BULGARIAN ACADEMY OF SCIENCES

GEORGI NADJAKOV
INSTITUTE OF SOLID STATE PHYSICS

ANNUAL RESEARCH REPORT
2018

Compiled and Edited by J. Genova

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Foreword

In December 2018, the Institute had the privilege to organize a lecture of the Nobel Prize Laureate Prof. Barry Barish on Gravitational Waves that took place at "Prof. Marin Drinov" Hall, Bulgarian Academy of Sciences. The Institute organized the traditional 21st Winter Seminar "Interdisciplinary Physics" for doctoral students and young scientists from the Bulgarian Academy of Sciences during the winter of 2018.

To commemorate the 46th anniversary of our Institute an exhibition dedicated to the historical achievements and the equipment of the Institute in laser technologies was opened on October 15, 2018 at the central lobby of the Bulgarian Academy of Sciences. The exhibition included 17 poster presentations and video materials showing the possibilities of the available at the Institute great variety of laser and plasma sources, covering a wide range of wavelengths and pulse duration; spectral equipment and technologies for diagnostics and processing of materials.

2018 has seen the start of the project BG05M2OP001-1.001-0008, funded by the Operational Programme "Science and Education for Smart Growth" financed by the Ministry of Education, Youth and Science and co-financed by the European Union through European structural and investment funds. The purpose of the project is to build a National Center of Excellence for Mechatronics and Clean Technologies. ISSP is a one of the basic partners in this project.

In 2018, the project 312804 "Device For Large Scale Fog Decontamination"– COUNTERFOG, financed under the "Security" programme and the reintegration grant COPQE (Composite Pulses for Quantum Engineering) in the framework of the Horizon 2020 European programme were successfully finalized.

During 2018, the Jubilee 20th edition of the traditional International School on Condensed Matter Physics devoted to "Physics and Applications of Advanced and Multifunctional Materials" was organized. The event was held from 3rd to 7th September 2018 in Varna, Bulgaria. For the first time 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.

During the last year, the scientific personnel of the Institute published 116 papers: 88 printed and 28 at press. 84 articles have been published in internationally recognized high impact journals indexed in ISI web of knowledge and/or SCOPUS. The total number of citations in 2018 exceeds 1209. ISSP currently holds 13 BG patents and 13 applications for patents are in procedure, three of which were filed in 2018.

During 2018 three patents "Iron-based superconducting material", „Active zinc electrode mass composition for alkaline rechargeable batteries", and "Laser tube for strontium infrared laser with strontium halide vapours" were approved.

Acad. Alexander G. Petrov the former director of the Institute was awarded with the highest State Medal "Saints Cyril and Methodius" – a necklace for merit in the field of education and natural sciences. A diploma and a silver sign from the Bulgarian Industrial Association for the invention of a sensor for detecting pollution in aerosols developed within the project COUNTERFOG was given to Assoc. Prof Ognyan Ivanov. Prof. Krassimir Panayotov received the Pythagoras Award for Seminal Contribution to Science by a Bulgarian Scientist working abroad.

The scientific teams, led by Assoc. Prof. Krastyo Buchkov and Assoc. Prof. Ekaterina Radeva were awarded the prize for their scientific achievements for the year 2018 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. I. Bivas, D.Sc.
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:	

SCIENTIFIC COUNCIL

Chairman: Prof. D. Nesheva, D.Sc.
Deputy Chairman: Prof. I. Bivas, D.Sc.
Secretary: Assoc. Prof. E. Dimova, Ph.D.

1. Acad. A. G. Petrov, D.Sc.
2. Prof. H. Chamati, D.Sc
3. Prof. A. Paskaleva, D.Sc.
4. Prof. N. Ivanov, D.Sc.
5. Prof. K. Blagoev, D.Sc
6. Assoc. Prof. E. Nazarova, D.Sc.
7. Assoc. Prof. J. Genova, Ph.D.
8. Assoc. Prof. V. Vitkova, Ph.D.
9. Assoc. Prof. P. Rafailov, Ph.D.
10. Assoc. Prof. O. Ivanov, Ph.D.
11. Assoc. Prof. V. Mihailov, Ph.D.
12. Assoc. Prof. T. Tenev, Ph.D .
13. Assoc. Prof. E. Radeva, Ph.D
14. Assoc. Prof. Y. Marinov, Ph.D
15. Assoc. Prof. M. Primatarowa, Ph.D.
16. Assoc. Prof. M. Grozeva, Ph.D
17. Assoc. Prof. G. Popkirov, Ph.D.
18. Assist. Prof. K. Esmeryan, Ph.D. (Young scientists' representative)

LABORATORY

ELECTROMAGNETIC SENSORS

HEAD: **Assoc. Prof. Ognyan Ivanov, Ph.D.**
Tel: 979 57 77; e-mail: *ogi@phys.bas.bg*

TOTAL STAFF: **5**
RESEARCH SCIENTISTS: **2**
ASSOC. MEMBERS: **1**

Assist. Prof. L. Mihailov, Ph.D.; P. Todorov, Ph.D. student – Mechanical engineer; Y. Miroslavov, Ph.D. student – Mechanical engineer; V. Altunova, B.Sc. student – Laboratory technical assistant;

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

RESEARCH ACTIVITIES:

The laboratory performs experimental and theoretical investigations in the field of electromagnetic field – matter interaction. On this basis, sensors and devices designed for different areas of industry, security, scientific experiments, etc., are being developed. In 2018, we have worked on the improvement of a series of such sensors and devices, designed to improve the European security. They will work together with fluid-generating systems, created by colleagues from several institutions in Europe. Successful demonstrations of our developments have been carried out.

A series of experiments on investigation of the Surface photo-charge effect (SPCE) signals, generated by the solid body - two-phase fluid interface, has been completed. It has been proven that SPCE can be used successfully for the development of fog sensors.

The development of two systems for generation of fog with controlled parameters in laboratory environment has been completed. On of the systems generates fogs with controlled number and diameters of the droplets. The other system generates fogs with controlled chemical composition. It can work with up to 6 impurities simultaneously.

A new, express method for control of phase transitions in liquid crystals has been developed. It works on the basis of SPCE. When there is a change in the liquid crystal, the liquid crystal – solid body interface changes. The SPCE signal is formed namely from this boundary surface. Accordingly, any change in the liquid crystal alters the signal from the SPCE. The methodology has been successfully applied in studies of liquid crystals.

In the theoretical studies of electromagnetic field – matter interactions with application in astrophysics, we have worked on two topics:

A. The dependence of the energetic characteristics of the ground state in Helium-like electron systems on the isotopic composition have been studied. A detailed analysis has been performed within the frame of classical quantum mechanics for all of the actually investigated isotopes. The Schrodinger equation for a two-electron case is solved at proper perturbation suggested. The relations between these energies and the components for different isotopes have been investigated by finding features with many derivatives of functions - staggering analysis. It is remarkable that the results obtained correspond to all physical and mathematical principles and measurements. Unlike the world's best theoretical results so far, our obtained energy value for the ground state of helium-like electron systems is closer to the experimental data than the results obtained in all other queries within the classical quantum theory.

B. The influence of ultra-powerful magnetic fields on the crust of neutron stars is studied. The composition of the core and the boundary beyond which the atomic nuclei decay by neutron emission are determined numerically for different strengths of the magnetic field. The known experimental measurements for atomic masses are used in the calculations.
We also pay close attention to applied scientific tasks. Our developments are "Optimal Distribution of Locomotives" and "Dynamic Traction-Force Integrator", author of which is Dr. Mihailov. They are implemented in the railways with nationwide importance. The developed algorithms are included in scientific applied systems of general interest, for which we are constantly cooperating.
On May 17, 2018, we made demonstrations of our developments to the Minister of Education and Science Krassimir Valchev during his visit to the Institute of Solid State Physics. He was accompanied by the Deputy Minister Prof. Ivan Dimov, the Director of the Science Department Dr. Milena Damyanova and the Deputy Chairman of BAS correspondent member Kostadin Hadjivanov.
On June 14, 2018, at Tech Park, Sofia, we made presentations and carried out demonstrations of results obtained under the COUNTERFOG project to a delegation from the European Commission headed by Jean-Eric Paquet, General Director of the Research and Innovation Department.

AWARDS:
First place in the competition *Most Significant Applied Science Achievement 2017* at the Institute of Solid State Physics, Bulgarian Academy of Sciences, for the development of *SPCE sensor with a liquid layer for detection of contamination in fog*.

A diploma and a silver sign from the Bulgarian Industrial Association for the sensor for control of pollutions in aerosols developed under the COUNTERFOG project.

PUBLICATIONS:
In 2018 we have published 6 articles in journals with impact factor and one chapter in a book. There is also one article accepted for publication, and one more has been submitted.

1. Christova K., Maslyanitsyn I. A., Miloushev I., Shigorin V. D., Tenev T., Voronov V., Second Harmonic Generation in Thin Zinc Sulfide Films, *Physics of Wave Phenomena*, 26, 1, Allerton Press, Inc., 2018, ISSN:ISSN 1541-308X, doi: 10.3103/S1541308X18010028, 9-15;
2. Ivanov O., Petrov M., Naradikian H., Perez-Diaz J. L., Phase transition detection by surface photo charge effect in liquid crystals, *Phase Transitions*, 91, 5, 2018, ISSN:0141-1594 (Print) 1029-0338 (Online), doi: 10.1080/01411594.2018.1431644;
3. Ivanov O., Pérez-Díaz J. L., Serkedzhiev M., Fog Influenced signal generation by Surface photo-charge effect (SPCE), *Comptes rendus de l'Académie bulgare des Sciences*, 71, 1, 2018, ISSN:1310–1331 (Print), 2367–5535 (Online), 22-28;
4. Ivanov O., Ralev Y., Todorov P., Popov I., Angelov K., Perez-Diaz J. L., Kuneva M., Laboratory system for artificial fog generation with controlled number and size distribution of droplets, *Bulgarian Chemical Communications*, 50, 1, 2018, ISSN:0324-1130, 89-93;
5. Ivanov O., Ralev Y., Todorov P., Popov I., Perez-Diaz J. L., Kuneva M., System for generation of fogs with controlled impurities, *Bulgarian Chemical Communications*, 50, 1, 2018, ISSN:0324-1130, 94-99;
6. Perez-Diaz J.L., Qin Y., Ivanov O., Quinones J., Stengl V., Nylander K., Hornig W., Álvarez J., Ruiz-Navas E. M., Manzanec K., Chapter: Fast Response CBRN High-Scale Decontamination System: COUNTERFOG: Science as the first countermeasure

for CBRNE and Cyber threats, In book: *Enhancing CBRNE Safety & Security*, Andrea Malizia, Marco D'Arienzo, (Eds.), *Springer*, 61-69, January (2018), DOI: 10.1007/978-3-319-91791-7_8

The citations in 2018 are 16.

PATENTS:
In 2018, we have worked to assist the Patent Office in examining the 5 patents filed in 2017. So far, their discussion is normal and there are no significant remarks.
ONGOING RESEARCH PROJECTS:
European project: *Device For Large Scale Fog Decontamination* (COUNTERFOG) – FP7, Programme *Security*, Project Number - 312804

INTERNATIONAL COLLABORATION:
Within the project *COUNTERFOG* we have worked together with nine European partners. We have joint publication.
We have worked on the implementation of some results obtained under the abovementioned project with:
- *Faculty of Engineering and Applied Science, University of Ontario Institute of Technology*, Oshawa, Ontario.
On theoretical investigations of electromagnetic field – matter interaction with application in astrophysics, we have worked with:
- *University Pierre and Marie Curie (UPMC)* in Paris;
- *University of Montréal* – Department of Physics;
- *The Free University of Brussels - Institute of Astronomy and Astrophysics*.

LABORATORY

THEORY GROUP

HEAD: **Prof. Hassan Chamati, D.Sc.**
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TOTAL STAFF: **13**
RESEARCH SCIENTISTS: **13**
ASSOC. MEMBERS: **1**

Prof. N. Ivanov, D.Sc.; Prof. P. Ivanov, D.Sc.; Assoc. Prof. E.Korucheva, D.Sc.; Assoc. Prof. D. Shopova, Ph.D.; Assoc. Prof. Z. Dimitrova, Ph.D.; Assoc. Prof. R. Kamburova, Ph.D.; Assist. Prof. A. Donkov, Ph.D.; Assist. Prof. J. Boradjiev, Ph.D.; Assist. Prof. S. Varbev, Ph.D.; Assist. Prof. M. Georgiev;
Physicist H. Tonchev, Ph.D.; Physicist E. Popov, Ph.D.; Physicist K. Gaminchev

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

RESEARCH ACTIVITIES:

We phenomenologically study the phase diagram of some ferrimagnetic substances based on two bilinearly coupled Heisenberg models. Calculations are performed with the aid of Landau energy obtained through applying the Hubbard-Stratonovich transformation to the initial microscopic Heisenberg Hamiltonian. The phase transitions within the model are of second order with the emergence of a compensation point at lower temperatures for some values of parameters of the system. The main phase is a two-sublattice collinear ferrimagnet but also a metastable non-collinear phase is present within the exchange approximation presented here. The numerical results give a detailed description of temperature dependence of magnetization on the strength of intersublattice interaction and the difference between the effective exchanges of two ferromagnetically ordered sublattices.

Phase diagrams of Heisenberg chains with different cell spins $S_c=S_1+S_2$ and the role of the three-site exchange interactions are studied. The analysis is based on analytical as well as on large-scale DMRG numerical calculations, using as parameters the cell spin Sc and the constants of the shortest two-spin (J_1) and three-spin (J_3) exchange intersctions. Actually, we have compared the phase diagrams of two models with the parameters $(S_1,S_2) = (1,1/2)$ and (3/2,1/2), corresponding to systems with odd and even cell spins (S_c= 3/2 и 2). A basic conclusion of this large-scale calculations is that in the parametric region of the phase diagram characterized by macroscopically degenerate classical ground state different quantum phase are stabilized, depending on the cell spin (odd, or even). We have analyzed also the quantum phase diagrams and the low-lying excited states of a uniform-spin (S=1/2) and a mixed-spin $(S_1,S_2) = (1,1/2)$ Heisenberg models defined on kagome strips. The analysis combines the alalytical spin-wave approach with numerical exact diagonalizations. In the uniform-spin system, we have studied two critical spin phases corresponding to the ground states of Heisenberg chains with effective lattice spins S=3/2 and 5/2, respectively. On the other hand, in the mixed-spin system with $(S_1,S_2) = (1,1/2)$, the above critical states are transformed to gapped Haldane-type phases with effective lattice spins 1 and 3, respectively.

The interaction of bright solitons with impurities in anisotropic ferromagnetic chain is studied. We consider a ferromagnetic Heisenberg chain of spins with magnitude S described in the nearest-neighbors approximation and the impurities characterize the change in the anisotropy constant of a single spin. This type of impurities leads to linear and nonlinear perturbing terms in the corresponding nonlinear Schroedinger equation. We have found static soliton-impurity bound states and considered the conditions for their formation. For large values of the anisotropy the character of the impurities is mainly linear. The interaction of propagating solitons with the impurities is also investigated. We have obtained that the solitons can be transmitted, trapped or reflected. The behavior depends on the soliton velocity and width, magnetic parameters and the impurity strength.

We study the dynamics of networks with coupling delay, from which the connectivity changes over time. The synchronization properties are shown to depend on the interplay of three time scales: the internal time scale of the dynamics, the coupling delay along the network links and time scale at which the topology changes. Concentrating on a linearized model, we develop an analytical theory for the stability of a synchronized solution. In two limit cases, the system can be reduced to an "effective" topology: In the fast switching approximation, when the network fluctuations are much faster than the internal time scale and the coupling delay, the effective network topology is the arithmetic mean over the different topologies. In the slow network limit, when the network fluctuation time scale is equal to the coupling delay, the effective adjacency matrix is the geometric mean over the adjacency matrices of the different topologies. In the intermediate regime, the system shows a sensitive dependence on the ratio of time scales, and specific topologies, reproduced as well by numerical simulations. Our results are shown to describe the synchronization properties of fluctuating networks of delay-coupled chaotic maps.

