BULGARIAN ACADEMY OF SCIENCES

GEORGI NADJAKOV
INSTITUTE OF SOLID STATE PHYSICS

ANNUAL RESEARCH REPORT
2019

Compiled and Edited by J. Genova

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Foreword

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To commemorate the 150th anniversary of the Bulgarian Academy of Sciences an exhibition dedicated to technologies and materials for the benefit of society was open on October 16, 2019 at the central lobby of administrative building of the Bulgaran Academy of Sciences. The exhibition included 18 poster presentations demonstrating the scientific achievements of the Institute departments that have contributed to the creation and development of microelectronics, acoustoelectronics and nanotechnology in Bulgaria. Past achievements in the field were presented along with the research results carried out in recent years.

2019 has seen the effective start of the realization of the project BG05M2OP001-1.001-0008, funded by the Operational Programme "Science and Education for Smart Growth" of the Ministry of Education and Science co-financed by the European Union through European structural and investment funds. The 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 2019, the institute was the beneficiary of several scientific projcts financed by Ministry of Education and Science. One of these the project "Optimized Nanocomposite Polymeric Membranes for Na- и Mg- ion conducting electrolytes, proton exchange and applications" in the framework of the National Scientific Program "Petar Beron i NIE" (P. Beron).

The Institute organized the traditional 22nd Winter Seminar "Interdisciplinary Physics" for doctoral students and young scientists from the Bulgarian Academy of Sciences during the winter of 2019. Furthermore, the organization of the 21st edition of the traditional International School on Condensed Matter Physics devoted to "Progress and Perspectives in Functional Materials" has started. The event will be held from August 31st to September 4th 2020 in Varna, Bulgaria.

During the last year, the scientific personnel of the Institute published 153 papers: 146 printed and 7 at press. 113 articles have been published in internationally recognized high impact journals indexed in Web of Science and/or SCOPUS. The total number of citations in 2019 exceeds 1440. ISSP currently holds 14 BG patents and 11 applications for patents are in procedure.

During 2019 one patent "Method for superhydrophobic coating stabilization from carbon nanoparticled" was approved.

The scientific teams, led by Assoc. Prof. Emilia Dimova and Assoc. Prof. Yordan Marinov were awarded the prize for their scientific achievements for the year 2019 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: Assoc. Prof. V. Vitkova, Ph.D.
Laser, Atomic, Molecular and Plasma Physics	Head: Assoc. Prof. V. Mihaylov, Ph.D.
Innovation Department:	Head: Assoc. Prof. D. Spassov, Ph.D.
Education Department:	Head: Prof. A. Paskaleva, D.Sc.
Center for Investigation of the Physical Properties of Materials, Surfaces and Structures:	Head: Assoc. Prof. P. Rafailov, Ph.D.

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: **8**
RESEARCH SCIENTISTS: **4**
ASSOC. MEMBERS: **1**

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

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

RESEARCH ACTIVITIES:

The department performs experimental and theoretical studies in the area of electromagnetic field – matter interaction. On this basis we develop sensors and devices, intended for various fields of industry, security, scientific experiments and more. Our ambition is to undertake projects that are of national interest. In 2019, we worked on improving a series of sensors and devices designed to enhance European security and for civil applications. They will operate in conjunction with fluid generation systems created by colleagues from several institutions in Europe. We successfully held demonstrations and discussions of our inventions. We focused on working with state and public institutions such as *Road Infrastructure Agency, Sofia Municipality, and Dimitrovgrad Municipality;* since we estimated that there we can develop technologies in the field of security and environmental protection that are of nationwide importance. We also participate in nationwide operational activities. Such are the continuing support of the projects "*Optimal distributions of Locomotives*" and "*Dynamic Traction Force Integrator*" (funded by *Bulgarian State Railways*), which are important for the functioning of the railway transport, we also have a participation in a committee with the Prosecutor's Office to clarify specific facts and circumstances.

Results from research activity in 2019:

- **Experimental study of the changes occurring in fog when mixing with additives with different composition**

The impact of aerosols on fog formation in lab environments was studied. Physical and chemical properties of aerosols affect droplet formation and size spectra, which are dependent on thermodynamical conditions. Fog, as a natural phenomenon, is widely studied because it

can affect visibility, air quality, climate, agriculture, and human health. Fog is also used in some industrial processes. Fog with suitable additives can be used as a cleaning agent for various incidents: military or terrorist actions, accidents or natural disasters. In order to achieve our goals, automated systems for fog generation were created, including for fog with controlled amounts of additives. The results obtained showed that the particle size distribution of fog droplets varies with the addition of chemical impurities and their mass concentration. This is an original result of serious practical importance, considering the important functions of fog, some of which were mentioned above.

- **Equation of state of magnetars**

Neutron stars are characterised by strong magnetic fields and fields of the order of 10^{15} G have been measured at the surface of some of them, called magnetars. Much stronger magnetic fields are expected to be present in the solid region beneath the surface. The effects of the magnetic field on the equation of state and on the composition of the crust due to Landau-Rabi quantization of electron motion were studied. Both the outer and inner crust were described in a unified and consistent way within the nuclear-energy density functional theory.

The r-process nucleosynthesis triggered by the decompression of ejected crustal materials from binary neutron star mergers has been recently confirmed by electromagnetic observations following the gravitational-wave event GW170817. Isolated magnetars, might be another astrophysical site for the r-process since some material is also ejected during giant flares. The final abundance distribution depends on the crustal composition. Making use of the latest experimental nuclear mass data supplemented with microscopic models, the nuclear abundances of the different layers were calculated.

