third harmonic generation and microscopy, enhanced by a bias harmonic field", *Optics Communications*, **457**, art. No. 124660, 2020 **IF = 2.125** & **Q1** in **Web of Science**, https://doi.org/10.1016/j.optcom.2019.124660;
6. **I. K. Kostadinov**, **K. A. Temelkov**, **G. P. Yankov**, B. L. Ivanov, "High-beam-quality sealed-off laser system oscillating in middle infrared spectral range on strontium atomic transitions", Optical and Quantum Electronics, **52**, art. No. 94 (8pp), 2020 **IF = 1.842** & **Q2** in **Web of Science**, https://doi.org/10.1007/s11082-020-2207-z;
7. K. D. Esmeryan, **Y. I. Fedchenko**, **G. P. Yankov**, **K. A. Temelkov**, "Laser irradiation of super-nonwettable carbon soot coatings – physicochemical implications", *Coatings*, **11**, art. No. 58, 2021 **IF = 2.436** & **Q2** в **Web of Science**, https://doi.org/10.3390/coatings11010058;
8. **K. A. Temelkov**, **S. I. Slaveeva**, **I. K. Kostadinov**, **Yu. I. Fedchenko**, "Theoretical determination of the gas temperature in a nanosecond pulsed longitudinal discharge exciting high-power strontium atom lasers", *Journal of Physics: Conference Series*, **1492**, art. No. 012008, 2020 (online ISSN: 1746-6596, SJR: 0.227), doi:10.1088/1742-6596/1492/1/012008, link: https://iopscience.iop.org/issue/1742-6596/1492/1;
9. **K. A. Temelkov**, **S. I. Slaveeva**, T. P. Chernogorova, "A simple method for theoretical determination of the radius and time-dependent electron temperatures in nanosecond pulsed longitudinal discharges in helium and neon assuming a bi-Maxwellian electron energy distribution function", *Journal of Physics: Conference Series*, **1492**, art. No. 012009, 2020 (online ISSN 1746-6596, SJR 0.227), doi:10.1088/1742-6596/1492/1/012009, link: https://iopscience.iop.org/issue/1742-6596/1492/1.
10. **D. Yordanova**, **K. Temelkov**, D. Mihailova, J. van Dijk, "Plasimo modeling of hollow-cathode geometry: laser tube configuration for sputtering metal-vapor lasers", *Journal of Physics: Conference Series*, **1492**, art. No. 012010, 2020 (online ISSN 1746-6596, SJR 0.227), doi:10.1088/1742-6596/1492/1/012010, link: https: //iopscience.iop.org/issue/ 1742-6596/1492/1;
11. **G. Yankov**, **E. Iordanova**, N. Nedyalkov, M. Zamfirescu, "Preliminary results on non-

linear effects in Au-ion-doped glass materials irradiated by femtosecond laser pulses", *Journal of Physics: Conference Series*, **1492**, art. No. 012060, 2020 (online ISSN: 1746-6596, SJR: 0.227), doi:10.1088/1742-6596/1492/1/012060;

12. Ro. Nikov, N. Nedyalkov, M. Koleva, N. Stankova, **E. Iordanova**, **G. Yankov**, L. Aleksandrov, R. Iordanova, "Femtosecond laser modification of the optical properties of glass containing noble-metal nanoparticles", *Journal of Physics: Conference Series*, **1492**, art. No. 012058, 2020 (online ISSN: 1746-6596, SJR: 0.227), doi:10.1088/1742-6596/1492/1/012058.
13. S. Y. Buhmann, S. Giesen, M. Diekmann, R. Berger, S. Aull, M. Debatin, **P. Zahariev**, K. Singer, "Quantum sensing protocol for motionally chiral Rydberg atoms", in arXiv.org > quant-ph > arXiv:2012.12959 (https://arxiv.org/abs/2012.12959).

PATENTS:

Maintained patents:

1. Method of atmospheric electricity extraction, No. 67018 B1 from 28.02.2020	**D. N. Astadjov**, I. Angelov, M. Gospodinov
2. Laser tube for infrared strontium laser with strontium halide vapour, No. 66683 B1 from 15.06.2018	N. K. Vuchkov and **K. A. Temelkov**
3. Laser tube for infrared strontium laser with strontium halide vapour, No. 66247 from 29.09.2012	N. K. Vuchkov, **K. A. Temelkov**, **N. V. Sabotinov**
3. Three-component glassy matrices processing variable nonlinear optical properties, No. 66129, 30.06.2011	**T. S. Petrov**, B. Shivachev and H. Yoneda
4. Gas discharge tube for sputtered hollow cathode laser, No. 65813, 24.08.2009	**M. G. Grozeva**, D. Mihailova, **N. V. Sabotinov**
5. Laser tube for ultraviolet copper laser, No. 64880, 2006	N. K. Vuchkov, **K. A. Temelkov**, **P. V. Zahariev**, **N. V. Sabotinov**
6. Gaseous copper laser, No. 64017B1, 30.09.2003	**N. V. Sabotinov**
7. Gaseous laser with copper halide vapours No. 64016, 19.03.2001	**N. V. Sabotinov**, **K. D. Dimitrov**