In addition to regular sleep/wake cycles, humans and animals exhibit brief arousals from sleep. Although much is known about consolidated sleep and wakefulness, the mechanism that triggers arousals remains enigmatic. Here, we argue that arousals are caused by the intrinsic neuronal noise of wake-promoting neurons. We propose a model that simulates the superposition of the noise from a group of neurons, and show that, occasionally, the superposed noise exceeds the excitability threshold and provokes an arousal. Because neuronal noise decreases with increasing temperature, our model predicts arousal frequency to decrease as well. To test this prediction, we perform experiments on the sleep/wake behavior of zebrafish larvae and find that increasing water temperatures lead to fewer and shorter arousals, as predicted by our analytic derivations and model simulations. Our findings indicate a previously unrecognized neurophysiological mechanism that links sleep arousals with temperature regulation, and may explain the origin of the clinically observed higher risk for sudden infant death syndrome with increased ambient temperature.

We study propagation of traveling waves in a blood filled elastic artery with an axially symmetric dilatation (an idealized aneurysm) in long-wave approximation. The processes in the injured artery are modelled by equations for the motion of the wall of the artery and by equation for the motion of the fluid (the blood). For the case when balance of nonlinearity, dispersion and dissipation in such a medium holds the model equations are reduced to a version of the Korteweg-de Vries-Burgers equation with variable coefficients. Exact travelling-wave solution of this equation is obtained by the modified method of simplest equation where the

differential equation of Riccati is used as a simplest equation. Effects of the dilatation geometry on the travelling-wave profile are studied.

We consider an extension of the methodology of the modified method of simplest equation to the case of use of two simplest equations. The extended methodology is applied for obtaining exact solutions of model nonlinear partial differential equations for deep water waves: the nonlinear Schroedinger equation. It is shown that the methodology works also for other equations of the nonlinear Schroedinger kind.

We devise a formalism to investigate in a systematic way the spectroscopic magnetic excitations in molecular magnets. This consists in introducing a bilinear spin Hamiltonian that allows for discrete coupling parameters accounting for distinct spin coupling mechanisms among the constituent magnetic ions, as well as the influence of the nonmagnetic ions in the system. The model is applied to explore the magnetic excitations of the trimeric magnetic compounds $A_3Cu_3(PO_4)_4$ (A = Ca, Sr, Pb) and the tetrameric molecular magnet Ni_4Mo_{12}. Our results are in a very good agreement with the available experimental data: For all trimers $A_3Cu_3(PO_4)_4$, calculations reveal the existence of one thin energy band referring to the flatness of observed excitation peaks. Moreover, for the tetramer Ni_4Mo_{12}, we concluded that the magnetic excitations might be traced back to the specific geometry and complex chemical structure of the exchange bridges leading to the splitting and broadness of the peaks centered about 0.5 meV and 1.7 meV.

PUBLICATIONS:

1. **Boradjiev, I.**, Christova, E., Eberl, H.. Dispersion theoretic calculation of the H→Z+γ amplitude. Physical Review D, 97, 2018, ISSN: 2470-0010, DOI: 10.1103/PhysRevD.97.073008, 073008(13).
2. **Georgiev, M.**, **Chamati, H.**. Magnetic Exchange in Spin Clusters. arXiv.org, Cornell University, 2018, ISSN: 2331-8422.
3. **Georgiev, M.**, **Chamati, H**. A systematic approach to determine the spectral characteristics of molecular magnets. arXiv.org, Cornell University, 2018, ISSN: 2331-8422.
4. D'Huys O., Rodríguez-Laguna, J., Jiménez, M., **Korutcheva, E**, Kinzel, W.. Understanding the enhanced synchronization of delay-coupled networks with fluctuating topology. Eur. Phys. J. Special Topics, 227, Springer, 2018, ISSN: 1951-6355, DOI:10.1140/epjst/e2018-800086-6, 1129-1150.
5. Dvir, Hila, Elbaz, Idan, Havlin, Shlomo, Appelbaum, Lior, **Ivanov, Plamen Ch.**, Bartsch, Ronny P.. Neuronal noise as an origin of sleep arousals and its role in sudden infant death syndrome. Science Advances, 4, 4, American Association for the Advancement of Science, 2018, ISSN: 2375-2548, DOI:10.1126/sciadv.aar6277, eaar6277(10).
6. Nikolova E. V., Jordanov I. P., **Dimitrova Z.I.**, Vitanov N. K.. Nonlinear Evolution Equation for Propagation of Waves in an Artery with an Aneurysm: An Exact Solution Obtained by the Modified Method of Simplest Equation. Advanced Computing in Industrial Mathematics, 728, Springer, 2018, ISBN: 978-3-319-65530-7, DOI:10.1007/978-3-319-65530-7_13, 131-144.
7. Vitanov N. K., **Dimitrova Z. I.**. Modified Method of Simplest Equation Applied to the Nonlinear Schrödinger Equation. Journal of Theoretical and Applied Mechanics, 48, 1, De Gruyter Open, 2018, ISSN: 1314-8710, DOI:10.2478/jtam-2018-0005, 59-68.
8. **H. Chamati** and **D. Shopova**, Application of two-sublattice bilinearly coupled Heisenberg model to the description of certain ferrimagnetic materials. arXiv.org, Cornell University, 2018, ISSN 2331-8422.

ONGOING RESEARCH PROJECTS:

- Quantum effects in low-dimensional and nanostructured magnetic systems
- Phases and excited states of highly frustrated magnetic systems
- Liquid crystal approach for model lipid membrane functions optimization by nanoparticles insertion
- Synthesis and theoretical studies of graphene nanostructures
- Investigation of the interaction of magnetic solitons with quantum bits

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: **Assoc. Prof. Peter Rafailov, PhD**
tel: 979 5718; e-mail: rafailov@issp.bas.bg

TOTAL STAFF: **15**
RESEARCH SCIENTISTS: **10**
*HONORARY MEMBERS:***1**
ASSOC. MEMBERS: **1**

Assoc. Prof. E.K. Nazarova, D.Sc.; Assoc. Prof. D.Z. Dimitrov, Ph.D.; Assoc. Prof. P.K. Sveshtarov, Ph.D.; Assoc. Prof. B.S. Blagoev, Ph.D.; Assist. Prof. K.M. Buchkov, Ph.D.; Assist. Prof. L. K. Yankova; V.T. Tomov, Ph.D.;S. Boyadjiev, Ph.D.; V. B. Mehandjiev, M.Sc.; S. Petrov, B.Sc., M. Valkovski, B.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*

We report a single-crystal neutron diffraction study of the magnetic structure of the multiferroic compound YbMnO3, a member of the hexagonal manganite family, in zero field and under a magnetic field applied along the c axis. We propose an explanation for the zero-field magnetic ordering and for the field-induced magnetic reorientation of the Mn atom and of the two Yb atoms on distinct crystallographic sites.

It is demonstrated that hexagonal ErMnO3 single crystals unveil a giant rotating magnetocaloric effect by spinning them in constant magnetic fields around their a or b axes. The generated anisotropic thermal effect is about three times larger than that exhibited by the hexagonal HoMnO3 single crystal. This effect in ErMnO3 arises from the unique features of the Er^{3+} magnetic sublattice.

Aluminum-doped zinc oxide (AZO) layers are prepared by using atomic layer deposition technique. By varying the Al content, optimal growth compositions are established for maximizing the AZO electrical conductivity. Based on performed characterization, selected AZO films are implemented as transparent electrodes in liquid crystal display devices and found to perform comparably to commercial ITO electrodes

- *Carbon-nanostructure research*

By microstructure polarization and electro-optic analysis of nanocomposites of dimeric liquid crystal 7OBA and graphene flakes it is shown that the □□□ interaction of the dimeric and biphenylene rings of the liquid crystal with the carbon hexagons of the graphene layer leads to a sharp reduction in the symmetry and in the smectic C temperature range of pure 7OBA a ferroelectric smectic CG phase with triple symmetry is induced.

- *High-temperature superconductors*

A comparative analysis of the superconducting and transport properties of Fe(Se, Te) single crystals obtained by two different methods (Bridgman and self-flux) was performed. Bridgman crystal shows higher critical temperature and upper critical magnetic field and smaller magnetic background with respect to the self-flux one. Correspondingly the higher critical current density as a function of temperature was observed for the Bridgman crystal. Double peak effect in critical current versus magnetic field dependence was registered only for $FeSe_{0.5}Te_{0.5}$ obtained by Bridgman technology. This is a result of crossover from weak to strong pinning, determined from correlated defects like twin boundaries. These defects are among the most effective pinning centers and cause important processes in vortex dynamics leading to increasing critical current in strong magnetic fields.

FeSe polycrystalline samples with and without Ag addition were prepared and investigated. It was found that Ag addition enhances critical temperature, critical magnetic field- $B_{c2}(0)$, critical current density, magnetoresistance and pinning energy. It was established that the temperature dependence of Hall constant, $R_H(T)$, is non-linear and shows a sign reversal for Ag doped samples. Consistent with the non-compensated nature of the samples, negative R_H values are observed in large temperature interval. At high temperatures, R_H strongly increases and a sign reversal of R_H is found. This effect underlines the importance of charge mobility and its large value for holes carriers at higher temperatures. The magnetoresistance of Ag-doped FeSe samples increases with the Ag concentration and shows deviations from the Kohler scaling at higher temperatures in consistency with the multiband structure of FeSe. However, at temperatures below ~30 K the Kohler plot is restored indicating the dominance of one type of carriers for the magnetotransport. Thus Ag addition not only improves the tetragonal phase formation of FeSe and its superconducting properties, but provides new insight into the influence of carriers type and concentration on the characteristics of superconducting FeSe system.

AWARDS:

The works reported in Publications 9, 10, 11 and 12 in the following list were elected by the Scientific Council of the Institute of Solid State Physics as the best research and development achievements of the Institute for the year 2018.

PUBLICATIONS:

1. **Blagoev, B. S.**, Aleksandrova, M., **Terziyska, P.**, Tzvetkov, P., Kovacheva, D., Kolev, G., **Mehandzhiev, V.**, Denishev, K., **Dimitrov, D.**. Investigation of the structural, optical and piezoelectric properties of ALD ZnO films on PEN substrates. Journal of Physics: Conf. Series, 992, 1, IOP, 2018, 012027.
2. **Boyadjiev, S**, **Georgieva, V.**, Vergov, L., Szilágyi, I.M.. QCM gas sensor characterization of ALD-grown very thin TiO2 films. Journal of Physics: Conference Series, 992, 1, IOP Publishing, 2018, 012054.
3. **Genova, J.**, **Petrov, M.**, **Bivas, I.**, **Rafailov, P.**, **Naradikian, H.**, **Katranchev, B.**. Fourier-transform Infrared and Raman characterization of bilayer membranes of the phospholipid SOPC and its mixtures with cholesterol. Coll. Surf. A, 557, 2018, 85-93.
4. **Petrov, M., Rafailov, P.**, **Naradikian, H.**, **Katranchev, B.**, Todorov, N. Graphene-induced bi-tilted two component smektic CG phase with bulk ferroelectricity in hydrogen-bonded dimer liquid crystals. Journal of Molecular Liquids, 272, Elsevier B. V., 2018, 97-105.
5. Balli, M, Jandl, S, Fournier, P, Vermette, J, **Dimitrov, D. Z.**. Unusual rotating magnetocaloric effect in the hexagonal ErMnO3 single crystal. Physical Review B, 98, 2018, 184414.

6. Chattopadhyay, S, Simone, V, Skumryev, V, Mukhin, A.A., **Dimitrov, D.Z.**, **Gospodinov, M**, Ressouche, E. Single-crystal neutron diffraction study of hexagonal YbMnO3 multiferroic under magnetic field. Physical Review B, 98, 13, 2018, 134413.
7. Su, Y. C., Chiou, C. C., Marinova, V., Lin, S. H., Bozhinov, N., **Blagoev, B.**, Babeva, T., Hsu, K. Y., **Dimitrov, D. Z.**. Atomic layer deposition prepared Al doped ZnO for liquid crystal displays applications" Opt. Quant. Electron, 50:205 (2018). Opt. Quant. Electron,, 50, 2018, 205.
8. **Stoyanova-Ivanova, A**, **TERZIEVA, S**, GEORGIEVA, S, **BLAGOEV, B**, KOVACHEVA, D, ZALESKI, A, MIKLI, V. SUPERCONDUCTIVITY AND MAGNETIC STUDIES OF BULK Y123/ BaCuO 2 COMPOSITE. Romanian Journal of Physics, 63, 2018, 602. ISI IF:1.758
9. A. Galluzzi, **K. Buchkov, V. Tomov, E. Nazarova**, A. Leo, G. Grimaldi, A. Nigro, S. Pace and M. Polichetti, Evidence of pinning crossover and the role of twin boundaries in the peak effect in FeSeTe iron based superconductor, Supercond. Sci. Technol. 31 (2018) 015014.
10. **E. Nazarova, N. Balchev, K. Buchkov**, K. Nenkov, D. Kovacheva, G. Fuchs, Superconducting and multiband effects in FeSe with Ag addition, Chapter 8 in book "High-Temperature Superconductors: Occurrence, Synthesis and Applications" eds. M. Koblishka and M. Muralidhar, Nova Science Publishers, Inc., USA, 2018, pp 195-212
11. A. Galluzzi, **K. Buchkov, V. Tomov, E. Nazarova**, A. Leo, G. Grimaldi, S. Pace and M. Polichetti, Superconducting properties of Fe(Se,Te) iron based materials fabricated by two different techniques: Bridgman and Self-flux methods, J. Appl. Phys. 123 (2018) 233904.
12. **V. Tomov, K.Buchkov**, A. Galluzzi, M.Polichetti, K. Nenkov. and S. Pace, Multiferroic Single Crystals with Layered Structure in Pb-Mn-Ni-Ti-O System – Growth and Investigation of Their Properties, Chapter 3 in Concept, Property and Application of Micro/Nanostructured Materials eds. **Jinjin Li** and **Sen Du,** Nova Science Publishers, Inc., USA, 2018, pp 67-106.

PATENTS:

Iron-based superconducting material, Reg. № 66791 B1/ 30.11.2018
N. Balchev, E. Nazarova, K. Nenkov, K. Buchkov, D. Kovacheva, A. Zahariev, G. Fuchs

ONGOING RESEARCH PROJECTS:
- National Scientific Research Fund: Projects DFNI-T02/26 and DH08/9;
- Projects funded under the Academy's bilateral agreements and in the framework of institute-to-institute cooperation: with National Ciao Tung University – Taiwan and Institute for Structure Studies and Low Temperatures, Wroclaw, Poland;
- COST Action "Functional oxide nanolayers and nanolaminates deposited by the ALD method"

INTERNATIONAL COLLABORATION:
- Institute of Low Temperature and Structure Research, PAS, Wroclaw, Poland;
- National Ciao Tung University, Hsinchu, Taiwan;
- University of Salerno, Salerno, Italy

LABORATORY

PHYSICAL PROBLEMS OF MICROELECTRONICS
HEAD: **Assoc. Prof. D. Spassov, Ph.D.**
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TOTAL STAFF: **10**
RESEARCH SCIENTISTS: **4**
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, physicis E.Gajdarzhieva, eng. T. Stanchev technologist S. Tsvetanov, technologist M. Stoicheva, technologist Ch. Petkanov , technologist M. Atanasov

RESEARCH ACTIVITIES:

The research activities of the laboratory during the year 2018 can be summarized as follows:

Leakage currents and conduction mechanisms in nanolaminated HfO_2/Al_2O_3 deposited by atomic layer deposition (ALD) on Si were investigated for different Al_2O_3 content (thickness of the Al_2O_3 sublayers) and post deposition annealings (PDA). Leakage currents at low applied voltage range depend on the Al_2O_3 sublayer thickness (0.2 to 1 nm). The observed behavior is attributed to the modification of the role of Al_2O_3 in the multilayer dielectric in dependence on its content: passivation of preexisting defects in HfO_2 matrix at small Al concentrations, generation of new defect sites with the increase of alumina amount, and finally at a sublayer thickness of about 1 nm Al_2O_3 starts to behave rather as a separate layer than a dopant. It has been found that rapid thermal annealing in N_2 at 800 C increases the leakage of the stacks, while the same treatment in O_2 ambient slightly reduce the current in comparison with the current in as-deposited samples. Current-Voltage characteristics (*I-V*) of the stacks in the low voltage region are highly symmetrical in respect to the polarity of the applied voltage suggesting that current is governed by bulk limited conduction mechanism. The current in this range is well described with power law relation ~ V^n (n=0.6-1). Upon applying voltage pulses with high enough magnitude *I-V* curves are shifted towards lower or higher *I* values depending on polarity of the voltage pulse. Depending on both the pulse and measurement bias polarity leakage current after the voltage stress is expressed either by ~ V^n or by $(V\text{-}V_t)^n$ where V_t is a threshold voltage (0.2÷0.8V), and n is in the interval 0.6÷1.6. The observed results can be interpreted by the model of collective transport in an array of metal quantum dots in which the current is limited by the empty available sites along the current path. The current paths in the investigated stacks are made of the existing traps.