- **Automated 2D laser scanning systems for investigation of solid surfaces**

Automated optical scanning systems for analysis of solid surfaces were created. The prototypes are capable of detecting various parameters and irregularities related to the surface of solid bodies by measuring the amplitude of modulated signals obtained by the *Electromagnetic Echo Effect*. The systems allow various sizes of all kinds of surfaces to be scanned and the results to be visualized on a computer screen. Their general purpose is to scan different areas of specimens and visualize their sensitivity to the *Electromagnetic Echo Effect* onto a plot of coordinates but they are also capable of providing valuable information about structural, mechanical and electrical surface parameters.

- **Mathematical representation of a CFD model for artificial fog spray investigation**

A mathematical apparatus, used in a numerical simulation model created with ANSYS CFX Software, was developed. The purpose of the model is to perform computations of fog parameters in different points of artificially generated fog sprays, which are then used to

calibrate a novel type of fog sensors. By changing the distance between the nozzle and the measuring laser beam of the sensor, we can assess how the number flow rate and diameter distribution of fog droplets are varied within in the spray.

PUBLICATIONS:

In 2019 we have 5 publications and 9 presented conference reports. We have also 2 submitted manuscripts that are currently under review. We have noticed 30 citations in 2019.

1. Todorov P., Ivanov O., Pashev K., Ralev Y., Pérez-Díaz J. L.. Automated 2D Laser Scanning Systems for Investigation of Solid Surfaces, *Machines. Technologies. Materials*, 7, 306-309, 2019, ISSN: ISSN PRINT 1313-0226, ISSN WEB 1314-507X

2. Todorov P., Mathematical Representation of a CFD Model for Artificial Fog Spray Investigation, *Mathematical Modelling*, 3,□97-100, 2019, ISSN:(Print) 2535-0986, (Online) 2603-2929

3. Todorov P. Mathematical Representation of a CFD Model for Artificial Fog Spray Investigation. *Proceedings of III International Scientific Conference CONFSEC*, vol 5, 146-149, Scientific-Technical Union of Mechanical Engineering - Industry 4.0, Sofia, Bulgaria, 2019, ISSN:(Print) 2603-2945, (Online) 2603-2953

4. Y. D. Mutafchieva, N. Chamel, Zh. K. Stoyanov, J. M. Pearson, and L. M. Mihailov, Role of Landau-Rabi quantization of electron motion on the crust of magnetars within the nuclear energy density functional theory, *Physical Review C*, 99, 055805 (2019)

5. Todorov P., Ivanov O., Pashev K., Ralev Y., Pérez-Díaz J. L., Automated 2D Laser Scanning Systems for Investigation of Solid Surfaces, *Proceedings of XVI International Congress Machines. Technologies. Materials 2019*, vol 4, 15, Scientific Technical Union of Mechanical Engineering, 2019, ISSN:2535-0021 (Print), 2535-003X (Online), 378-381

- **Conference Reports:**

1. Zh. K. Stoyanov, Y. D. Mutafchieva, N. Chamel and L. M. Mihailov, Nuclear abundances in the crust of magnetars, *38-th International Workshop on Nuclear Theory*, 23.06-29.06 2019 Rila Mountains, Bulgaria

2. Y. D. Mutafchieva, Zh. K. Stoyanov, N. Chamel, J. M. Pearson, and L. M. Mihailov, Unified equation of state for magnetar crusts, *38-th International Workshop on Nuclear Theory*, 23.06-29.06 2019 Rila Mountains, Bulgaria

3. Ivanov O., Todorov P., Gultepe I., Komar J., Experimental study of fog physical response to chemical compounds dissolved in pure water, *8th International Fog and Dew Association Conference*, 14.07.2019 - 19.07.2019, Taipei, Taiwan

4. Todorov P., Ivanov O., Pashev K., Ralev Y., Pérez-Díaz J. L., Automated 2D Laser Scanning Systems for Investigation of Solid Surfaces, *XVI International Congress Summer Session "Machines. Technologies. Materials"*, 11.09.2019 - 14.09.2019, Varna, Bulgaria

5. Ivanov O., Pérez Díaz J. L., Nikolova N.., Device for Large Scale Fog Decontamination, *2nd International Conference on Photonics Research Interphotonics 2019*, 04.11.2019 - 09.11.2019, Antalya, Turkey

6. Ivanov O., Todorov P., Nikolova N., Application of Electromagnetic Charge Effect for Development of Optical Sensors (invited), *2nd International Conference on Photonics Research Interphotonics 2019*, 04.11.2019 - 09.11.2019, Antalya, Turkey

7. Todorov P., Mathematical Representation of A CFD Model for Artificial Fog Spray Investigation, *The Third International Scientific Conference on Security*, 09.12.2019 - 12.12.2019, Borovets, Bulgaria

8. Zh. K. Stoyanov, Y. D. Mutafchieva, N. Chamel and L. M. Mihailov, Magnetar crust stratification and nuclear abundances, *XXIII International School on Nuclear Physics, Neutron Physics*, September 22 -28 2019, Varna, Bulgaria

9. Y. D. Mutafchieva, Zh. K. Stoyanov, N. Chamel, J. M. Pearson, and L. M. Mihailov, Unified equation of state for describing the outer and inner crust of magnetars, *XXIII International School on Nuclear Physics, Neutron Physics*, September 22 -28 2019, Varna, Bulgaria

PATENTS:

Throughout 2019, we worked closely with The Patent Office of Republic of Bulgaria for the review of five of our patent applications. The patent applications are a result of innovative collaborative work with international partners. There are funded by the *Research Executive Agency* of the European Commission.

We are interacting with a large number of institutions and private companies. In 2019, we received several letters of interest to our results. We are actively collaborating with public institutions. This fact gives us reason to believe that the patent applications will quickly find their real, practical applications once they have been approved.