Patents in procedure:

1. Gas-discharge laser, reg. No. 113173 from 23.06.2020	**I. K. Kostadinov**, **D. N. Astadjov**, **K. A. Temelkov**, **G. P. Yankov**
2. Method and system for deposition of micro- and nanoparticles on transparent substrate, reg. No. 112379 from 13.09.2016	**K. D. Dimitrov**

ONGOING RESEARCH PROGECTS:

- Basic research and development of high-beam-quality high-power laser system oscillating in visible spectral range (funded by BSF KP-06-H37/2 06.12.2019).
- Functionalization of 3D printed fibrous matrixes by femtosecond laser modelling (funded by BSF KP-06-PH-38/4 06.12.2019).
- Basic research and development of high-beam-quality high-power laser system oscillating in middle infrared spectral range (funded by BSF KP-06-H27/5 08.12.2018).
- Experimental and theoretical investigation on ultrafast dynamics of processes, induced by subpicosecond laser nanomachining of wide gap semiconductors (funded by BSF DN 18/07 2017).
- Nonlinear interaction and effects of ultrafast laser pulses in dielectric media (funded by BSF DN 18/11 2017).
- Laser induced formation of three-dimensional structures of nanoparticles and study of their optical properties, (funded by NFS №.H08/25 01.09.2016).
- Lasers, laser technologies and applications (funded by the budget subsidy of BAS).
- Femtosecond laser applications (under the Academy's bilateral agreements with IFFM, Gdansk, PAS, Poland).
- Material processing and analysis by ultrashort laser pulses (under the Academy's bilateral agreements with National Institute for Lasers, Plasma and Radiation Physics, RAS, Romania).

INTERNATIONAL COLABORATION:

The **METAL VAPOUR LASERS,** has international collaborations with:
√ Institute of Fluid-flow Machinery - Polish Academy of Sciences, Gdansk, Poland;
√ Institute for Laser Science – UEC, Chofu-shi, Tokyo, Japan;
√ TU/e, Eindhoven, The Netherlands
√ Tomsk State and Tomsk Polytechnic Universities, Tomsk, Russian Federation
√ National Institute for Lasers, Plasma and Radiation Physics, RAS, Romania

TEACHING ACTIVITIES:

Assist. Prof. Ognian Sabotinov organized series of introductory courses for medical doctors for work with laser systems.

The young scientists of the laboratory participated in the traditional 23th Winter Seminar of PhD Students and Young Scientists in Physics (Webinar), 08-10 December, 2020.

Assoc. Prof. Todor Petrov is a full-time lecturer in the Technical University – Sofia.

Prof. Dr. K. Temelkov gave an invited lecture "High-power atomic and ionic lasers with metal and metal halide vapor excited in nanosecond pulsed longitudinal discharge – advance and prospects" at the 13th Spring Seminar of PhD Students and Young Scientists in Chemistry (Webinar), 22-24 June, 2020 and a lecture "Simplicity in Physics – my arrogant or modest view in 1985–1988" at the 23th Winter Seminar of PhD Students and Young Scientists in Physics (Webinar), 08-10 December, 2020.

MUSEUM
HISTORY OF PHYSICS IN BULGARIA
CURATOR: **Assoc. Prof. Dr. Ganka Kamisheva**
Tel. +359 2 979 58 31, E-mail: gkamish@issp.bas.bg
TOTAL STAFF **1**
RESEARCH SCIENTIST **1**

SCIENTIFIC RESULTS

We celebrated 200 anniversaries of Dr. Demetrius Stefanov Mutieff (04.09.1818 – 13.01.1864) two years ago. He is the first Bulgarian physicist with Ph.D from the University of Berlin (1842). Character of his scientific research and his contribution to the prosperity of Bulgarian school in Bolgrad have been supplemented [1].

A new ten-minutes biographical movie has prepared and recorded about Georgi Nadjakov scientific research [2].

Institute of Solid-State Physics has a new patent № 67144 from 25.08.2020. Our request № 112181 started on 17.12.2015. It is a new *Method for movable electron copy creation for printed or manuscript text* [3].

The manuscript of a new book starts but it has not finished last year. It will collect results from documentary investigation about Georgi Nadjakov experimental scientific activities [4].

PUBLICATIONS

1. Г. Камишева, *Д-р Димитър Мутев живот и дейност*, сп. Наука (1) 62-65 (2020).
2. Г. Камишева, *Георги Наджаков - физиката е забавна* (10:00) https://www.youtube.com/embed/31fyqQdHBrs
3. Г. Камишева, *Method for movable electron copy on printed or manuscript text creation*, Patent № 67144 / 25.08.2020
4. Г. Камишева, *Експерименталната физика в България*, незавършен ръкопис