The temperature dependence of leakage currents in nanolaminated HfO_2/Al_2O_3 ALD stacks with 10 and 30 cy of Al_2O_3 revealed that traps taking part in the low field conductivity are positioned at 0.5-0.6 eV below the conduction band of the dielectric. At high applied voltages (above 10V) the conduction is dominated by the space charge limited current in presence of deep traps (~0.06 eV below Fermi level). The density of the deep traps estimated from *I-V* measurements is in a good agreement with the values obtained by capacitance-voltage (*C-V*) technique.

Retention and endurance characteristics of the nanolaminated HfO_2/Al_2O_3 were estimated. For oxygen annealed stacks about 65% of the stored charge would remain into the dielectric

after 10 years. The observed charge loss agrees with tunnel discharging mechanism. The stacks demonstrated excellent endurance remaining operable for ~2.5x10^4 program/erase operations cycles with a change of memory windows of ~6%.

Etching of Al_2O_3, pSi and TiO_2 films by atomic force microscope (scalpel-AFM technique) was studied. The etched parts were investigated by leakage current measurements with C-AFM and cross-section TEM. It was shown that scalpel-AFM method modifies significantly electric properties of the films in an uncontrollable manner due to the high contact forces/pressures needed for the etching. Depending on the film's material undesirable effects as phase transitions, defects creation and metal atoms penetration were observed. This limits the resolution of the method in studying nanosize objects, e.g. electrical characteristics of conduction nanofilaments formed during the resistive switching. An approach for a correct implementation of scalpel-AFM to 3D characterisation of electrical characteristics of nanomaterials were proposed.

MOS structures with double layer dielectric SiO_2/SiO_x were examined for existence of resistive switching effect. Part of the structures received post deposition annealing in N_2 at 1000□C for 60 min to form silicon nanocrystals into SiO_x matrix. Cross- section TEM analysis showed that during the annealing phase separation takes place with formation of nanocrystals with size of ~4-5 nm. Current-Voltage measurements showed, that bipolar resistive switching is observed only in the annealed structures. The model explaining the change of the resistance with formation of conductive path in SiO_x−Si NCs layer by the electric field under negative gate voltages and the current rupture of the conductive filament under positive gate voltages was verified by high frequency capacitance-voltage measurements (*C-V*). Dielectric constant of as-grown SiO_x films with x=1.3 was obtain as 4.6 from the *C-V* results.

The feasibility of manufacturing Al_2O_3 and MgO films with set thermal expansion on corundum substrates by electric-beam evaporation was evaluated. The experiment conducted on a request by Sensata aimed development of a fabrication technology for high temperature sensor for monitoring exhaust car gases. The works were carried out under collaboration with Lab. Optics and spectrometry.

PUBLICATIONS:

1. D. Spassov, A. Paskaleva, T.A Krajewski, E. Guziewicz, G. Luka, G., Tz. Ivanov, Al_2O_3/HfO_2 Multilayer High-k Dielectric Stacks for Charge Trapping Flash Memories. Physica Status Solidi (A) Applications and Materials Science, 2018, 201700854.
2. D. Spassov, A. Paskaleva, T.A Krajewski, E. Guziewicz, G. Luka, Hole and electron trapping in HfO_2/Al_2O_3 nanolaminated stacks for emerging non-volatile flash memories. Nanotechnology, 29, 2018, 505206.
3. S. Danković, I. Manić, A. Prijić, V. Davidović, Z. Prijić, S. Golubović, S. Djorić-Veljković, A. Paskaleva, D. Spassov, N. Stojadinović, A review of pulsed NBTI in P-channel power VDMOSFETs. Microelectronics Reliability, 82, 2018, 28-36.
4. N. Novkovski, A. Paskaleva, A., Skeparovski, D. Spassov, Analysis of Conduction and Charging Mechanisms in Atomic Layer Deposited Multilayered HfO_2/Al_2O_3 Stacks for Use in Charge Trapping Flash Memories. Advances in Condensed Matter Physics, 3708901, Hindawi Limited, 2018.
5. S. Chen, L. Jiang, M. Buckwell, X. Jing, Yanfeng Ji, E. Grustan-Gutierrez, Fei Hui, Y. Shi, M. Rommel, A. Paskaleva, G. Benstetter, W.H. Ng, A. Mehonic, A. J. Kenyon, M. Lanza. On the Limits of Scalpel AFM for the 3D Electrical Characterization of Nanomaterials. Advanced Functional Materials, 28, 52, 2018.
6. V. Dzhurkov, D. Nesheva, I. Bineva, P. Terziyska, M. Šćepanović, I. Stambolova, V. Blaskov, V. Mihailov, E, Manolov, Z.V. Popović Microstructure of nanocrystalline sol gel ZnO thin films treated with infrared nanosecond pulse laser. Nanoscience & Nanotechnology: Nanostructured materials applications and innovation transfer, 18, 2, Bulgarian Academy of Sciences, National Coordination Council on Nanotechnologies, 2018, ISSN:1313-8995, 5-9

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.

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. Institute of Physics, St.St. Cyril and Methodius University, Skopie, Macedonia.
4. University of Nish, Serbia.
5. Institute of Physics, Polish Academy of Science, Warsaw, Poland.
6. Universidad Autonoma de Baja California, Mexicale, Mexico.

LABORATORY

ACOUSTOELECTRONICS
HEAD: **Assoc. Prof. Ekaterina Radeva**
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TOTAL STAFF: **9**
RESEARCH SCIENTISTS: 4
ASSOC. MEMBERS: 2

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

Associated members: Cor. Mem. Lozan Spassov; Assoc. Prof. V. Georgieva

RESEARCH ACTIVITIES:

Resonant Structures Using Rayleigh Surface Acoustic Waves (RSAW), Bulk Acoustic Waves (BAW) and Surface Transverse Waves (STW). Applications to Sensors.

Interactions of the RSAW mode with fluorescently labeled phospholipidic Langmuir-Blodgett (LMB) films on the surface of quartz based two-port RSAW resonators have been studied for possible mass sensitive biological sensor applications. Monolayers of phospholipidic ethanolamine head labelled with nitrobenzoxadiazole (DPPE-NBD) have been deposited onto the surface of 433 MHz RSAW resonators by using a controlled withdrawal from a LMB bath. Such DPPE-NBD molecules can serve as an appropriate matrix for implementation of selectively reacting proteins or enzymes while preserving their function. In this study, the physical properties of the films were studied with fluorescence spectroscopy and atomic force microscopy (AFM). Additional measurements of the electrical characteristics of the RSAW devices after LMB film deposition revealed that the monolayers are firmly attached to the surface of the RSAW device, thus robust and stable over time biosensors are to be expected. The frequency shifts as a result of mass changes due to bioreactions at the film surface are typically measured by connecting the SAW device to an oscillator loop and measuring its frequency shift with a frequency counter. In this study, we measured a 10 kHz per monolayer frequency down shift which is an excellent sensitivity for possible biosensor applications keeping in mind that such sensor oscillators provide a short term stability of a few parts in 10^{-10}/s. Also, an unexpected improvement in insertion loss was observed which means that the thin LB nanofilms are very well tolerated by RSAW resonant devices on piezoelectric quartz.

Synthesis, study and application of plasma polymers and composites

The plasma polymerization method (PPM) was studied as an approach for fast and simple modification and improvement of ultra- and nanofiltration membranes. The method has demonstrated a clear ability to optimize operating parameters in PEEK membranes where up to 400% improvement in permeability has been achieved and selectivity from initial 800-1500 Daltons to less than 300 with one plasma treatment. The plasma treatment of ultrafiltration membrane types PAN and Ultem proved the possibility of direct transformation of ultra → nanomembranes with remarkable selectivity ≥ 200 Daltons throughout the studied range at fully acceptable permeability. The method described has potential as an inexpensive, fast and simple way for membrane refinement.

An application of PPM for the synthesis of composite coatings from a suspension of hexamethyldisiloxane and diamond nanoparticles in different amounts (0.1, 0.5 and 1 mg / ml) suitable for osteointegration was also investigated. It was found that with increasing particle concentration the modulus of elasticity (ME) of the layers was reduced while the other surface properties - wettability and topography - did not change. It was demonstrated that composites with ME close to that of bone tissue stimulated the growth and osteogenic differentiation of human mesenchyme stem cells. Matrix mineralization and cell spreading was maximal on coatings with the highest ME, and their pre-coating with Fibronectin increased this effect. Therefore, the layers are suitable not only for osteointegration but also for modification of already applied implants as well as a substrate model for testing the elasticity of the material on cellular behavior.

Superhydrophobic coatings and the use of QCM to evaluate their anti-icing and antimicrobial properties

Within 2018, novel fundamental research on the anti-icing properties of superhydrophobic carbon soot coatings, in particular their anti-frosting capability, was carried out. By means of controlled combustion of rapeseed oil, three types of soot with varying degrees of oxidation and structural defects were deposited on 16 MHz quartz crystal microbalances (QCMs). The anti-frosting performance of the material was assessed by analyzing *in-situ* the signal generated by each sensor upon placing it in ambient environment at sub-zero temperatures and moderate humidity (~ 50-60%). The experimental results unambiguously showed that the frost formation and its propagation velocity depend on the quantity of oxygen functional groups and structural defects in the soot, where the reduction of both parameters shifted the onset of frost incipiency down to -20 ° C. A new fundamental knowledge on the antimicrobial activity of superhydrophobic soot coatings to Gram-negative bacteria *Pseudomonas putida* was also obtained. Two modes of bacterial adhesion, namely reversible and irreversible, were identified on the soot based on its detailed surface characterization and the real-time sensor response of four representative soot coated 5 MHz QCMs. The mechanism of each bioadhesion mode is related to the presence and spatial distribution of surface features commensurable with the scale of bacterial cells, resulting in morphologically triggered partial wetting and lower kinetic barrier that the bacteria have to overcome in order to reach the surface.

AWARDS:

The paper:
D.Mitev;**E.Radeva**;D.Peshev;J.Burgal;M.Cook;L.Peeva;A.Livingston, PECVD modification of nano & ultrafiltration membranes for Organic Solvent Nanofiltration, *Journal of Membrane Science*, **2018**, 548, 540–547, doi.org/10.1016/j.memsci.2017.11.070
won the 1-st place in the contest of the Institute of Solid State Physics for best application oriented scientific paper for 2018

PUBLICATIONS:

1. George R. Ivanov and Ivan D. Avramov, "Langmuir – Blodgett Films from Fluorescently Labeled Phospholipids on Surface Acoustic Wave Devices", 20th International School on Condensed Matter Physics, Sept. 3-7, 2018, Varna, Bulgaria, accepted for publication in Journal of Physics: Conference Series (JPCS), IOP Conference Series; for Journal of Physics: Condensed Matter)
2. D.Mitev, E. Radeva, D. Peshev, J. Burgal, M. Cook, L. Peeva, A. Livingston, PECVD modification of nano & ultrafiltration membranes for organic solvent nanofiltration, Journal of Membrane Science 2018, 548, 540–547,DOI: 10.1016/j.memsci.2017.11.070, JR:2.062.

3.Milena Keremidarska-Markova, Ekaterina Radeva, Dimitar Mitev, Kamelia Hristova-Panusheva,Brett Paull, Pavel Nesterenko, Joseph Šepitka, Ita Junkar, Aleš Iglič, Natalia Krasteva, Increased elastic modulus of plasma polymer coatings reinforced with detonationnanodiamond particles improves osteogenic differentiation of mesenchymal stem cells, Turk J Biol, March 2018, 42(2), 195-203, DOI: 10.3906/biy-1711-26 2.
4. K. D. Esmeryan, C. E. Castano, R. Mohammadi, Y. Lazarov, E. I. Radeva, Delayed condensation and frost formation on superhydrophobic carbon soot coatings by controlling the presence of hydrophilic active sites, Journal of Physics D Applied Physics 51 (2018) 055302.
5. K. D. Esmeryan, I. A. Avramova, C. E. Castano, I. A. Ivanova, R. Mohammadi, E. I. Radeva, D. S. Stoyanova, T. G. Vladkova, Early stage anti-bioadhesion behavior of superhydrophobic soot based coatings towards Pseudomonas putida, Materials&Design 160 (2018) 395-404.
6. S Boyadjiev, V Georgieva, L Vergov, I M Szilágyi, QCM gas sensor characterization of ALD-grown very thin TiO_2 films, Journal of Physics: Conference Series,Volume 992, Issue 1, 5 April 2018, Article number 012054

ONGOING RESEARCH PROJECTS:

Joint Research Project between the Institute of Solid State Physics and the Research Center Karlsruhe, Germany for the Development of SAW Resonators Using Gold Electrode Structure for Sensor Applications.

Superhydrophobic graphite-like amorphous carbon coatings - innovative and economically expedient approach for the atmospheric icing and biofouling prevention - Research project under the support program for young scientists, project N DFNP-17-19/24.07.2017.

INTERNATIONAL COLLABORATION:

Research center Karlsruhe, Germany
Chemical Engineering and Chemical Technology, Imperial College London, England
Virginia Commonwealth University

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: **6**

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

Honorary members: Prof. E. Vateva, D.Sc; Assoc. Prof. K. Kolentsov;
Associated members: Prof. S. Kaschieva, D.Sc; Prof. S. Alexandrova, D.Sc; Assoc.Prof. S. Balabanov, Ph.D.; Assoc.Prof. S. Simeonov, Ph.D.; Assoc.Prof. A. Szekeres, Ph.D.; Assoc.Prof. D. Arsova, Ph.D.; Assoc.Prof. Z. Ivanova, Ph.D.; Assoc.Prof. N. Peev,, Ph.D.;

RESEARCH ACTIVITIES

Research is carried out to develop a technique for depositing thin films of different morphology by applying frequency modulation of the substrate during thermal vacuum evaporation (FATEV) and examining the influence of frequency modulations on the mechanism of growth of deposited thin films. Tellurium films with nominal thicknesses of 60 nm were deposited using various input frequencies of the vibrational impact - 0, 50, 4000 and 10000 Hz. Atomic and scanning electron microscopies (AFM and SEM), X-ray diffraction (GIXRD) and spectroscopic ellipsometry (SE) are used to get information about the basic structural parameters and to enlighten the in-depth organization of thin tellurium films. It is found through XRD that the structure of all deposits corresponds to hexagonal tellurium with crystal lattice parameters in good agreement with those in the literature and with a micro-strain varying ranging from 0 to 0.2 (at frequency of 4 kHz). In all samples, the average size of the crystallites is around 17 nm. The morphological observations on the samples' surface confirm the FATEV effect determined previously for thicker films - the organization of the particles forming the films increases with increasing the frequency of applied vibrations with a peak of the rms surface roughness at input frequency of 50 Hz. When 4 and 10 kHz are applied, there is a change in the growth mechanism in depth of the layers - while the samples deposited without excitement impact and under vibrations with a frequency of 50 Hz consist of bulk homogeneous bottom layer and a very well defined coarse layer on top, these deposited using kHz frequencies consist of singular nanoribbons growing predominantly towards the z-axis from the very beginning of the film formation. The microscopy observations were confirmed by the ellipsometry estimations – the samples are divided in two groups: (1) bulks with highly porous surface layer, and (2) bottom-to-top porous layers with average voids content of ~ 15 %. It is assumed that the excitement of the substrate with input frequencies in the kilohertz range causes a width limitation of the nanoformations defined by the corresponding resonance period of the substrate.