ONGOING RESEARCH PROJECTS:

- **European projects**

In 2019 we worked on *Device for Large Scale Fog Decontamination*, acronym *COUNTERFOG* – FP7, Programme *Security*, Project Number - 312804

There are 57,500 euros received.

- **National and operational activities serving the country**

We actively support previously developed applications in Bulgaria - for example, systems developed under contracts with “Bulgarian State Railways” (BDZ) for traction force

calculation of trains and optimal allocation of locomotives, which are used successfully for planning the movement of trains, determining the actual location of trains and locomotives, as well as for minimizing the number of locomotives used. The work on these two successfully completed contracts of Lyubomir Mihaylov with BDZ has created dozens new work places, and now the algorithms are being integrated into scientific systems of national importance and with opportunities for information on the Internet, for which we assist the National "Railway Infrastructure" Company.

Ognyan Ivanov participates in a committee of the Prosecutor's Office for clarification of physical circumstances in various lawsuits. The task, which is now before the commission, is to prepare an expert examination by order of the Regional Prosecutor's Office, Varna.

- **Publishing and information activity of the department**

In fulfilling the commitments, we have with the European Commission to disseminate and implement the results obtained from the COUNTERFOG project, we did a broad campaign with this aim. A large number of meetings, discussions and demonstrations were held, reports were presented to industrial and scientific centers and at international conferences. Over the past year, most of our efforts have been in this direction. As a result, we have presented several reports at international conferences, two reports before scientific centers (Institute of Solid State Physics and Institute of Electronics), active communication with state and public institutions (*Road Infrastructure Agency, Sofia Municipality, Dimitrovgrad Municipality, Defense Industry Association, etc.*). Active contacts with a large number of companies. As a result of these activities, there was a clearly expressed interest from different potential end users. For example, letters of interest were sent by:

- *ECCC, Meteorological Research Division, OBRS*, Toronto, ON M3H-5T4, Canada;

- *Prolife Technology Ltd.*, Sofia;

- *Software Company, Ltd*, Sofia;

- *Ultraflex Company*, USA;

Within the campaign for dissemination of the results of the COUNTERFOG project, in 2019 we prepared the shooting of a 30-minute film on the BNT – 2 channel about our activity. The work on the film began with the assistance of Assoc. Prof. Kamburova -

https://www.bnt.bg/bg/a/studenti-i-prepodavateli-razrabotikha-senzori-za-sigurnost-na-obshchestveni-mesta

- **Participation of the department in the training of specialists**

In the *Electromagnetic sensors* department, are working two PhD students and four undergraduates, who are refining their academic and experimental in theoretical and applied science.

INTERNATIONAL SCIENTIFIC COOPERATION:

Within the COUNTERFOG project, we worked with participants in the consortium engaged in the project, which are nine in total. We have submitted a proposal for a new European project with some of the members of the consortium - acronym: FASTFOG, Call: H2020-SU-SEC-2019, Type of action: RIA, Topic: SU-DRS04-2019-2020, Coordinating organization: COUNTERFOG EBT DE LA UAH S.L. (PIC: 898660866, located in Valdemoro, ES). The topic is related to applying the results of the COUNTERFOG project. We also expect a response to a project proposal submitted in 2018 to the *European Space Agency*, with roughly the same participants and a similar topic.

We worked on the implementation of some of the results obtained under the COUNTERFOG project with:

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

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

We worked on theoretical studies of electromagnetic field – matter interaction having applications in astrophysics with:

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

- J. M. Pearson: *Département de Physique, Université de Montréal*, Montréal, Canada.

Ognyan Ivanov is a member of 6 editorial boards of international scientific journals and conferences. He has written reviews of the thesis of Francisco José Llerena Aguilar from *Universidad de Alcalá, Departamento de Teoría de la Señal y Comunicaciones*, Madrid, Spain, and for the journal *Air Quality, Atmosphere & Health*.

THEORY

LABORATORY

THEORY GROUP

HEAD: **Prof. Hassan Chamati, D.Sc.**
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RESEARCH SCIENTISTS: **16**
ASSOC. MEMBERS: **1**

Prof. N.B. Ivanov, D.Sc.; Prof. T.M. Mishonov, D.Sc.; Prof. P.C. Ivanov, D.Sc.; Assoc. Prof. E.R. Korutcheva, D.Sc.; Assoc. Prof. D. Shopova, Ph.D.; Assoc. Prof. Z. Dimitrova, Ph.D.; Assoc. Prof. R. Kamburova, Ph.D.; Ass. Prof. I. Boradjiev, Ph.D.; Ass. Prof. A. A. Donkov, Ph.D.; Assist. Prof. S. Varbev, Ph.D.; Ass. Prof. M. Georgiev, Ph.D.; Ass. Prof. A.M. Varonov, Ph.D.; Ass. Prof. H. Tonchev, Ph.D; Physicist E. Popov, Ph.D.; Physicist K. Gaminchev; assist. Prof. V.I. Vaskivskyi

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

RESEARCH ACTIVITIES:

The phase diagram of some ferrimagnetic materials modeled by two bilinearly coupled Heisenberg models sitting on two interpenetrating simple magnetic cubic lattices we constructed. The transitions to the magnetically ordered phases within the model are found to be of second order with the occurrence of a compensation point at lower temperatures for some values of the system's parameters. It is found that the main stable phase is a two-sublattice collinear ferrimagnet in addition to a metastable non-collinear phase. 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. These results are in qualitative agreement with the experimental results on $Y_3Fe_5O_{12}$ in the strong coupling limit and the compounds $ErFe_2$ and $GdCo_{12}B_6$ for weak couplings.

The magnetic properties of nanomagnetic systems, such as molecular magnets and isolated spin units embedded in larger compounds are investigated theoretically. One of the basic problems in studying nanomagnetism lies in addressing the effect of the nanomagnets' structural symmetry and type of atomic bondings on their magnetic properties. These effects are taken into account by developing an alternative to the conventional spin techniques methods. Our approach involves the molecular orbital theory, the multi-configuration self-consistent field method and the inelastic neutron scattering theory. Our approach is used to analyze the magnetic properties of the molecular magnet Ni_4Mo_{12}. The obtained results reproduce both quantitatively and qualitatively the main features of the magnetic spectrum. Furthermore, the computations for the magnetization and the low-field susceptibility are in very good agreement with their experimental counterparts. Thus, they improve upon the results obtained with the conventional isotropic Heisenberg model.

The classical phase diagram of a mixed-spin Heisenberg system defined on a Kagome strip, which is a cutout from the kagome lattice is analyzed. The unit cell of the spin model contains

a pair of corner-sharing triangles with four **s** spins on the outer vertices and **S** spin on the central site (S>s). The model is a natural mixed-spin extension of the previously studied spin-1/2 Heisenberg Kagome strip. Using Kaplan's method for the unit-cell spin clusters, we have shown that the model exhibits a rich classical phase diagram containing two collinear magnetic phases, two collinear antiferromagnetic phases with different cell spins, as well as a macroscopically degenerate canted phase occupying a region around the limit of isolated **s** chains.

Using 1/S expansions as well as ED numerical simulations, the quantum phase diagram and the low-lying excited states of the mixed-spin Kagome strip described above is studied also. Apart from the standard ferromagnetic and ferrimagnetic phases, the quantum phase diagram contains two Haldane-type non-degenerate phases with effective site spins $S+s$, $S-4s$, as well as a doubly-degenerate phase resulting from the macroscopically degenerate classical canted phase.

The W-loop contribution to the amplitude of the decay $H\rightarrow Z\gamma$ in the unitary gauge through the dispersion method and in the R_ξ gauge using dimensional regularization (DimReg) is calculated. It is shown that the results of the calculations with DimReg and the dispersion method, adopting the boundary condition at the limit $M_W\rightarrow 0$ defined by the Goldstone boson equivalence theorem (GBET), completely coincide. This implies that the dispersion method obeying the GBET is compatible with DimReg. The advantage of the applied dispersion method is that we work with finite quantities and no regularization is required.

The real-time dynamics of a periodic XY system exposed to a composite field comprised of a constant homogeneous magnetic and a quantized circularly polarized electromagnetic fields is studied. The interaction between the quantized mode and spin-magnetic moments is modeled by the Dicke Hamiltonian. The rotating wave approximation is applied and the conditions for its validity are discussed. It is shown that if at the beginning of the dynamic process all of the excitations are contained in the field then, in the regime of large detuning, the main evolutionary effect is the oscillations of the excitations between the zero-momentum modes of the chain and the field. Accordingly, the reduced photon number and magnetization per site reveal a sort of oscillatory behaviour. Effective Hamiltonians approximating the short-time dynamics of the actual problem for small number of excitations and large detuning are introduced. The resonance case is considered in the context of photon emission from the chain initially prepared in the (partially) excited state. In particular, it is demonstrated in the framework of a specific example that the superradiant behaviour can be presented in the beginning of the emission, when the evaluation starts from maximally excited XY chain. The model is potentially applicable to problems such as spin chain/linear molecular aggregates in a single-mode cavity.

The conditions for the existence and stability of solitons in an anisotropic ferromagnetic chain with first- and second-neighbor interactions is studied. The effects of the second-neighbor interactions and the anisotropy for the homogeneous case and arbitrary wave number in the Brillouin zone are analyzed. Analytical solutions are obtained for static solitons bound to a linear point defect. The type of the soliton solutions and their form depend on both, the anisotropy parameters and the exchange interactions.

Soliton interactions with localized defects of different types in an anisotropic Heisenberg spin chain in nearest neighbor approximation are investigated. Evolutionary equations are derived after consistently applying semiclassical and continuum limits (spins are classical vectors and the length of the soliton excitations is larger than the lattice constant). Localized bound soliton impurity solutions are obtained analytically for linear and nonlinear point defects and their

stability is studied numerically. The influence of a defect spin modelled by a different exchange with its neighbors is analyzed in detail.

The propagation of soliton excitations in a system of two magnetic chains with impurities is studied. The inhomogeneous chains are coupled through ferromagnetic interaction between the opposite spins. The presence of the impurities leads to linear perturbing terms in the evolutionary equations. The influence of the soliton parameters, the interchain coupling, and the defect strength on the soliton dynamics are investigated numerically. The conditions of perfect soliton switching are obtained.

The interaction between solitons, propagating in a magnetic chain, with a qubit is studied. The spin chain is described by the Heisenberg model in a nearest-neighbour approximation with anisotropy. The quantum bit (qubit) is modelled by a two level quantum system. The equation for the evolution of the qubit is obtained. The role of the parameters of the soliton for the quantum bit dynamics is investigated. The results are analysed using a geometrical representation for the qubit as a Bloch sphere.

Third-order correlation functions for two particles with the electrostatic interaction have been obtained for the first time using the direct algebraic method. The main relations for the correlation functions that do not depend on the explicit form of the interaction potential between particles, as well as the relations that appear for four specific forms of the interaction operator, are considered.