Through AFM, the morphology and topography of 0-5 mol% of As_2O_5 doped SnO_2 thin films are studied. Morphology typical of nanocrystalline films is observed. The root mean square roughness of the films surface and nanoparticle size and size distribution are determined. It is defined an optimal layer with an As content (2 mol% As_2O_5), a thickness of 230 nm, a grain size of ~ 70 nm and a Rq = 14 nm for the application as large area position-sensitive photodetector.

The morphology and topography of thin nanotubular Pt coatings and TiO_2/Pt/TiO_2 nanolaminate structures obtained by radio frequency magnetron sputtering are studied. The results of these studies are applied in the development of a new technological approach for sensitivity of strain resistors based on nanolaminate structure with Pt granulates is developed.

Ellipsometric investigations of thin metal oxide layers (Al_2O_3, ZnO, WO_3, SnO_2, TiO_2) deposited by atomic layer deposition (ALD) on silicon, and on flexible substrates (PEN, PET, Polycarbonate) are carried out in order to determine the thickness of the layers, the optical constants and the width of the band gap. The dependence of the optical band gap of ZnO thin films on the thickness of the layers and the deposition temperature (50-250° C) is investigated. It is found that for these layers the band gap increases from 3.27 to 3.37eV when the deposition temperature increases from 50 to 250° C. Ellipsometric measurements are also performed on a series of thin carbon layers deposited by pulsed laser deposition on SiO_2/Si substrates. Their thicknesses and optical constants are determined.

Homogeneous SiO_x layers with four different compositions (x = 1.2, 1.3, 1.5, 1.7) and SiO_x layers thermally treated at 1000 oC and containing silicon nanocrystals (composite layers) are irradiated with 20 MeV electrons with two different doses (2.4×10^{14} or 3.6×10^{15} electrons/cm^2). Infrared transmission results obtained indicate that in the homogeneous layers the degree of phase separation induced by electron irradiation is highest at the dose of 3.6×10^{15} electrons/cm^2. In the composite layers, TEM results demonstrate the existence of nanocrystals with a similar filling factor in the non-irradiated and irradiated layers, and the Raman scattering data testify to the presence of a small amount of pure amorphous silicon phase in both non-irradiated and electron-irradiated layers. SE reveals that, similarly to the observation for amorphous nanoparticles, the electron irradiation reduces the nanocrystallite size, i.e. the reduction of the Si nanoparticle size by irradiation with 20 MeV electrons is an effect which is not influenced by the lattice order in nanoparticles.

Thin films from ZnSe with thicknesses of 50-160 nm are deposited by thermal evaporation in vacuum. Two groups of layers, as-deposited and relaxed (stored for 4 months after deposition at 25 ºC in air), are examined with spectroscopic ellipsometry and AFM. It is concluded that all layers are nanocrystalline with a grain size of about 25-30 nm. It is found that the relaxation of the layers results in significant porosity decrease - from about 30% in the fresh films to 15-19% in the relaxed ones, while the surface roughness increases - from ≤ 0.5 nm in the fresh layers with thickness of 50 nm to 2.6 nm after the film relaxation. Chemical sensing studies at room temperature show that the sensitivity of ZnSe layers to ethanol vapors increases with decreasing thickness. Besides, the fresh layers are more sensitive than the relaxed ones, which indicates that porosity has a stronger effect on the sensitivity of the layers than the surface roughness.

Research is continued on $Ge_xSb_{40-x}Se_{60}$ (x = 15, 20, 25, 27, 32 and 35 at.%) bulk glasses and chalcogenide layers deposited on quartz substrates by thermal evaporation in vacuum of powdered glasses with corresponding compositions. AFM data indicate that the layers have a smooth surface (< 2.3 nm). They are also transparent in the spectral range of 0.85-3.5 μm (T ~ 80%). Neutron and X-ray diffraction measurements on bulk samples prove that the synthesized glasses are amorphous. By Reverse Monte-Carlo modeling of the diffraction data, presence of Ge-Se and Sb-Se heteropolar bonds, forming structural units, as well as Se-Se and Ge-Ge homopolar bonds is shown. Optical studies on the layers confirm the results of diffraction studies, and also show the presence of hydrogen and oxygen impurity bonds. At a Ge content of about 27 at.% peculiarities in the compositional dependencies of the parameters of the studied layers are observed. This indicates a phase transition from a two-dimensional to three-dimensional structure in chalcogenide materials at such Ge content.

PUBLICATIONS

1. **Z. .Ivanova,** Complex Studies on the Photoluminescence of Er-doped GeS2-Ga2S3 Glasses for Photonic Applications, Chapter in Book: Photoluminescence: Advances in Research and Applications. Nova Science Publishers, New York, 2018. pp 1-52.
2. **T. Hristova-Vasileva,** P. Petrik, **D Nesheva,** Zs. Fogarassy, J. Lábár, **S. Kaschieva,** S. N. Dmitriev, **K. Antonova,** Influence of 20 MeV electron irradiation on the optical properties and phase composition of SiOx thin films, Journal of Applied Physics, 123, 195303-8pp, 2018.
3. **D. Nesheva, V. Dzhurkov,** I. Stambolova, V. Blaskov, **I. Bineva,** J.M.C. Moreno, S.Preda, M. Gartner, **T. Hristova-Vasileva,** M. Shipochka, Surface modification and chemical sensitivity of sol gel deposited nanocrystalline ZnO films, Materials Chemistry and Physics, 209, 165-171, 2018.
4. V. Zhelev, P. Petkov, P. Shindov, I. Bineva, S. Vasilev, V. Ilcheva, T. Petkova. As-doped SnO_2 thin films for use as large area position sensitive photodetector. Thin Solid Films, 653, 19-23, 2018.
5. N. Dulgheru, M. Gartner, M. Anastasescu, M. Stoica, M. Nicolescu, H. Stroescu, I. Atkinson, V. Bratan, I. Stanculescu, A. **Szekeres, P. Terziyska, M.** Fabian, Influence of compositional variation on the optical and morphological properties of Ge-Sb-Se films for optoelectronics application, Infrared Physics and Technology, 93, 260-270, 2018.
6. N. Dulgheru, M. Stoica, J-M. Calderon-Moreno, M. Anastasescu, M. Nicolescu, H. Stroescu, I. Atkinson, I. Stanculescu, A. **Szekeres, M.** Gartner, Optical, morphological and durability studies of quaternary chalcogenide Ge-Sb(As)-(S,Te) films, Materials Research Bulletin, 106, 234-242, 2018.
7. M. Fabian, N. Dulgheru, K. **Antonova, A. Szekeres, M.** Gartner, Investigation of the Atomic Structure of Ge-Sb-Se Chalcogenide Glasses, Advances in Condensed Matter Physics, 2018, 7158079-11pp, 2018.
8. **B.S. Blagoev,** M. Aleksandrova, P. **Terziyska, P.** Tzvetkov, D. Kovacheva, G. Kolev, V. **Mehandzhiev, K.** Denishev, D. **Dimitrov,** Investigation of the structural, optical and piezoelectric properties of ALD ZnO films on PEN substrates, Journal of Physics: Conf. Series, 992, 012027-5pp, 2018.
9. C. Dikov, P. Vitanov, T. Ivanova, V. Stavrov, E. Tomerov, G. Stavreva, I. **Bineva,** Optical and electrical properties of TiO_2/Pt/TiO_2/nanolaminate structures. Journal of Physics: Conference Series, 992, 012033, 2018.
10. E. Halova, N. Kojuharova, S. **Alexandrova, A. Szekeres,** Electrical characterization of thin nanoscale SiO_x layers grown on plasma hydrogenated silicon, Journal Physics: Conf. Series, 992, 2018.
11. **V. Dzhurkov, D. Nesheva, I. Bineva, P. Terziyska,** M. Šćepanović, I. Stambolova, V. Blaskov, **V. Mihailov, E. Manolov,** Z. V. Popović, Microstructure of nanocrystalline sol gel ZnO thin films treated with infrared nanosecond pulse laser. Nanoscience & Nanotechnology: Nanostructured materials applications and innovation transfer, 18 (2), 5-9, 2018.

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.

INTERNAL RESEARCH PROJECTS

Financed by the Bulgarian Academy of Sciences:

1. Preparation and properties of nanostructured and amorphous chalcogenide, oxide and nitride semiconductors and structures for applications in optoelectronics and sensors.

Financed by the Bulgarian Ministry of Education and Science:

1. Characterization of new chalcogenide materials by atomic force microscopy, Contract DMU 03-91/12.2011.

ONGOING INTERNATIONAL COLLABORATION PROJECTS

1. Optical, structural and electronic properties of metal oxides obtained by physical and chemical methods for application in optoelectronics and sensors, Institute of Physical Chemistry, Bucharest, Romania, coordinator Assoc.Prof. P. Terziyska.
2. Raman scattering and photoluminescence from laser modified nanocrystalline ZnO thin films suitable for sensor applications, Center for Solid State Physics and New Materials, Belgrade, Serbia, coordinator Prof. D. Nesheva.
3. Morphological and structural investigations of nanostructured and amorphous semiconductor films for application in microelectronics and sensorics, National Institute for Research and Development in Microtechnology, IMT Bucharest, Romania, coordinator Assoc.Prof. I. Bineva.
4. Structural and optical properties of new semiconductor materials and structures for advanced opto- and nanoelectronics applications, Centre for Energy Research, Hungarian Academy of Sciences, coordinator Prof. D. Nesheva.

DEPARTMENT SOFT MATTER PHYSICS

LABORATORY

LIQUID CRYSTALS

HEAD: **Assoc. Prof. Victoria Vitkova, Ph.D.**
tel: 979 5796; e-mail: victoria@issp.bas.bg

TOTAL STAFF: **5**
RESEARCH SCIENTISTS: **3**
ASSOC. MEMBERS: **1**

Prof. I. Bivas, Ph.D., D.Sc., Assoc. Prof. J. Genova, Ph.D.;
Eng. D. Mitkova, PhD student; Eng. Z. Slavkova (part-time)

Associated member: Assoc. Prof. A. Zheliaskova, Ph. D.

RESEARCH ACTIVITIES:

The influence of low-molecular weight carbohydrates and their interaction with biomimetic membranes is of both fundamental and technological importance for clarifying the role of sugars in the natural mechanisms of plant protection from drought, cryopreservation and biopreservation in various industrial and medical applications. We studied the effect of sucrose on the electrical properties of synthetic lecithin bilayers. Their electric capacitance was measured in salt solutions at different sugar concentrations by analyzing the shape deformation of lipid vesicles in alternating electric field. In the electrochemical experiments the unilamellar lipid vesicles of dozens of micrometers in size represent a suitable biomimetic object with low mechanical tension. The experimental method is based on ing the vesicle shape change at varied frequency of the applied electric field and at given ratio of the conductivity of the surrounding solutions. After measuring the vesicle radius, the internal and external aqueous conductivity as well as the frequency at which the vesicle becomes spherical, the specific membrane capacitance is subsequently calculated. The results from our measurements in salt solutions without sucrose provide evidences about a lower membrane capacitance compared to the values obtained for black lipid membranes and supported bilayers. The reported difference might be due to the higher mechanical tension of the membrane in the two latter model systems, associated to a smaller bilayer thickness. The addition of sucrose in the surrounding aqueous solution leads to an increase of the membrane capacitance with increasing the sugar concentration. Taking into account the inverse proportionality of the bilayer thickness and the electrical capacitance, we can conclude that the obtained result is consistent with the effect reported in the literature about the membrane thinning in the presence of sugar molecules in the aqueous solution. At the same time, the reduction of the bilayer thickness is not sufficient to explain the measured increase in the electrical capacitance of the membrane, attributed also to a higher dielectric permittivity of the lipid bilayer.

The electrodeformation method was applied to measure the electrical capacitance of phosphatidylcholine membranes in the presence of 0.03 mol % of an azobenzene-containing peptide with potential anticonvulsant activity. The obtained value is lower than the electric capacitance of the single-component bilayer from the same synthetic lipid. Our result testifies to a thickening of the azopeptide-containing membranes accompanied with alterations in the bilayer dielectric constant. The reported results allow the evaluation of the membrane charging

time and nerve impulse propagation as well as the quantification of the external electric fields' influence on cells.

The evaluation of the bending elasticity modulus of the lipid membrane in presence of different concentrations (0.5 and 1 weight percent) of gold hydrophobic nanoparticles in it was performed by means of thermally- induced shape fluctuation method of quasi-spherical vesicles. The nanoparticles were synthesized by the colleagues from the Moscow University of Chemical Technology. The results of the study show that the addition of nanoparticles slightly increases the bending elasticity modulus in the studied concentration range.

Using the Differential Scanning Calorimetry (DSC) method, we investigated the thermodynamic characteristics of SOPC phospholipid within a gradual increase in its hydration and in mixtures with cholesterol in concentrations between 10 and 50 mol%. Our DSC analysis shows that hydration of SOPC, expressed by adding different water quantities ranging from 0 to 33 wt% dramatically influences the behaviour of thermodynamic quantities. At fixed water concentrations, both, the enthalpy and the transition temperature increase as a function of the heating rate, indicating hydrocarbon chains disordering. On the other hand, at a fixed heating rate the enthalpy and the entropy linearly decrease with water concentrations, predominantly indicating the ordering of the hydrocarbon chains. We found that a drastic decrease of the energetic quantities – enthalpy and entropy – by water concentration causes hydrocarbon chains effective ordering within the bilayer matrix and enhances the hydrogen bonding of water with C=O carbonyl or P=O phosphate groups. In accordance with our former spectroscopic results.

The asymmetric shape of the endothermic peaks of the DSC curves indicated a novel effect concerning gel-liquid crystal phase transition as such driven by van't Hoff enthalpy, pointing to an intermediate, partially cooperative phase transition.

A considerable modification of the structure conformation and biophysical properties of the bilayer of the phospholipid system after the cholesterol incorporation were detected. Concentrations below 30 mol %, and especially in the range 10-20 mol% revealed to be optimal in the effective miscibility of SOPC and cholesterol components. The effective miscibility completeness mainly in the gel and liquid crystal phases were indicated. It was discovered that cholesterol mixed with SOPC slightly shifts its gel ($L_{\square}$) to liquid crystals ($L\alpha$) phase transition temperature, decreases cooperativity, expressed by the van't Hoff enthalpy, markedly and progressively reduce the transition enthalpy to almost zero at 50 mol % . By deep incubation of the cholesteric phospholipid mixture was revealed that the endothermic peak associated with laminar crystal to gel phase transition, does not exist in conventional pure SOPC bilayer systems.

PUBLICATIONS:

1. **V. Vitkova,** D. Mitkova, K. Antonova, G. Popkirov, R. Dimova, Sucrose alter the electric capacitance and dielectric permittivity of lipid bilayers, Colloids and Surfaces A: Physicochemical and Engineering Aspects, vol. 557, p. 51-57 (2018) Available online 5 May 2018; https://doi.org/10.1016/j.colsurfa.2018.05.011; IF 2.714
2. **J. Genova**, M. Petrov, **I. Bivas,** P. Rafailov, H. Naradikian, B. Katranchev, Fourier-transform Infrared and Raman characterization of bilayer membranes of the phospholipid SOPC and its mixtures with cholesterol, Coll. Surf. A 557 (2018) 85–93. IF-2,108
3. P. Todorov, P. N. Peneva, St. I. Georgieva, J. Tchekalarova, **V. Vitkova**, K. Antonova, A. Georgiev, Synthesis, characterization and anticonvulsant activity of new azobenzene-containing VV-hemorphin-5 bio photoswitch, *Amino Acids* (accepted); ISSN: 0939-4451 (Print) 1438-2199 (Online); https://link.springer.com/article/10.1007/s00726-018-02691-1; IF 2.906
4. D. Mitkova, K. Antonova and **V. Vitkova**, Mechanical and electrical properties of biomimetic membranes in the presence of sweeteners, AIP Conference Proceedings, ISSN 0094243X (accepted); SJR 0.165

ONGOING RESEARCH PROJECTS:

Research Project "The deformability as a key feature of biomembranes and the influence of biologically relevant substances on it – experimental studies on model systems" (National Science Fund, Bulgaria – Grant DMU03-80/2011), coordinator Assoc. Prof. Dr. V. Vitkova
Research Project "Mechanical and electrical properties of model lipid membranes in the presence of biologically active substances" (National Science Fund, Bulgaria – Grant DN08-7/13.12.2016), coordinator Assoc. Prof. Dr. V. Vitkova
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
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
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 Galya Staneva, IBPBME-BAS; Coordinator from ISSP-BAS /partner organization/: Assoc. Prof. Dr Victoria Vitkova
Research Project "Impact of oxidized lipids on rafts as sorting and signaling platforms of cells. Biomimetic systems: smart tool to reveal lipid-lipid and lipid-protein interactions"; DPTS/France 01-4/09.05.2017) coordinator: Professor Dr Galya Staneva, IBPBME-BAS and Professor Dr Miglena Angelova, University Paris VI: Pierre and Marie Curie and Paris VII: Didrot; ISSP members of the research team: Assoc. Prof. Dr Victoria Vitkova and Assist. Prof. Dr Denitsa Mitkova
Research Project "Modeling of molecular mechanisms in oxidative stress: effect of palmitoyl-oxo-valeroyl phosphatidylcholine on the membrane organization" coordinator: Assist. Prof. Dr. Rusina Hazarosova (National Science Fund, Bulgaria, „Young Researchers – 2017") with a member of the research team from ISSP-BAS Assist. Prof. Dr Denitsa Mitkova
Research Project "Preparation and characterization of biomimetic archeolipid nanostructures" ("Program for Supporting of Young Scientists and PhD Students at the Bulgarian Academy of Sciences - 2017" Grant DFNP-17-22/24.07.2017), coordinator: Assist. Prof. Dr Denitsa Mitkova and scientific consultant Assoc. Prof. Dr Victoria Vitkova
Bilateral Research Project /ISSP – BAS and Wallonie Bruxelles International – Belgium/: "Etude des propriétés mécaniques par holographie digitale", coordinator
Assoc. Prof. Dr. Victoria Vitkova

INTERNATIONAL COLLABORATION:

BELGIUM: Dr Christophe Minetti, Université libre de Bruxelles
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)

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

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

USA: Assoc. Prof. Petia Vlahovska, Department of Engineering Sciences and Applied Mathematics, Northwestern University

TEACHING ACTIVITIES:
Ph.D. student Denitsa Mitkova Brankova – Supervisor Assoc. Prof. V. Vitkova;
Thesis defense on May 16, 2018

DEPARTMENT SOFT MATTER PHYSICS

LABORATORY

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RESEARCH SCIENTISTS: **3**
EMERITUS MEMBERS: **1**

Assoc. Prof. Dr. Angelina K. Stoyanova-Ivanova; Assist. Prof. Lidia T. Popova; Assist. Peter A. Lilov; Chem. Eng. Maria Dencheva-Zarkova; Chem. Todor E. Vlakhov; Technol. Vasil L. Stanoev
Part-time members: Physicist, Dr. Stanimira D. Terzieva; Chem. Eng. PhD Ivana Ilievska; Techn. Fellow Alexander Y. Vasev; Techn. Fellow Violeta P. Petrova

Emeritus member: Academician Alexander G. Petrov

RESEARCH ACTIVITIES:

In 2018, science activity of "Biomolecular layers" laboratory compraised further investigations on electrical and electro-optical properties of various nanocomposites containing liquid crystals or superconductive ceramics by employing various methods as: electro-optical, impedance spectroscopy etc. The research group within the Laboratory “BML” continued ongoing research on multifunctional materials and materials for medicine.

Flexible and free standing composite membranes based on polyethylene oxide (PEO) and the nematic liquid crystal (LC) E8 are studied for use as novel composite electrolytes for rechargeable metal ions batteries. The effect of the LC concentration on the structural modifications of PEO/E8 LC composites was investigated by FTIR spectroscopy, X-ray photoelectron spectroscopy (XPS), micro-Raman and differential scanning calorimetry (DSC) and electrochemical impedance spectroscopy in the frequency range of 0.1Hz – 2MHz. With respect to pure PEO, 30 wt% LC doped composite membrane displayed conductivity values of two orders of magnitude higher than undoped membranes.

Stable three-component photoresponsive nanocomposite was prepared from photo-insensitive nanofilled nematic by inclusion of 3 wt.% azobenzene-containing photoactive mesogen 4-(4_-ethoxyphenylazo)phenyl hexanoate (EPH). The host nanofilled nematic was produced from the room-temperature nematic liquid crystal 4-n-heptyl cyanobiphenyl (7CB) and 3 wt.% filler of Aerosil 300 hydrophilic silica nanospheres of size 7 nm. Apparent effect of stimulation with a relatively weak continuous illumination by UV light (375 nm wavelength) takes place for both the alternating-current electric field-dependent optical transmittance and the electro-optic amplitude-frequency modulation by thin films (25μm thick) of the EPH/aerosil/7CB nanocomposite. The light-stimulated electro-optics of EPH-doped aerosil/7CB films and the corresponding reversible light control are achieved through trans-cis-trans photoisomerization of the photoactive agent EPH. As such, the initial electro-optical response of the studied photoactive nanocomposites is recovered with continuous blue-light

illumination. The examined EPH/aerosil/7CB nanocomposites exhibit photo-controllable electro-optical response that is of practical interest.

We examined the conductivity of BSCCO and YBCO ceramics by impedance spectroscopy in order to obtain initial qualitative data about their electrochemical characteristics and behavior exposed to various electrolyte solutions: 7M KOH, the electrolyte used in Ni-Zn cells, an alkaline phosphate (AF) - electrolyte containing KOH and Na3PO4.12H2O, and a proprietary PSPAA electrolyte. This stydy aimed at evaluation of their potential application as a conductive additive in Ni-Zn batteries. An equivalent circuit model of corresponding electrochemical cell was proposed and its parameters were obtained through curve fitting. We found that BSCO 2201 and BSCCO 2212's behavior strongly depends on electrolyte composition. Results suggest that among the examined ceramics BSCO 2201 is the best candidate as a conductive additive for the zinc anode in Ni-Zn batteries.

AWARDS:

Awarding of Academician A. G. Petrov State prize: medal "Saints Cyril and Methodius" - a necklace of merit in the field of education and natural sciences - 10 May 2018 г.

PUBLICATIONS:

1. Georgi B. Hadjichristov, Yordan G. Marinov, Alexander G. Petrov, Subbarao Krishna Prasad, "Light-stimulated electro-optics by azo-doped aerosil/7CB nanocomposites", Opto-Electronics Review 26 (2018) 172–182, ISSN: 1230-3402, doi.org/10.1016/j.opelre.2018.04.001, IF= 1.449

2. T. Vlakhov, Y. Marinov, G. Hadjichristov, A.G. Petrov, "Electrical Impedance Spectroscopy of Graphen-E7 Liquid-Crystal Nanocomposite", CHEMISTRY: BULGARIAN JOURNAL OF SCIENCE EDUCATION, ISSN 0861-9255 27 Number 5, 2018, 648-657(2018)

3. H.K. Koduru, Y.G. Marinov, G.B. Hadjichristov, A.G. Petrov, N. Godbert, N. Scaramuzza, "Polyethylene oxide (PEO) – Liquid crystal (E8) composite electrolyte membranes: Microstructural, electrical conductivity and dielectric studies", Journal of Non-Crystalline Solids 499 (2018) 107–116, IF=2.488

4. H. K. Koduru, F. Scarpelli, Y. G. Marinov, G. B. Hadjichristov, P. M. Rafailov, I. K. Miloushev, A. G. Petrov, N. Godbert, L. Bruno, N. Scaramuzza, Characterization of PEO/PVP/GO nanocomposite solid polymer electrolyte membranes: microstructural, thermo-mechanical, and conductivity properties, Ionics (2018) 24: 3459- 3473. https://doi.org/10.1007/s11581-018-2484-8, pp 1–15, https://doi.org/10.1007/s11581-018-2484-8, ISSN 1862-0760, IF=2.347

5. Alexander Ayriyan, Edik Ayryan, Alexandre Egorov, Maria Dencheva-Zarkova, Georgi Hadjichristov, Yordan Marinov, Igor Maslyanitsyn, Alexander Petrov, Lidia Popova, Vladimir Shigorin, Alfredo Strigazzi, and Sofia Torgova, Modeling Static Electric Field Effect on Nematic Liquid Crystal Director Orientation in Side-Electrode Cell , EPJ Web of Conferences 173, 03002 (2018) eISSN: 2100-014X, https://doi.org/10.1051/epjconf/201817303002

6. Mariya Aleksandrova, Georgi Dobrikov, Georgi Kolev, Yordan Marinov, Todor Vlakhov and Krassimir Denishev, Flexible and Lead-Free Barium Strontium Titanate Based Generators, 978-1-5386-5731-7/18/$31.00 ©2018 IEEE 1 2018 41st International Spring Seminar on Electronics Technology (ISSE)

7. Georgi B. Hadjichristov, Marin P. Marinov and Yordan G. Marinov, Journal of Physics and Technology, Volume 1 (2017), Number 2, pp. 80-84 ISSN 2535-0536

8. Lidia Popova, Stefan Todorov, Water memory displayed by the contact angle distribution of evaporating drops, Proceedings 10th Anniversary Seminar of Ecology with international participation, издат. ФАРАГО, pp. 184-187 (2018).
ISBN: 979-853-476-132-4

9. Lidia Popova, Stefan Todorov, Effect of water filtration on CAE distribution of a sample sessile drop, Compt. rend. Acad. Bulg. Sci., Vol. 71, No5, pp. 606-612 (2018).
DOI: 10.7546/CRABS.2018.05.03

10. A. K.Stoyanova-Ivanova, S. D. Terzieva, S. I. Georgieva, B. S. Blagoev, D. G. Kovacheva, A. Zaleski, V. Mikli, "Superconductivity and Magnetic Studies of Bulk Y123/ BaCuO2 Composite", Romanian Journal of Physics,Volume 63, Number 1-2, (pp. 1-15), (2018) ISSN 1221-146X,
http://www.nipne.ro/rjp/, IF 1.758

11. P. A. Lilov, A. Y. Vasev, A. Stoyanova ,Y. G. Marinov, A. K. Stoyanova-Ivanova, "Electrochemical impedance study of HTSC ceramics YBCO and BSCCO in presence of electrolyte", Bulgarian Chemical Communications, Volume 50, Special Issue A, 153-157, (2018) ISSN: 0342 – 1130, http://bcc.bas.bg/ , IF 0.238

12. I. Ilievska, V. Petrov, V. Mihailov, S. Karatodorov, L. Andreeva, A. Zaleski, V. Mikli, M. Gueorgieva, V. Petrova, A. Stoyanova-ivanova, "Elemental composition and structure characteristics of as-received tritanium orthodontic archwire", IOP Conf. Series: Journal of Physics: Conf. Series, Volume 992, 20th International Summer School on Vacuum, Electron and Ion Technologies IOP Publishing (2018), 012036
doi: 10.1088/1742-6596/992/1/012036.,
http://iopscience.iop.org/article/10.1088/1742-6596/992/1/012036

13. V. Ivanova, Y. Trifonova, V. Lilova, V. Mikli, A. Stoyanova-Ivanova, "Srtuctural investigation of tellurium based thin films", Journal of Chemical Technology and Metallurgy, Vol. 53 (4), pp. 749-754, (2018), ISSN 1314-3859,
http://dl.uctm.edu/journal/node/j2018-4/17_18-122_p_749-754.pdf

14. Stela Georgieva, Violeta Petrova, Angelina Stoyanova-Ivanova, "Introducing engineering chemistry students into the workplace: a qualitative study among general scientific and business companies in Bulgaria", Science, Engineering & Education, 1, (2), 123-131, 2017

15. A. Vasev, P. Lilov, G. Ivanova, Y. Marinov, A. Stoyanova, V. Mikli, A. Stoyanova-Ivanova, "Electrochemical impedance study of BSCCO (2212) cuprate ceramic additive to the zinc electrode in Ni-Zn batteries", Chemistry: Bulgarian journal of science education, Vol. 27 (6), pp. 876-886, (2018)

16. Rozina Yordanova, Valeri Petrov, Svetla Yankova, Angelina Stoyanova – Ivanova "Investigation of the chemical composition and mechanical characteristics of orthodontic archwires depending on the duration of their use in orthodontics treatment", New trends in fatigue and fracture - NT2F18, Lisbon – Portugal, 2018

17. A. Stoyanova-Ivanova, A. Vasev, P. Lilov, G. Ivanova, Y. Marinov, A. Stoyanova, V. Mikli. Electrochemical impedance study of BSCCO (2212) cuprate ceramic additive to the zinc electrode in Ni-Zn batteries. Chemistry: Bulgarian journal of science education, 27, 6, 876-886, 2018, ISSN: Print ISSN: 0861-9255 Online-ISSN: 1313-8235, http://bcc.bas.bg/
IF 0.238

PATENTS:

Reg. No BG 66730B1 / 28.09.2018

„Active zinc electrode mass composition for alkaline rechargeable batteries"

Patent Applicants: ISSP & IEES-BAS
Contact person: Angelina K. Stoyanova-Ivanova.

ONGOING RESEARCH PROJECTS:
1. Project financed by the Ministry of Education and Science, National Science Fund of Bulgaria DFNI-TO2/18: “Nanostructured liquid crystals for tunable photonic devices” (2015-2018)
2. Projects, additionally financed by contracts with Ministry of Education and Science: Indo-Bulgarian intergovernmental programme, contract DNTS/ India 1/04, NSF, “Investigations of Photostimulation Effects in Nano-Structured Liquid Crystals”.
3. Bilateral Scientific Exchange, Estonia 2015-2017: ISSP and Tallin University of Technology - Estonia, Prof. Valdek Mikli: „Synthesis and structural investigations of nanomaterials“

INTERNATIONAL COLLABORATION:
2018: University of Calabria – Italy, prof. Nicola Scaramuzza
2018: Centre for Nano and Soft Matter Sciences (CeNS) – India, Prof. Krishna Prasad
2018-2020: ISSP and Tallin University of Technology - Estonia, Prof. Valdek Mikli

TEACHING ACTIVITIES:
Assoc. Prof. Dr. Angelina Koleva Stoyanova-Ivanova is a PhD supervisor of Ivana Ilievska, appointed in ISSP-BAS on 01/09/2015г.
Assoc. Prof. Dr. Angelina Koleva Stoyanova-Ivanova – The Erasmus Programme lecture courses: 15 hours.

THESISIS:
Successfully defended PhD thesis entitled "Research of materials for orthodontic applications" by Ms. Ivana Ilievska, supervisor Assoc. Prof. Dr. Angelina K. Stoyanova-Ivanova.

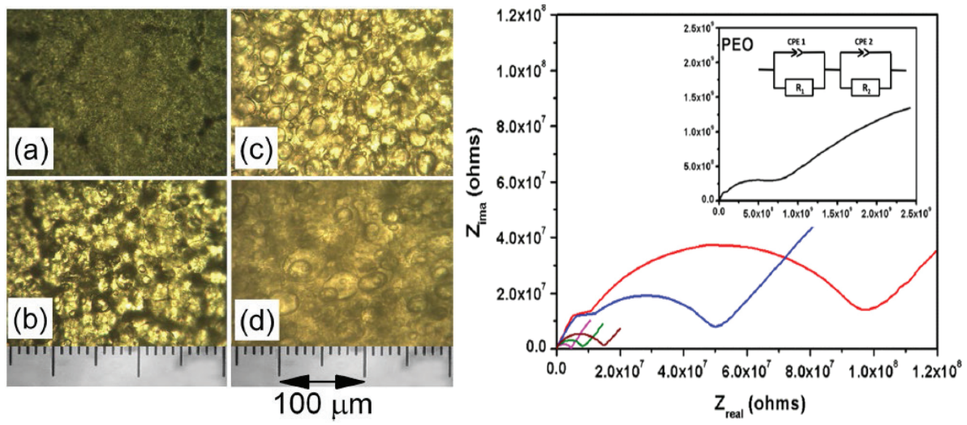

Fig. 1. Optical microscope images and Nyquist plots for PEO/E8-Liq.Cryst. composites of different weight percentages of E8, at room temperature; (a) pure PEO, (b) PEO (90 wt.%)/E8 (10 wt.%), (c) PEO (70 wt.%)/E8 (30 wt.%) and (d) PEO (50 wt.%)/E8 (50 wt.%). With respect to pure PEO, 30 wt% LC doped composite membrane displayed conductivity values of two orders of magnitude higher than undoped membranes.