We considered a model of power distribution in a social system where a set of agents play a simple game on a graph: the probability of winning each round is proportional to the agent's current power, and the winner gets more power as a result. We show that, when the agents are distributed on simple 1D and 2D networks, inequality grows naturally up to a certain stationary value characterized by a clear division between a higher and a lower class of agents. High-class agents are separated by one or several lower class agents, which serve as a geometrical barrier preventing further flow of power between them. Moreover, we consider the effect of redistributive mechanisms, such as proportional (non-progressive) taxation. Sufficient taxation will induce a sharp transition towards a more equal society, and we argue that the critical taxation level is uniquely determined by the system geometry. Interestingly, we find that the roughness and Shannon entropy of the power distributions are a very useful complement to the standard measures of inequality, such as the Gini index and the Lorenz curve.

The density of agents is controlled by a parameter which can be viewed as measuring the attractiveness of the city-lattice. This model is directly related to the zero-temperature dynamics of the Blume-Emery-Griffiths (BEG) spin-1 model, with kinetic constraints. With a varying vacancy density, the dynamics with agents making deterministic decisions leads to a new variety of "phases" whose main features are the characteristics of the interfaces between clusters of agents of different types. Different phenomena as roughness between the different regions as well as the avalanche dynamics between them is studied in deep. The corresponding scaling exponents and the corresponding universality classes are discussed.

The nonlinear partial differential equations describing system behavior incorporates dispersion and dissipative properties of the medium. We have developed a method for obtaining exact solutions of nonlinear partial differential equations called the Simple Equations Method (SEsM) which is based on representation of the searched solution as function of solutions of one or several simple equations. We describe the methodology and show that SEsM contains as particular cases the Modified Method of Simplest Equation, G’/G - method, Exp-function method, Tanh-method and the method of Fourier series for obtaining exact and approximate solutions of linear differential equations. These methods are just a small part of methods that

are particular cases of the methodology of SEsM. SEsM is applied for obtaining exact solutions of nonlinear partial differential equations (PDEs) from the kind of the generalized Kawahara equation (gKE). The ordinary differential equation of Abel of first kind is used as the simplest equation and two exact solutions of the studied equation are obtained. Particular cases of one of the obtained solutions are visualized. For these cases, the special function is reduced to elementary functions and the corresponding solutions describe a kink and a solitary wave.

Very high water levels of the large rivers are extremely dangerous events that can lead to large floods and loss of property and thousands and even tens of thousands human lives. The information from the systematical monitoring of the water levels allows us to obtain probability distributions for the extremely high values of the water levels of the rivers of interest. We study time series containing information from more than 10 years of satellite observation of the water level of the Huang He River (Yellow river) in China. We show that the corresponding extreme values distribution is the Weibull distribution and determine the parameters of the distribution. The obtained results may help for evaluation of risks associated with floods for the population and villages in the corresponding region of the Huang He River.

We present a short review of the history and contemporary computer simulations of the work of an electronic device for generation of electric oscillation by negative differential conductivity of a supercooled below the critical temperature superconductor. The superconductor is cooled below its critical temperature at a small constant electric field and this applied external voltage keeps the superconductor in normal state. In order to simulate the device, we use the formerly derived explicit analytical expressions for the conductivity of nanostructured superconductors supercooled below the critical temperature in electric field. Numerical analysis intended to alleviate the development of a device reveal that the negative differential conductivity region of the current-voltage characteristic leads to excitation of electric oscillations. This gives a hint that a hybrid device of nanostructured superconductors will work in terahertz frequencies. The study of layered high-T_c superconductors and electromagnetic waves emitted from them in space vacuum would be an important task for the future space technology

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5. **H. Chamati, D. Shopova,** Ferrimagnetism in a Two-sublatttice Bilinearly Coupled Heisenberg Model**. AIP** Conf. Proc., American Institute of Physics, 2075, 020007 (2019), ISSN:0094-243X, SJR:0.165
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18. **R. S. Kamburova, S. K. Varbev, M. T. Primatarowa,** Interaction of solitons with impurities in anisotropic ferromagnetic chains, Phys. Lett. A 383(5), 471-476 (2019).
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21. **R. S. Kamburova, M. T. Primatarowa** and **S. K. Varbev**, Soliton-impurity interaction in two coupled ferromagnetic chains, Journal of Physics: Conference Series, 1186 012017 (2019); SJR (Scopus):0.241, JCR-IF (Web of Science):0.001

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26. **T.M. Mishonov**, A.P. Petkov, V.I. Danchev, **A.M. Varonov**, Electric Oscillations Generated by Fluctuation Cooper Pairs. 2019 https://arxiv.org/abs/1910.10684
27. **T.M. Mishonov**, A.P. Petkov, V.I. Danchev, **A.M. Varonov**, Generation of terahertz oscillations by supercooled in electric field superconductors. Preliminary results. American Institute of Physics Conference Proceedings, 2178, 1, AIP Publishing, 2019, ISBN: 978-0-7354-1925-4, https://doi.org/10.1063/1.5135398, 020001-1-020001-4. SJR (Scopus):0.18

ONGOING RESEARCH PROJECTS:

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

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

TEACHING ACTIVITIES:
Latex Basics
Computer modeling of complex systems

DEPARTMENT FUNCTIONAL MATERIALS AND NANOSTRUCTURES

LABORATORY

PHYSICS OF MATERIALS AND LOW TEMPERATURES

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

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

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

RESEARCH ACTIVITIES:

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

High mechanical flexibility light valves have been obtained based on transparent films of polymer dispersed liquid crystal (PDLC) and $TiO_2/Ag/TiO_2$ heterostructure on polyethylene terephthalate (PET). By optimizing the deposition time of the Ag layer, the best combination of optical transmittance and sheet resistance are achieved. For the most successful specimens, the sheet resistance of the structure is preserved even after 1000 bending cycles.