DEPARTMENT PHYSICAL OPTICS AND OPTICAL METHODS

LABORATORY

OPTICS AND SPECTROSCOPY

HEAD: **Assoc. Prof. T. Tenev, Ph.D.**
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TOTAL STAFF: **18**
RESEARCH SCIENTISTS: **13**
ASSOC. MEMBERS: ***4***

Prof. K. Panayotov D.Sc.; Assoc. Prof. L. Tsonev, Ph.D.; Assoc. Prof. A. Andreev, Ph.D.; Assoc. Prof. S. Tonchev, Ph.D.; Assoc. Prof. G. Hadjihristov, Ph.D.; Assoc Prof. K. Antonova, Ph.D.; Assoc. Prof. B. Zafirova, Ph.D.; Assoc. Prof. M. Kuneva, Ph.D; Assoct. Prof. B. Katranchev, Ph.D.; Assoc. Prof. E. Karakoleva, Ph.D.; Assist. Prof. H. Naradikian Ph.D.; Assist. Prof. I. Milushev, Ph.D.; Physicist E. Stoyanova; Physicist M. Molerova; Eng. 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.;

RESEARCH ACTIVITIES:

The ongoing research on optical, electrical, dielectric and electro-optical properties of multifunctional & smart materials, as well as various nanocomposites containing liquid crystals and nanoparticles, was continued. They were investigated by employing various methods as: UV-VIS and Fourier-Transformed IR (FTIR) absorption spectroscopy, diffuse reflectance spectroscopy, Raman spectroscopy, X-ray photoelectron spectroscopy (XPS), electrical complex impedance spectroscopy, dielectric spectroscopy, as well as by other optical, electrical, electro-optical and thermo-optical measurements.

Poly(ethylene-oxide)(PEO)/polyvinylpyrrolidone(PVP) blended nanocomposite polymers, incorporating graphene oxide (GO) nanosheets and embedded with $NaIO_4$ salt, were prepared using solution casting technique. The as-prepared nanocomposite electrolyte membranes were characterized by SEM, TEM, XRD, and Raman vibrational spectroscopic techniques to confirm the dispersion of GO nanosheets and to understand the synergistic properties of GO/polymer interactions as a function of GO nanosheets concentration. GO fillers incorporated electrolyte membranes demonstrated distinctive surface morphology composed of circular-shaped protuberances of different dimensions. The decrease of Raman intensity ratio (ID/IG) and in-plane crystallite size of the nanocomposites suggested the good dispersion and confinement of the GO nanosheets. The optical properties of blend electrolyte films were studied as a function of GO filler concentration using optical absorption and diffuse reflectance spectra. In reference to PEO/PVP/$NaIO_4$, the resultant PEO/PVP/$NaIO_4$/GO (0.4% in weight) electrolyte membrane demonstrated both an increase in tensile strength of ca. 42% and in Young’s modulus of ca. 40%, improvements coupled with a maximum fractured elongation of 3%. Through impedance spectroscopy analysis, the role of the GO nanosheets onto the room temperature conductivity properties of the prepared electrolyte membranes has been probed.

Flexible and free standing composite membranes based on PEO and the nematic liquid crystal (NLC) E8 are studied for use as novel composite electrolytes for rechargeable metal ions batteries. The effect of the NLC concentration on the structural modifications of PEO/E8NLC composites was investigated by FTIR spectroscopy, X-ray diffraction (XRD), XPS, micro-Raman, differential scanning calorimetry (DSC), impedance & dielectric spectroscopy in the frequency range of 0.1 Hz – 2 MHz. With respect to pure PEO, 30 wt% NLC E8 doped composite membrane displayed conductivity values of two orders of magnitude higher than undoped membranes.

Stable three-component photoresponsive nanocomposites were prepared from photo-insensitive nanofilled nematic by inclusion of 3 wt.% azobenzene-containing photoactive mesogen 4-(4-ethoxyphenylazo)phenyl hexanoate (EPH). The host nanofilled nematic was produced from the room-temperature nematic liquid crystal 4-n-heptyl cyanobiphenyl (7CB) and 3 wt.% filler of Aerosil 300 hydrophilic silica nanospheres of size 7 nm. Apparent effect of stimulation with a relatively weak continuous illumination by UV light (375 nm wavelength) takes place for both the alternating-current electric field-dependent optical transmittance and the electro-optic amplitude-frequency modulation by thin films (25μm thick) of the EPH/aerosil/7CB nanocomposite. The light-stimulated electro-optics of EPH-doped aerosil/7CB films and the corresponding reversible light control are achieved through trans-cis-trans photoisomerization of the photoactive agent EPH. As such, the initial electro-optical response of the studied photoactive nanocomposites is recovered with continuous blue-light illumination. The examined EPH/aerosil/7CB nanocomposites exhibit photo-controllable electro-optical response that is of practical interest.

The group of ”Optics and spectroscopy of liquid crystals” in collaboration with researchers on phospholipids, as well as with researchers on electro magnet wave sensors, worked over 3 tasks, as follows:

 Nanocomposites of the hydrogen-bonded dimeric liquid crystal heptyloxybenzoic acid (7OBA) with admixture of graphene flakes (GFs) are investigated with microtexture polarization analysis for new effects in their electrooptical behavior and are characterized with Raman spectroscopy. With optical and electro-optical microtexture analysis we find a sequence of phase transitions and new phases in the nanocomposite which are not characteristic of pristine 7OBA: N^* (chiral nematic) and C*(ferroelectric smectic C) although 7OBA itself is achiral. However, the most intriguing result is the detection below C* of a triclinic smectic C_G phase, which is chiral, biaxial, and exhibits bulk ferroelectricity. Using very slow cooling and electro-optical analysis we were able to identify two detached C_G components: C_{Gcl}, and C_{Gln} appearing due to different combinations of the clinic tilt of the director with respect to the layer’s normal and leaning of the molecular tilt plane around the director axis. We present molecular models of the C_{Gcl} and C_{Gln} sub-states explaining them as syn-clinic anti-leaning and syn-clinic syn-leaning configuration, respectively. Results from Raman spectroscopy of the LC phases of the 7OBA/GFs nanocomposite support the presented models. SEM images from the nanocomposite's cross-section in the solid state demonstrate that the graphene in form of distinct nanoparticles are well dispersed in the bulk of the nanocomposite thus indicating the bulk character of the new low symmetry LC phases. We detect a thermally induced transition between the two C_G components which is second-order. Using contacting C_{Gcl} and C_{Gln} microtextures, separated by a horizontal temperature gradient, we examined their response to lateral *dc* and low-frequency *ac* electric field, demonstrating ferroelectric polarization with polar vector pointing out of the smectic layers planes, thus confirming the triclinic symmetry of the C_G phase.

Addition of cholesterol (Chol) to 1-stearoyl-2-oleoyl-sn-glycerol-3-phosphocholine (SOPC) acts upon the polar head, the polar-apolar interface and the hydrophobic region. We have detected the Infrared and Raman bands, which most sensitively reflect the interactions of

cholesterol with the phosphate and choline groups of the hydrophilic head, the carbonyl ester groups of the interface and the conformational state of the hydrophobic chains. The intra-chain ordering by Chol is more pronounced with the gauche/trans population ratio showing a stable decrease trend on rising Chol content. However, the influence of Chol on the inter-chain ordering is weaker. Upon insertion into the bilayer membrane Chol is actively involved in H-bonding formation at the carbonyl sites and possibly replaces water in some H-bonds upon increasing its concentration to 30 mol%. The H-bonding process of water to the C=O groups, however, remains also active and is facilitated by the rise in Chol content. Our spectroscopic results indicated that the carbonyl group in only one of both SOPC hydrophobic tail chains is involved in the H-bonding, which we identified as the sn-2 chain. We found that the higher wave number band expose the free carbonyl group, while the lower one reflects the ester conformers included in H-bonds. Such a band component diferentiation allows the generation and multiplication of hydrogen bonding to be quantified. As a result we estimated the relative population of H bonding to the carbonyl C=O groups.

The surface photo charge effect (SPCE) was applied for the first time at structure and phase transitions study of hydrogen bonded in dimer liquid crystals (HBDLCs). Due to the high sensitivity of this method, besides first-order phase transitions, characteristic for the p,n-octyloxibenzoic acids (8OBA), an intermediate order transition was definitely detected within the nematic range. We state that the SPCE, arises at the solid–HBDLCs interface due to the double electrical layer (DEL), which is invariably concomitant with solid surface–liquid interfaces. We indicated that the changes of the characteristics of the DEL, under incident optical irradiation, induces the surface charge rearrangement and results an alternating potential difference. We proposed a mechanism of induction of the SPCE at the interface of solid surface–anisotropic liquids. We also indicated that this mechanism can be adapted for solid surface–isotropic liquid interface, including colloids (milk) and fog (aerosols)–condensed medium.

The spectrophotometric laboratory carried out a large number of investigations on different type of samples. Infrared spectra of thin films of electrolytic polymers; solid and liquid organic materials; thin layers of SiOx irradiated by electrons; powders taken from archaeological artifacts were measured. The physical-chemical properties or the elemental analysis of the specimens were under discussion.

Mutual experiments to study the electrooptical and dielectric properties of thermotropic liquid crystals composed of “banana”-shape molecules were done in the University Jules Verne, Amiens, France. Opposite signs of their dielectric anisotropy were obtained with minimal changes in the molecule structure. The investigations give a contribution to the knowledge of the complicated twist-bend phase in nematic liquid crystals.

We have introduced a spin-flip model for a broad-area vertical-cavity surface-emitting laser (VCSEL) with a saturable absorber. We have demonstrated simultaneous existence of orthogonally linearly polarized and elliptically polarized cavity solitons. We showed that polarization degree of freedom leads to a period-doubling route to spatially localized chaos of the elliptically polarized cavity solitons.

We considered the Brusselator reaction–diffusion model, which is a paradigm for the understanding of dissipative structures in systems out of equilibrium. In showed the formation of stationary localized structures in this model. By using numerical continuation methods in two spatial dimensions, we have established a bifurcation diagram showing the emergence of localized spots and characterized the transition from a single spot to an extended pattern in the form of squares. We incorporated delayed feedback control and showed that it induces a spontaneous motion of both localized and periodic dissipative structures. We characterize this motion by estimating the threshold and the velocity of the moving dissipative structures.

We proposed a tunable 1550 nm VCSEL design with enclosed intra-cavity liquid-crystal (LC) cell. The laser is electrically pumped and the wavelength selectivity is obtained by varying LC's refractive index through electro-optical tuning of the LC director. By performing one-dimensional transfer-matrix optical calculations, supplemented with a fully-vectorial three-dimensional self-consistent modeling of thermal, electrical and optical phenomena, we optimized the design leading to 68.5 nm tuning range.

We show that a change to the quality factor of a laser diode cavity affects the electrical properties of the device. The mechanism is demonstrated experimentally and numerically via a 980-nm InGaAs/GaAs oxide-aperture VCSEL enabling the detection of a substance that rests on or is in close proximity to the exposed laser top mirror in the form of a monolithic subwavelength high-index contrast grating without the need for a photodetector.

We have performed experimental and theoretical studies on the noise-induced attractor hopping between dynamical states in a single transverse mode VCSEL subject to parallel optical injection. We reported an experimental map identifying, in the injected power-frequency detuning plane, regions where attractor hopping between two, or even three, different states occur. We identified multistability regions that are characterized by heavy-tailed residence time distributions and attractor hopping between chaotic states with different polarization. Simulation results showed that frequency detuning variations and spontaneous emission noise play a role in causing switching between attractors.

Determining optimal modes of the technological process for realizing optical thin films with the necessary characteristics (refractive index, density, strength, adhesion, etc.) with new optical materials using ion assisted electron beam evaporation with Symphony 9 vacuum deposition system, purchased under Operational Program "Development of Competitiveness of the Bulgarian Economy", were continued. Layers of Al_2O_3 and MgO (200, 400, 600 nm) were deposited on corundum matted wafers (Al_2O_3) by ion-assisted electron beam evaporation under various technological conditions ordered by Sensata Technologies for a high-temperature sensor. Layers were analyzed and at high temperature annealing (above 1300 °C), the materials in the layers at these thicknesses diffuse and spinel is formed.

Framework agreements for cooperation and joint activities with companies from the optical industry (Optix JSC, Cimcoop Holding Ltd., Milkotronik Ltd., Opteco & Partners Ltd.) were signed.

The theoretical expressions obtained by locating local coordinate systems at the photonic crystal fibers (PCFs) and the Galerkin method for the propagation constants and the electric and magnetic fields of the modes along

- the Bragg PCFs consisting of concentric annular dielectric layers with different refractive indices for using them as gas sensors and
- the PCFs consisting of a host medium with holes which surface is covered by concentric layers with different refractive indices in order to enhance the sensitivity of the fibers when using them as chemical sensors

are reduced to suitability for coding and the obtained expressions are incorporated into a created code.

A part of the results for PCFs with material inclusions within the holes are presented to the 10th Jubilee International Conference of the Balkan Physical Union, 26-30 August 2018, Sofia, Bulgaria, in the form of oral presentation, together with the poster presentation.

The most important waveguide structures in proton-exchanged lithium niobate for different modulators used in modern integrated and fiber optics devices (navigation equipment, temperature sensors, electric field sensors, etc.) are described. An emphasis is put on optical gyroscopes and sensing elements based on integrated optical phase and amplitude modulators.

A comparative analysis has been performed on the results obtained by using different methods for phase composition and optical quality characterization of a series of proton-exchanged waveguide layers in lithium niobate. The waveguides were obtained at different technology modifications allowing varied phase composition and thickness of phase sublayers. The methods used include mode spectroscopy, vibration spectroscopy (infrared absorption and reflection, Raman and microraman), XPS, mechanical stress measurements.

The approach used allows evaluation of the technological parameters influence on the phase formation mechanism. The combination of methods for characterization suggested contribute to the selection of technological conditions suitable for better control of proton concentration and obtaining of desired phase composition, necessary for waveguide devices with improved performance and for further development of the proton-exchanged technology for their production as well.

A reference book was published presenting data on the places of birth and the education of Bulgarian professors in the Sofia University who have studied and/or received a doctoral degree abroad, for the period 1888 – 1938.

The range of archaeological sites that are difficult to date in classical ways and that offer the opportunity for optically stimulated luminescence dating (OSL) was significantly expanded.

The megalithic correspondence between the Balkans and the Caucasus was followed, which testifies about cultural interactions between these regions from prehistory to antiquity. The fate of megalithic sites in Bulgaria after the adoption of Christianity was followed.

AWARDS:

Prof. Krassimir Panayotov Panayotov – Pythagor Award for Bulgarian Scientist abroad for Seminal Contribution to Science (2018)

PUBLICATIONS:

1. **Christova K.**, Maslyanitsyn I. A., **Miloushev I.**, Shigorin V. D., **Tenev T.**, Voronov V. Second Harmonic Generation in Thin Zinc Sulfide Films. Physics of Wave Phenomena, 26, 1, 2018, 9-15.
2. **Genova, J.**, **Petrov, M.**, **Bivas, I.**, **Rafailov, P.**, **Naradikian, H.**, **Katranchev, B.** Fourier-transform Infrared and Raman characterization of bilayer membranes of the phospholipid SOPC and its mixtures with cholesterol. Coll. Surf. A, 557, 2018, 85-93.
3. **Hadjichristov,G B**, **Marinov, Y.G**, **Petrov, A. G.**, Prasad, S. K. Article Light-stimulated electro-optics by azo-doped aerosil/7CB nanocomposites. Opto-Electronics Review, 26, 2, 2018, 172-182.
4. **Hristova-Vasileva, T.**, Petrik, P., **Nesheva, D.**, Fogarassy, Zs., Lábár, J., **Kaschieva, S.**, Dmitriev, S. N., **Antonova, K.** Influence of 20 MeV electron irradiation on the optical properties and phase composition of SiOx thin films. Journal of Applied Physics, 123, 2018, 3-8.
5. **Ivanov O.**, **Petrov M.**, **Naradikian H.**, Perez-Diaz J. L. Phase transition detection by surface photo charge effect in liquid crystals. Phase Transitions, 91, 5, 2018, 1431644
6. **Ivanov O.**, Ralev Y., **Todorov P.**, Popov I., Angelov K., Perez-Diaz J. L., **Kuneva M.** Laboratory system for artificial fog generation with controlled number and size distribution of droplets. Bulgarian Chemical Communications, 50, 1, 2018, 89-93
7. **Ivanov O.**, Ralev Y., **Todorov P.**, Popov I., Perez-Diaz J. L., **Kuneva M.** System for generation of fogs with controlled impurities. Bulgarian Chemical Communications, 50, 1, 2018, 94-99.
8. **M Petrov**, **P Rafailov**, **H Naradikian**, **B Katranchev**, N Todorov. Graphene-induced bi-tilted two component smektic CG phase with bulk ferroelectricity in hydrogen-bonded dimer liquid crystals. Journal of Molecular Liquids, 272, 2018, 97-105.