Composite nanofibers of polyvinylpyrrolidone/titanium tetraisopropoxide (PVP/TTIP) were prepared by electrospray from alcoholic solutions and then these 800-900 nm thick PVP / TTIP fibers were annealed in different atmospheres and temperatures to obtain anatase and rutile TiO2 nanofibers. Heating at 550°C yields smaller diameter nanofibers of predominantly anatase-TiO_2, while rutile-TiO_2 fibers were obtained at 900°C. If nitrogen atmosphere was applied, the nanofibers contained also some carbon residues.

ALD deposition and optimization of the growth parameters for thin layers of ZnO, ZnO: Al, ZnO: Fe, ZnO: Ni, ZnO: Co on different substrates (Si, glass, sapphire) were performed; also ZnO thin layers on PAA - porous anodized aluminum for photocatalysts and thin layers of AlN on Si substrates. The superconducting response and the critical temperature of bulk composite materials - Graphene-YBCO-Ag were measured.

Bismuth titanate single crystals doped with ruthenium and rhodium were characterized by optical and Raman spectroscopy. The observed differences in the intensity ratio of the LO / TO components of the tetrahedral asymmetric-stretching vibration mode were analyzed with respect to the accommodation and the ordering of the doping elements in the crystal lattice and their distribution over oxidation states.

- *Carbon-nanostructure research*

In an optimized low pressure CVD regime for large-grain single-layer graphene growth, a perturbation of the gas flow was created near the substrate. This led to an increased creation of two-layer graphene as indicated by the hardening of the 2D Raman band with respect to its position for single-layer graphene. The massive formation of bilayer graphene is additionally confirmed by scanning and transmission of electron microscopy, atomic force microscopy, as well as by measuring of the optical transmission. This creates the possibility to control the number of layers in CVD growth of graphene at low pressure by manipulating the geometry of the gas flow. Multilayer graphene (3-4 layers) was obtained by CVD growth at atmospheric pressure.

Raman characterization of the nematic phase of pure E7 and E7 doped with graphene nanoparticles at different concentrations was performed.

- *High-temperature superconductors*

The AC magnetic response of multi-domain $Fe_{1.02}Se$ crystals has been explored by means of fundamental and third harmonic AC magnetic susceptibility (ACMS) analysis. The composite domain morphology modifies the pinning landscape resulting in the so-called 'pseudo' peak effect detected with the sensitive third harmonic component. This effect originates from the different nonlinear processes in the vortex system along the inter- and intra-domain responses. The magnetic anomalies observed by varying the DC field, effectively resembling a surface barrier action and avalanche activity also in ACMS, suggesting that this kind of phenomenon could be strongly related to the morphology of the crystals.

In spite of the low Tc (~9K) of the investigated $Fe_{1.02}Se$ compound, thermal fluctuations are significant because of large effective mass and low carriers density. The interplay of pinning and thermal fluctuations results in a vortex-glass (VG) phase evidenced by the negative curvature of measured ρ-J isotherms at $T<Tg$ and a vortex–liquid (VL) phase with a positive curvature of ρ-J isotherms at $T>Tg$. Using the universal scaling function of the VG model, the E-J dependencies are scaled in the two master curves for both states, thus confirming the VG-VL phase transition at Tg.

A Fe(Se,Te) crystals fabricated by the Bridgman technique were investigated by measurements of DC magnetization (M) as a function of temperature (T), magnetic field (H) and time (t). The temperature dependence of irreversibility line (Hirr(T)) and upper critical field (Hc2(0) = 46.5 T) were determined. The critical current density and its anisotropy $\gamma = JcH||c/JcH||ab$ were obtained as a function of temperature and magnetic field from M(H) dependencies in two field configurations (H||c and H||a,b). In perpendicular field configuration a stronger superconducting signal and lower magnetic background is associated with the presence of a clear peak effect, due to a weak-strong pinning crossover. The temperature dependence of the pinning energy (U) was determined from the relaxation measurements performed at only perpendicular field configuration which is more promising in view of applications. The U(T) curves show a maximum in their trend that shifts to lower temperature with the increasing magnetic field. This anomalous scaling of the U(T) curves at different fields depends on the presence of the peak effect phenomenon. A great stability (in particular for inter-grain) of the resistive transition in $FeSe_{0.5}Te_{0.5}$ at high magnetic fields (up to 14 T) or current amplitudes (intra- and inter-grain grain contributions are almost indistinguishable) should also be **pointed out**.

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4. Petrov, S., Rafailov, P. M., Marinova, V., Lin, S. H., Lai, Y.-C., Yu, P., Chi, G. C., Dimitrov, D. Z., Karashanova, D., Gospodinov, M., Chemical vapor deposition growth of bilayer graphene via altering gas flux geometry. Thin Solid Films, 690, Elsevier, 2019, DOI:https://doi.org/10.1016/j.tsf.2019.137521, 137521.

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6. Chiou, Chung Chin, Marinova, Vera, Petrov, Stefan, Fidanova, Cvetelina, Angelova, Ina, Petrova, Dimitrina, Dimitrov, Dimitre, Lin, Shiuan- Huei. Flexible and stretchable optoelectronic devices using graphene. Proc. SPIE 11047, 20th International Conference and School on Quantum Electronics: Laser Physics and Applications, 11047, SPIE, 2019, 110471H.