9. **Panajotov K.**, Tlidi M. Localized chaos of elliptically polarized cavity solitons in broad-area VCSEL with a saturable absorber. Optics Letters, 43, 22, 2018, 5663-5666.
10. **Tsvetkova T.** Townsend P.D. Imperfections – the basis of life and technology. The world of physics, XXXI, 3, 2018, 245-253
11. **Tsvetkova T.** Townsend P.D. The dilemmas of scientific assessment. The world of physics, XXXI, 1, 2018, 36-43
12. **Tsvetkova T.** Ion beams for nanoscale optical data storage. Ion Beam Applications, IntechOpen, 2018, 23, 89-111
13. **Vitkova, V.**, **Mitkova, D.**, **Antonova, K.**, Popkirov, G., Dimova, R. Sucrose solutions alter the electric capacitance and dielectric permittivity of lipid bilayers. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 557, 2018, 51-57.
14. **Vlakhov, T.**, **Marinov, Y.G.**, **Hadjichristov, G.**, **Petrov, A. G.** ELECTRICAL IMPEDANCE SPECTROSCOPY OF GRAPHENE-E7 LIQUID-CRYSTAL NANOCOMPOSITE. Chemistry: Bulgarian Journal of Science Education, 27, 5, 2018, 648-657.
15. Alexander Ayriyan, Edik Ayryan, Alexandre Egorov, **Maria Dencheva-Zarkova**, **Hadjichristov, G. B.**, **Marinov, Y. G.**, Igor Maslyanitsyn, **Petrov, A. G.**, **Lidia Popova**, Vladimir Shigorin, Alfredo Strigazzi, Sofia Torgova. Modeling Static Electric Field Effect on Nematic Liquid Crystal Director Orientation in Side-Electrode Cell. EPJ Web of Conferences, 173, 2018, DOI:https://doi.org/10.1051/epjconf/201817303002
16. Coarer F. D., Quirce A., Valle A., Pesquera L., Rodríguez M. A., **Panajotov K.**, Sciamanna M. Attractor hopping between polarization dynamical states in a vertical-cavity surface-emitting laser subject to parallel optical injection. Physical Rewiew E, 97, 2018, 032201.
17. Fabian, M, Dulgheru, N, **Antonova, K**, **Szekeres, A**, Gartner, M. Investigation of the Atomic Structure of Ge-Sb-Se Chalcogenide Glasses. Advances in Condensed Matter Physics, 2018, ID 7158079-ID 7158090.
18. Frasunkiewicz L., Czyszanowski T., Thienpont H., **Panajotov K.** Electrically tunable VCSEL with intra-cavity liquid crystal: Design, optimization, and analysis of polarization- and mode-stability. Optics Communications, 427, 2018, 271-277.
19. H. K. Koduru, **Y. G. Marinov**, F. Scarpelli, **G. B. Hadjichristov**, **A. G. Petrov**, N. Godbert, N. Scaramuzza. Polyethylene oxide (PEO) - Liquid crystal (E8) composite electrolyte membranes: microstructural, electrical conductivity and dielectric studies. Journal of Non-Crystalline Solids, 499, 2018, 107-116.
20. Koduru, H. K., Scarpelli, F., **Marinov, Y. G.**, **Hadjichristov, G. B.**, **Rafailov, P. M.**, **Miloushev, I. K.**, **Petrov, A. G.**, Godbert, N., Bruno, L., Scaramuzza, N. Characterization of PEO/PVP/GO nanocomposite solid polymer electrolyte membranes: microstructural, thermo-mechanical, and conductivity properties. Ionics, 2018.
21. Kostet B., Tlidi M., Tabbert F., Frohoff-Hulsmann T., Gurevich S. V., Averlant E., Rojas R., Sonnino G., **Panajotov K.**. Stationary localized structures and the effect of the delayed feedback in the Brusselator model. Phil. Trans. R. Soc. A, 376, 2135, 2018, 20170385.
22. Marciniak M., Piskorski L., Gebski M., Dems M., Wasiak M., **Panajotov K.**, Lott J.A., Czyszanowski T. The Vertical-Cavity Surface-Emitting Laser as a Sensing Device. Journal of Lightwave Technology, 36, 16, 2018, 3185-3192.
23. Nagareddy, V.K., **Sandulov, M.**, **Tsvetkova, T.**, Ott, A., Ferrari, A.C., Craciun, M.F., Wright, C.D. The effect of nitrogen implantation on the resistive switching properties of diamond-like carbon films for non-volatile memory applications. Diamond and Related Materials, 87, 2018, 90-98.
24. Tlidi M., Clerc M. G., **Panajotov K.** Dissipative structures in matter out of equilibrium: from chemistry, photonics and biology, the legacy of Ilya Prigogine (part 1). Phil. Trans. R. Soc. A, 376, 2124, 2018, 20180114.
25. Tlidi M., Clerc G., **Panajotov K.** Dissipative structures in matter out of equilibrium: from chemistry, photonics and biology, the legacy of Ilya Prigogine (part 2). Phil. Trans. R. Soc. A, 376, 2135, 2018, 20180276.

CITATIONS FOR 2018: 176

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", 2018/20, budjet subsidy from the Bulgarian Academy of Sciences (BAS)

Financed by the Bulgarian Ministry of Education and Science:

NSF support for periodicals 2018-2019, **The World of Physics**) НП06/24 (Assoc. Prof. M. Kuneva - team member).

Participation in three-year (2016-2018) project "Liquid crystal approach for model lipid membrane functions optimization by nanoparticles insertion" (FNI-DH08-2) head: Assoc. prof. J. Genova, ISSP-BAS (Assoc. Prof. B. Katranchev and Assoc. Prof. G. Hadjihristov – team members)

Participation in three-year (2016-2018) project "Mechanical and electrical properties of model lipid membranes in the presence of biologically active substances" (FNI-ДН08-7) head: Assoc. prof. V. Vitkova, ISSP-BAS (Assoc. Prof. K. Antonova – team member)

TEACHING ACTIVITIES:

Assoc. Prof. T. Tsvetkova – supervisor of PhD Theses of

1. M. Berova: "Nanosized optical recording of information in diamond-like carbon by focused ion implantation", May 2018, Sofia
2. M. Sandulov: "Applications of ion implantation for the purposes of a nanoscale electrical record of information in diamond-like carbon" May 2018, Sofia

Prof. K. Panayotov D.Sc.; Supervisor of PhD Thesis of Ludovic Marigo-Lombart: "Vertical integration of an electro-absorption modulator onto a VCSEL for high-speed communications", Novembre 2018, Brussels.

Assoc. Prof. T. Tenev, Ph.D. Supervisor of MSc Thesis of Petar Levicharov, "Design and practical realization of neutral, dichroic and polarization beam splitting optical coatings" February 2018, Plovdiv

Assoc. Prof. M. Kuneva, Ph.D - 64 hours laboratory exercises in physics, bachelor program, Technical University, Sofia, summer term, 2018

DEPARTMENT - LASER, ATOMIC, MOLECULAR AND PLASMA PHYSICS

LABORATORY

ATOMIC SPECTROSCOPY

HEAD: **Assoc. Prof. Valentin Mihailov, Ph.D.**
tel: 979 5740; e-mail: valentin@issp.bas.bg

TOTAL STAFF:**9**
RESEARCH SCIENTISTS: **6**
ASSOC. MEMBERS: **1**

Assoc. Prof. Emilia Dimova, Ph.D.; Assoc. Prof. Galina Malcheva, Ph.D.; Assoc. Prof. Boian Torosov, Ph.D.; Assist. Prof. Vasilka Steflekova, Ph.D.; Assist. Prof. Hristina Hristova, Ph.D.; Phys. Vani Tankova, Phys. Stefano Ognyanski

Associated members: Prof. Kiril **Blagoev,** D.Sc.;

RESEARCH ACTIVITIES:

Atomic spectroscopy laboratory has been working in the field of analytical atomic spectroscopy and archaeometry achieving information about the elemental composition of different archaeological objects. The rresearch on the development of hybrid plasma source combining laser ablation as a sample introduction source and hollow cathode discharge as a separate plasma source for additional excitation of the ablated sample atoms has been continued. In the area of quantum optics, we continued the work on composite pulses theory and the creation of broadband frequency conversion techniques.

We derived three classes of symmetric broadband composite pulse sequences, which we call twin pulses. The composite phases are given by analytic formulas (rational fractions of pi) valid for any number of constituent pulses. The transition probability is expressed by simple analytic formulas and the order of pulse area error compensation grows linearly with the number of pulses. Therefore, any desired compensation order can be produced by an appropriate composite sequence; in this sense, they are arbitrarily accurate. These composite pulses perform equally well as or better than previously published ones. Moreover, the current sequences are more flexible as they allow total pulse areas of arbitrary integer multiples of pi.

Also, we developed a method for high-fidelity coherent control which uses a sequence of detuning pulses, which are a generalization of composite pulses and can be used in physical systems where phase jumps are hard or impossible to implement. By using the detuning pulse areas as control parameters, and driving on an analogy with composite pulses, we report a great variety of detuning pulse sequences for broadband and narrow-band transition probability profiles.

Using quantum-optical analogies and in particular the method of composite pulses, the construction of an optical system for broadband rotation of linear polarization was studied theoretically and experimentally. This broadband polarization rotator was constructed using the combination of Frenelle rhombus and broadband composite half-wavelength plates.

The theoretical study on realizing the Jaynes-Cummings-Hubbard (JCH) one-dimensional model in a waveguide system is in the process of developing a program to simulate the effectiveness of such an analogue.

We continue to work on the construction of experimental apparatus and methodology for the manipulation of laser-cooled rubidium atoms. Several LabView programs were created for the control and detection of different atomic states. The experimental set-up and detection systems ware improved.

With Laser Induced Plasma Spectroscopy (LIBS) both qualitative and quantitative spectral analysis of archeological bronze artefacts from the Late Bronze Age and the Early Iron Age was made. The results of qualitative elemental analysis show elemental composition characteristic of bronze objects: the main elements are copper, tin and lead. Iron, nickel, zinc, aluminum and antimony were also found. The analyses showed increased antimony content, indicating that the antimony was deliberately added and not just from the ore. The amount of tin and lead is of interest as these two elements determine the mechanical properties of the alloy. With the help of calibration curves, a quantitative analysis was performed for these elements. Additional analyzes (including XRF) were made to determine the amount of antimony.

Spectral analyzes of fragments of ceramic pots from Early Chalcolith were carried out. The fragments are decorated with white strips. The purpose of the analyses is to determine the elemental composition of the objects and of the colored parts in order to understand the origin and composition of the dyes used for the decoration.

The influence of the ambient gas pressure in the range of 0.1-760 Torr on the spectral emission of the laser-induced plasma at is determined. The registered behavior indicates that decreasing ambient pressure results in a significant reduction in the emission of laser-induced plasma and in decreasing the duration of radiation.

The influence of cylindrical confinement on the emission spectrum of laser-induced plasma was investigated. The relationship between the diameter of the cylinder at fixed pressure and the emission from the laser-induced plasma is determined. The results show maximum intensity of the analytical lines at diameters from 6 mm to 8 mm in the pressure range 1-10 torr.

The optimal times for registration of the emission signal for elemental analysis under the conditions of combined plasma source - laser ablation with a hollow cathode at a cathode diameter of 6 mm and a pressure in the range (2-5 Torr) were determined. For this range of pressures, the time evolution of laser-induced plasma radiation was measured, and based on this, optimal time lag intervals were determined to perform elemental analyzes with enhanced analytical characteristics.

PUBLICATIONS:

1. Arbitrarily accurate twin composite pi-pulse sequences, B.T. Torosov, N.V.Vitanov, Physical Review A 97 (4), 043408 (2018).
2. Arbitrarily accurate variable rotations on the Bloch sphere by composite pulse sequences, B.T. Torosov, N.V.Vitanov, Physical Review A 99 (1), 013402 (2019).
3. Adiabatic control of surface plasmon-polaritons in a 3- layers graphene curved configuration, Wei Huang, Shi-Jun Liang, Elica Kyoseva, and Lay Kee Ang, Carbon 127, 187 (2018).
4. A new coupling mechanism between two graphene electron waveguides for ultrafast switching, Wei Huang, Shi-Jun Liang, Elica Kyoseva, and Lay Kee Ang, Semiconductor Science and Technology 33, 035014 (2018).
5. Complete achromatic and robustness electro-optic switch between two integrated optical waveguides,Wei Huang and Elica Kyoseva, Proc. SPIE 10456, Nanophotonics Australasia 2017, 1045654 (2018).
6. Experimental demonstration of efficient and robust second harmonic generation using the adiabatic temperature gradient method E Dimova, V Steflekova, S Karatodorov,

and E Kyoseva, , Journal of Physics: Conference Series 992 (1), 012007 (2018)
7. Microstructure of nanocrystalline sol gel ZnO thin films treated with infrared nanosecond pulse laser., Dzhurkov, V., Nesheva, D., Bineva, I., Terziyska, P., Šćepanović, M., Stambolova, I., Blaskov, V., Mihailov, V., Manolov, E., Popović, Z. V.. Nanoscience & Nanotechnology: Nanostructured materials applications and innovation transfer Volume 18, No 2, 2018
8. Elemental composition and structural characteristics of as-received TriTaniumTM orthodontic archwireicle: I Ilievska, V Petrov, V Mihailov, S Karatodorov, L Andreeva, A Zaleski, V Mikli, M Gueorgieva, V Petrova and A Stoyanova-Ivanova Journal of Physics: Conf. Series 992 (2018)
9. "Investigation of archaeological metal artefacts by laser induced breakdown spectroscopy (LIBS)",V. Tankova, G. Malcheva, K. Blagoev, L. Leshtakov, Journal of Physics: Conf. Series 992 (2018)
10. Self-induced optogalvanic effect in a segmented hollow cathode discharge, Steflekova, V, Zhechev, D. Journal of Physics: Conference Series (JPCS), 992, IOP Publishing, 2018,
11. "Investigation of the Emission Characteristics of a Hybrid Spectral Source: Laser Ablation Assisted Hollow Cathode Discharge" S. Karatodorov and V. Mihailov, American Institute of Physics Conference Proceedings, AIP Conference Proceedings 2075, 060006 (2019)
12. B.T. Torosov, N.V.Vitanov, Robust high-fidelity coherent control of two-state systems by detuning pulses, Physical Review A 99, 013424, 2019
13. A different optical composition for a broadband linear polarization rotator – Hristina Hristova, Andon Rangelov Stefano Ognyanski and Emiliya Dimova. Journal of Physics: Conference Series (JPCS) – (accepted)

PATENTS

Inventors: P. M. Pramatarov, M. S. Stefanova, Kudryavtsev, A. I.
Invention: " Method and ionization detector for analysis of impurities in gases"
Patent № 66623, Int. Cl. G 01 N 27/62 (2006.01)

ONGOING RESEARCH PROJECTS:

- Atomic and Plasma Physics (funded by the budget subsidy of BAS),
- Composite pulses in quantum engineering, Marie Curie reintegration grant (Horizon 2020 and COST),
- New plasma source for elemental spectral analysis of solid materials - laser ablation in hollow cathode discharge, joint project with MVL lab. (Program of BAS to support young scientists),
- Non-Hermitian Hamiltonian approach to quantum control (Program of BAS to support young scientists),
- Adiabatic control and quantum-optical analogues – new techniques (Program of BAS to support young scientists),
- Composite and adiabatic methods for control in quantum and optical technology. (National Science Fund).