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ONGOING RESEARCH PROJECTS:

- National Scientific Research Fund: Projects DH08/9, КП-06-Н38/10, Н28/8;

-Project 2D-SPIN-MEM;

- Inter-academic cooperation with:

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

(ii) University of Salerno, Italy

"Investigation of superconducting and multiferroic materials";

- COST Action "Nanoscale coherent hybrid devices for superconducting quantum technology"

INTERNATIONAL COLLABORATION:

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

- National Ciao Tung University, Hsinchu, Taiwan;

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

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

- Leibniz Institute for Solid State and Materials Research, (IFW Dresden),

DEPARTMENT FUNCTIONAL MATERIALS AND NANOSTRUCTURES

LABORATORY

PHYSICAL PROBLEMS OF MICROELECTRONICS

HEAD: **Assoc. Prof. Dencho Spassov, Ph.D.**
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TOTAL STAFF: **10**
RESEARCH SCIENTISTS: **5**
ASSOC. MEMBERS: **0**

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

RESEARCH ACTIVITIES:

The research activities of the laboratory during the year 2019 include:

Investigations of the effect of γ radiation on the electrical characteristics and charge trapping in metal-insulator-semiconductor (Si) capacitor structures with nanolaminated films Al_2O_3/HfO_2, fabricated by atomic layer deposition (ALD) and rapidly thermal annealed in oxygen. Radiation of Co^{60} source at two doses 1Mrad and 10Mrad was employed. It is established that irradiation increases the positive oxide charge in the layers. The effect is better pronounced for the as-grown (unannealed structures) for which an increase of the positive oxide charge with the dose is observed. The irradiation with the chosen doses does not result in a considerable generation of fast interface states as inferred by the density of states in the middle of Si band gap. A slight increase of density of fast states (about $3x10^{11}$ $eV^{-1}cm^{-2}$) is found only in the as-grown stacks; for structures treated in O_2 the density of interface states is not alerted after irradiation. Depending on the post deposition thermal processing and γ radiation dose, the irradiation can lead to both to reduction and increase of the hysteresis in capacitance-voltage (*C-V*) characteristics of capacitors, indicative for the density of so called slow interface states. At low radiation doses the hysteresis in *C-V* curves of as-grown samples decreases initially, but further increase of the dose results in hysteresis enlargement. Samples annealed in O_2 exhibit only reduction of the hysteresis for the investigated doses.

Substantial widening of the "memory windows" of the capacitors is found after irradiation. The effect is mainly due to enhancement of electron trapping in the stacks as the effect of radiation on the hole trapping is negligible. The improvement of electron trapping is found to be stronger for the as-grown structures. The irradiation does not inflict increase of leakage currents in the stacks, and for 1 Mrad even slight reduction of the current is observed. The leakage characteristics can be interpreted as a combination of Ohmic conduction and Poole-Frenkel mechanism. The retention characteristics of irradiated capacitors are not affected by the irradiation with the investigated doses.

The obtained results demonstrate that radiation hardness of nanolaminated Al_2O_3/HfO_2 dielectrics is better than the radiation hardness of SiO_2, and in accordance with the data of other investigators at low radiation doses annealing or passivation of interface defects could be observed. At the same time γ irradiation could be employed as a method for "memory windows" extension without compromising other important memory capacitor characteristics

In collaboration with Lab. Optics and spectrometry electrical characteristics of ion-conductive solid polymer electrolyte layers were studied. The ion-conductive solid polymer electrolytes composed from blends of poly-(ethylene oxide) (PEO) and poly(vinylpyrrolidone) (PVP), as complexed with the ionic compound sodium periodate (NaIO4), are tested for presence of electric charge trapping (CT) and ionic space charge polarization (SCP) under static electric field. Thin films (110 μm-thick) of these materials ware produced at a ratio of the polymers PEO: PVP. 70:30 wt%, the concentration of $NaIO_4$ is 5, 7.5, or 10 wt%. The electrical current at room temperature, as well as the charging/ discharging in the films are studied as depending on applied voltage and time. At a detectable level, no SCP and CT processes in PEO-PVP-$NaIO_4$ are evidenced, in contrast to identical experiments by PEO film under the same experimental conditions. The largely reduced SCP and CT are of importance for electrochemical applications of the considered ion- conducting PEO-PVP-$NaIO_4$ ion-polymer coupled system.

Selective UV sensitivity has been found in Metal-Oxide-Semiconductor structures with Si nanoclusters. Si nanocrystals and amorphous Si nanoparticles (a-Si NPs) were obtained by furnace annealing of SiO_x films with x = 1.15 for 60 min in N_2 at 1000 and 700 °C, respectively. XPS and TEM analysis prove phase separation and formation of Si nanocrystals in SiO_2, while the a-Si NPs are formed in $SiO_{1.7}$ matrix. Both types of structures show selective sensitivity to UV light; the effect is more pronounced in the structure with nanocrystals. The responsivity of the nanocrystal structure to 365 nm UV light is ~ 4 times higher than that to green light at 4 V applied to the top contact. The observed effect is explained by assuming that only short wavelength radiation generates photocarriers in the amorphous and crystalline nanoclusters.