INTERNATIONAL COLLABORATION:

- ✓ Faculty of Physics, University of Belgrade, Serbia,
- ✓ French National Centre for Scientific Research CNRS, Institut de physique.

LABORATORY

METAL VAPOUR LASERS

HEAD: **Assoc. Prof. Krassimir Temelkov, PhD**
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TOTAL STAFF: **18**
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. Ognian Sabotinov, PhD; Physicist Viktoria Atanasova, PhD; Assist. Krassimir Dimitrov; Assist. Danka Iordanova; Assist. Yu. I. Fedchenko; Physicist Ivan Kostadinov, Physicist Blagovela Blagoeva; Physicist Kaloyan Zlatanov

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

RESEARCH ACTIVITIES:

Experiments, in which glasses doped with Ag and Au nanoparticles were irradiated by femtosecond laser pulses, were carried out. We used Samples with varying concentrations of gold nanoparticles of 1, 5 and 10 % were used, while the silver ion samples were with 5 % concentration. The operating parameters of the laser radiation were varied in the following ranges: number of laser pulses – from 4.10^3 to 6.10^3; energy of laser pulses – from 20 to 60 μJ; wavelength of laser radiation – 266, 355, 532, 800 and 1064 nm. In the laboratories of INFLPR – National Institute for Laser, Plasma &Radiation Physics and CETAL - Center for Advanced Laser Technologies, analyses of some doped glass samples were done before and after heat treatment (annealing). The doped glass samples were with concentrations of 10% for silver and 1% for gold, respectively. The methods and techniques used to analyze the irradiated specimens were: terahertz spectroscopy to determine the coefficients of transition, refraction and reflection; LIPS to determine the elemental composition and the presence of silver and gold nanoparticles; XPS analysis.

Laser cleaning of metal samples of copper, brass and steel smudged with chlorine containing corrosive products was carried out, using the following laser sources: Q-switched Nd:YAG laser, oscillating at 1064 nm (laser pulse energy of 500 mJ) and 532 nm (laser pulse energy of 60 mJ) with laser pulse duration of 8 ns and pulse repetition frequency of 1 Hz; atomic CuBr vapour laser, oscillating at 510.6 nm with laser pulse duration of 30 ns, pulse repetition frequency of 20 kHz and average laser power of 6 W. Sample surfaces were analyzed (before and after cleaning) with optical spectroscopy, SEM, LIPS, XRF and XRD analyses. Optimal regimes, which will be used on real object (antique bronze coin found nearby Nessebar), were found for both lasers.

Laser oscillation with average output power of 4 W (duration and energy of the laser pulse 60 ns and 0.2 mJ, respectively) and laser beam divergence of 0.6 mrad ($2\theta_{1/2}$) was obtained in the Middle Infrared spectral range in a sealed-off laser tube with elemental strontium. Using the same laser tube construction and four-time enhancing the active volume (both in diameter and length), average output power of 10 W (duration and energy of the laser pulse 60 ns and 0.6 mJ, respectively) was also achieved. Based on these laser tubes, master oscillator–powerful amplifier laser system with average output power of 10 W and laser beam divergence of 0.3 mrad ($2\theta_{1/2}$), was developed. It must be noted that the discharge conditions were not optimal for maximal energy laser parameters, but were suitable for laser operation in a sealed-off regime.

Temporal and radial distribution of electron temperature $T_e(r, t)$ in DUV Cu^+ Ne-H_2-CuBr and Sr^+ recombination lasers was determined by developing 2D(r, t) numerical model. For that purpose the parameters of the nonstationary heat conduction equation for electrons, namely thermal conductivity and specific heat capacity of the electron gas at Maxwellian and Druyvesteyn electron energy distribution functions, were preliminary determined.

Using the subpicosecond (300 fs) laser, a new z-scan experimental setup was developed. Nonlinear refraction index n_2 of GaN, AlN and diamond monocrystals was experimentally determined. The setup and the calculation method were validated by diamond samples.

PUBLICATIONS:

1. **V. T. Atanassova**, Laser cleaning of graffiti spray paints on marble, limestone and granite, *chapter in book "Graffiti: Vandalism, Street Art and Cultural Significance"*, Editors: X. Paradis and M. Matthew, Nova Publishers, Inc., pp. 117-143, 2018 (ISBN: 978-1-53613-499-5).
2. **Н. В. Съботинов**, Лазерът, Издателство на БАН "Проф.Марин Дринов", София 2018 г. (118 стр.) (N. V. Sabotinov, The Laser, Prof.Marin Drinov Publishing House of Bulgarian Academy of Sciences, Sofia 2018 (118 pages)).
3. **T. Petrov**, E. Pecheva, A. D. Walmsley, S. Dimov, Femtosecond laser ablation of dentin and enamel for fast and more precise dental cavity preparation, *Materials Science and Engineering **C***, **90**, pp. 433-438, 2018 **IF = 5.080**.
4. N. Nedyalkov, M. E. Koleva, R. Nikov, N. E. Stankova, **E. Iordanova**, **G. Yankov**, L. Alexandrov, R. Iordanova, "Tuning optical properties of noble metal nanoparticle-composed glasses by laser radiation", *Applied Surface Science*, **463**, pp. 968-975, 2019 **IF = 4.439 Q1**.
5. D. A. Georgieva, **T. S. Petrov**, H. Yoneda, R. Shikne, N. N. Nedyalkov, L. M. Kovachev, Avalanche parametric conversion and white spectrum generation from infrared femtosecond pulses in glasses, *Optics Express*, **26(13)**, pp. 17649-17661, 2018 **IF = 3.356**.
6. N. Nedyalkov, N. E. Stankova, M. E. Koleva, R. Nikov, **M. Grozeva**, **E. Iordanova**, **G. Yankov**, L. Alexandrov, R. Iordanova, D. Karashanova, "Optical properties modification of gold doped glass induced by nanosecond laser radiation and annealing", *Optical Materials*, **75**, pp. 646-653, 2018 **IF = 2.320 Q2**.
7. **K. A. Temelkov**, **S. I. Slaveeva**, **Yu. I. Fedchenko** and T. P. Chernogorova, "Theoretical study on some plasma parameters and thermophysical properties of various gas mixtures in gas-discharge lasers", *Journal of Physics: Conference Series*, **992**, art. No. 012008 (5 pages), 2018 (online ISSN 1746-6596, SJR 0.19) **IF = 0**.

8. N. Nedyalkov, N. E. Stankova, M. E. Koleva, R. Nikov, P. Atanassov, **M. Grozeva**, **E. Iordanova**, **G. Yankov**, L. Alexandrov, R. Iordanova and D. Karashanova, "Optical properties modification induced by laser radiation in noble-metal-doped glasses", *Journal of Physics: Conference Series*, **992**, art. No. 012047, 2018 (online ISSN 1746-6596, SJR 0.19) **IF = 0**.
9. E. Dimova, V. Steflekova, **S. Karatodorov**, E. Kyoseva, Experimental demonstration of efficient and robust second harmonic generation using the adiabatic temperature gradient method, *Journal of Physics: Conference Series*, **992**, art. No. 012007, 2018(online ISSN 1746-6596, SJR 0.19) **IF = 0**.
10. I. Ilievska, V. Petrov, V. Mihailov, **S. Karatodorov**, L. Andreeva, A. Zaleski, V. Mikli, M. Gueorgieva, V Petrova and A Stoyanova-Ivanova, Elemental composition and structural characteristics of as-received TriTaniumTM orthodontic archwire, *Journal of Physics: Conference Series*, **992**, art. No. 012036, 2018 (online ISSN 1746-6596, SJR 0.19) **IF = 0**.
11. **K. A. Temelkov**, **S. I. Slaveeva**, **Yu. I. Fedchenko** and T. P. Chernogorova, "A Comparative Theoretical Study on Electron Temperature in Nanosecond Pulsed Longitudinal Discharge for Maxwellian and Druyvesteyn Electron Energy Distribution Functions", accepted for publication and in print in *American Institute of Physics Conference Proceedings* **IF = 0**.
12. **V. Atanassova**, **I. Kostadinov**, P. Penkova, Selective Laser Cleaning of Corroded Metal Objects, accepted for publication and in print in *American Institute of Physics Conference Proceedings* **IF = 0**.
13. **I. K. Kostadinov**, **S. I. Slaveeva** and **K. A. Temelkov**, "Powerful High-Beam-Quality Sealed-Off Laser System Oscillating in Middle Infrared Spectral Range on Strontium Atomic Transitions for Medical Applications", accepted for publication and in print in *Proceedings of SPIE* **IF = 0**.
14. N. Nedyalkov, M. E. Koleva, N. E. Stankova, R. Nikov, P. A. Atanassov. **E. Iordanova**, **G. Yankov**, L. Alexandrov, R. Iordanova, G. Sliwinski, M. Sawczak, K. Grochowska, M. Terakawa, "Direct laser writhing of Ag nanoparticle-composed structures in glass", accepted for publication and in print in *Proceedings of SPIE* **IF = 0**.
15. **V. Atanassova**, P. Penkova, **I. Kostadinov**, **S. Karatodorov**, Georgi V. Avdeev, Laser removal of chlorine from historical metallic objects, accepted for publication and in print in *Proceedings of SPIE* **IF = 0**.
16. **В. Т. Атанасова**, Приложение на лазерите за реставрация на паметници на културното наследство, приета за печат в списание Наука, 2018 г.
17. **K. A. Temelkov**, **S. I. Slaveeva**, **Yu. I. Fedchenko** and T. P. Chernogorova, "New methods for theoretical determination of some plasma parameters and thermophysical properties of nanosecond pulsed longitudinal discharge in multicomponent gas mixtures", invited paper sent for publication in *Journal of Physics: Conference Series* (online ISSN 1746-6596, SJR 0.19) **IF = 0**.

PATENTS:

Maintained patents:

1. Laser tube for strontium infrared laser with strontium halide vapours — N.K.Vuchkov and K.A.Temelkov

2. Laser tube for strontium infrared laser with strontium halide vapours	N.K.Vuchkov, K.A.Temelkov, N.V.Sabotinov
3. Gaseous laser with copper halide vapours	N.V.Sabotinov, K. Dimitrov
4. Laser tube for ultraviolet copper laser	N.K.Vuchkov, K.A.Temelkov, P. Zahariev, N.V.Sabotinov
5. Three-component glassy matrices prossessing variable nonlinear optical properties	T. Petrov, B. Shivachev, Hitoki Yoneda

Patents in procedure:

1. Method of atmospheric electricity extraction (No. 112379 13.09.2016)	D. Astadjov, I. Angelov, M. Gospodinov
2. Method and system for deposition of micro- and nanoparticles on transparent substrate	K. Dimitrov

ONGOING RESEARCH PROGECTS:

- 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 and Laser Assisted Annealing of nanostructures (WG 5) – part of "Research and Innovation Capacity Strengthening of ISSP-BAS in Multifunctional Nanostructures" (INERA/FP7-REGPOT-2012-2013-1).
- 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).
- Ultrafast laser applications in material processing and characterization (under the Academy's bilateral agreements with National Institute for Lasers Plasma and Radiation Physics, RAS, Romania).
- Laser induced fluorescence analysis for cultural heritage investigation and preservation (funded by NFS MDU 03/79 2012).

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 is organizing series of introductory courses for medical doctors for work with laser systems.

In 2018 one PhD student were working in the Laboratory under supervision of Assoc. prof. M.Grozeva and one PhD student was supervised by Assoc. prof. K. Temelkov.

The young scientists of the Laboratory participated in the traditional XXI Winter Seminar of PhD Students and Young Scientist.

Assoc. Prof. Todor Petrov reads lectures on a topic "Ultrafast laser processing" in Technical University – Sofia.

Assoc. Prof. Dr. K. Temelkov gave an invited lecture at 11th Spring Seminar of PhD Students and Young Scientists on Chemistry, 20-22 April, Vitosha, Bulgaria, 2018 and an invited lecture at 21th Winter Seminar of PhD Students and Young Scientists on Physics, 14-16 December, Vitosha, Bulgaria, 2018.

MUSEUM
HISTORY OF PHYSICS IN BULGARIA
CURATOR: **Assoc. Prof. Dr. Ganka Kamisheva**
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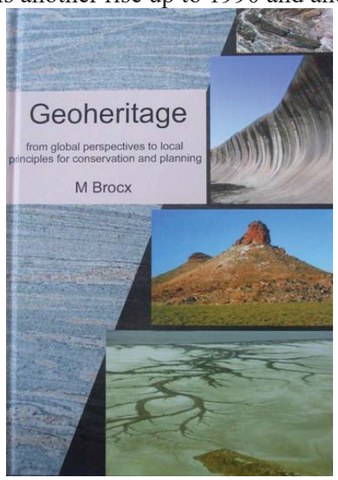
TOTAL STAFF **1**
RESEARCH SCIENTIST **1**

SCIENTIFIC RESULTS:

In 2018, two articles [1-2] and one review [3] have published, four reports have given, and two manuscripts have accepted for publication.

Union of Physicists in Bulgaria marks its one hundred and twenty anniversary officially in the Sofia University Aula on 20 March 2018. Contents of preserved sources from 1898 until 1950 has examined in published report [2].

Next report about the Union of Physicists in Bulgaria, given in the Third International Conference on the History of Physics, examines the history of the Union of Physicists in Bulgaria since its establishment in 1898 until today. Founded as a regional (Sofia) society, it raises to national Physical and Mathematical Society. It stops its activities in 1950. Physicists and mathematicians restores it under the hat of the Union of Scientists in Bulgaria in 1960. There is another rise up to 1990 and another decline after that [4].



Pivotal role of Eugene Leyarovski for creation of low-temperature physics in Bulgaria was demonstrated at the Ten jubilee conference of the Balkan Physical Union, held in Sofia from 26 to 30 August 2018. The Golden Age of Low Temperature Physics in Bulgaria is due to his brilliant ideas, innovative thinking and excellent experimental skills. His results in the field of low temperature physics make him a world-recognized scientist. In Bulgaria, he builds equipment and offers a new adsorption method for cryogenic separation of neon and helium from the air and from industrial gas mixtures [5].

The report presented at the 5th International Conference on Theoretical and Applied Physics on 2–3 July 2018 in Vienna shows possible effects from the theory of Professor Georgi Manev. Some consequences are: a) the laws of Kepler (27.12.1571-215.11.1630); (b) tides and day-to-day changes the atmospheric pressure – due to the change of our position toward direction of the axis translation for 24-hour [6].

Two consultations and eleven new donations comes in the Museum. Prof. P. Atanasov, Prof. P. M. Schuster (Austria), Prof. M. Brocx (Australia), Prof. B. Kovachev, Prof. N. Balabanov (Plovdiv), Prof. M. Mladenova, Prof. S. Kaschieva, Prof. E. Nazarova, A. Karastoyanov, M. Christova, and I. Azmanov are donors in 2018.

PUBLICATIONS:

1. Г. Камишева, Професор д-р Елисавета Карамихайлова (03.09.1897–22.04.1968), Списание на БАН (1) 48-57 (2018)
2. Г. Камишева, 120 години Съюз на физиците в България. Съюзна дейност 1898-1950, Светът на физиката (2) 154-159 (2018)
3. Г. Камишева, Мястото на д-р Димитър Мутев в „Ранните пътища на българската модерност“, Светът на физиката (4) 406-412 (2018)
4. G. Kamisheva, Union of Physicists in Bulgaria 120 Years Jubilee, 3rd International Conference on History of Physics of the EPS, Donostia/San Sebastian (Spain); 18–21 October 2018 (report)
5. E. Nazarova, G. Kamisheva, Eugene Leyarovski Founder of the Contemporary Low Temperature Physics in Bulgaria, AIP Conference Proceedings 2075, 190001 (2019) [10 Jubilee Conference of Balkan Physical Union, София, 26-30 август 2018]
6. G. Kamisheva, Consequences of the Maneff's theory, 5 International Conference of Theoretical and Applied Physics, Vienna, Austria, 2-3 July 2018 (report)