PUBLICATIONS:

1. Hadjichristov, G. B., Ivanov, Tz. E., Marinov, Y. G., Koduru, H. K., Scaramuzza, N.. PEO-PVP-NaIO4 Ion-Conducting Polymer Electrolyte: Inspection for Ionic Space Charge Polarization and Charge Trapping. Physica Status Solidi (A) Applications and Materials Science, 216, 13, Wiley-VCH Verlag, 2019.
2. Curiel, M., Nedev, N., Paz, J., Perez, O., Valdez, B., Mateos, D., Arias, A., Nesheva, D., Manolov, E., Nedev, R., Dzhurkov, V. UV Sensitivity of MOS Structures with Silicon Nanoclusters. Sensors, 19 (10), 2277.
3. D. Spassov, A. Paskaleva, T. A. Krajewski, E. Guziewicz, Tz. Ivanov. Leakage currents in Al_2O_3/HfO_2 multilayer high-k stacks and their modification by post-deposition annealing steps. Journal of Physics: Conference Series, 1186, IOP Science, 2019,.
4. Manolov, E., Paz-Delgadillo, J., Dzhurkov, V., Nedev, N., Nesheva, D., Curiel-Alvarez, M., Valdez-Salas, B.. Investigation of resistive switching in SiO2 layers with Si nanocrystals. Journal of Physics: Conference Series, 1186, IOP Science, 2019.
5. Spassov, D., Paskaleva, A., Davidovic, V., Djoric-Veljkovic, S., Stankovic, S., Stojadinovic, N., Ivanov, T.Z., Stanchev, T. Impact of γ Radiation on Charge Trapping Properties of Nanolaminated HfO_2/Al_2O_3 ALD Stacks. IEEE 31st International Conference on Microelectronics, MIEL 2019 – Proceedings September 2019, Article number 8889600, Pages 59-62, IEEE, 2019.

ONGOING RESEARCH PROJECTS:

Funded by Bulgarian Science foundation:

1. Resistive switching and magnetorsistanse effects in ZnO layers doped with transition metals (Co, Ni, Fe) for multifunctional applications

2. Atomic layer deposition of dielectric nanolayers on two-dimensional materials as active components for multifunctional devices.
3. Multilayered high-*k* dielectric structures for application in non-volatile flash memories
4. Investigation of crystallization mechanism of graphene and carbon nanotubes on catalytic surfaces.

Funded by Bulgarian Academy of Sciences:

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

INTERNATIONAL COLLABORATION:

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

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

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

4. University of Nish, Serbia.

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

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

DEPARTMENT FUNCTIONAL MATERIALS AND NANOSTRUCTURES

LABORATORY

ACOUSTOELECTRONICS

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ASSOC. MEMBERS: 2

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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.

Corrosion proof Rayleigh Surface Acoustic Wave (RSAW) two-port resonators with gold electrode structure, functionalized with gas sorptive layers of hexamethyldissiloxane (HMDSO) of optimized thickness have been probed at different concentrations of amonia (NH_3) vapors for chemical gas sensor applications. Despite the high frequency sensitivity of these devices, exceeding 250 ppm at 50 ppm NH_3 concentration, we found that the HMDSO layer does not release NH_3 completely even after thorough flushing with dry nitrogen. This reduces the sensor sensitivity with increasing the number of NH_3 probing cycles. Further studies towards minimizing this effect are planned in the near future.

First gas probing experiments have been performed with RSAW two-port resonators covered with Langmuir-Blodget (LMB) monolayers of dipalmethol phosphaditil ethanolamine marked with nitrobenzoxediazol (DPPE-NBE) to test their sensitivity to volatile organic compounds (VOC). Probing with saturated vapors of ethanol and chlorophorm have caused 730 and 340 ppm frequency downshifts, respectively, vs. just 50 ppm for water vapors. This substantial difference of the sensor sensitivity towards VOC vs. water is attributed to the high volatility of VOC and their high molecular mass.

A feasibility study of miniature dielectrically stacked bulk acoustic resonators (DSBAR), readily available at very low prices, has been performed to prove their suitability for the design of low-noise microwave voltage controlled oscillators (MVCO) for possible applications in synthesizers for cell phone base stations, satellite communications and digital radio. MVCO at 1,55 GHz with 44 MHz (3%) tuning range and extremely low phase noise (-114 dBc/Hz at 10 kHz carrier offset) have been demonstrated.

Synthesis, study and application of plasma polymers and composites

The plasma polymerization method is applied to prepare boron-containing polymer layers. Preliminary experiments were carried out using borax solutions as starting material in ethyl alcohol of different concentrations. The resulting thin layers on glass and silicon are characterized by XPS. The results show the presence of boron-carbon bonds, which proves the synthesis of a new boron-containing polymer. Raman spectroscopy is forthcoming.

STW resonators, with optimized parameters of the glow discharge polymerization process – discharge, current density and flow rate of the hexamethyldisiloxane monomer, as well as modification with ammonia plasma - were obtained. The purpose is to create a sensor element with an active layer to measure atmospheric pollution as ammonia vapor.

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

Within 2019, superhydrophobic piezoresonance sensors for human spermatozoa quality assessment and *in-situ* detection of postejaculatory dynamic characteristics (phases of coagulation and liquefaction) of fresh human semen were developed. Controlled combustion of rapeseed oil was used to synthesize carbon soot coatings and integrate them in piezoresonance sensor devices as an interface sensing material for suppression of the inevitably high noise levels during the sensor performance in biological suspensions. Furthermore, the first of its kind fundamental studies were conducted to establish a direct correlation between the combustion regimes of rapeseed oil and the corresponding optical properties of the superhydrophobic soot. It was observed for the first time that the soot can transmit up to 10 % of the incident light beam in the near-infrared region, which is 10 to 100 times higher optical transmittance compared to the existing graphite-like nanostructures (graphite, graphene, pyrolytic carbon, etc.). Such significantly improved optical properties of the carbon soot were found to result from changes in the chemical bonding of the material from sp^2 to sp^3 hybridization, which reduces the total amount of delocalized electrons and prevents the total light absorption (unlike graphite, for example). These flame synthesized soot coatings were further functionalized with silver hydrogen fluoride for significant improvement of their wear resistance. The as-prepared "hybrid" soot retained superhydrophobicity and structural integrity upon harsh finger wiping and high-impact water jetting (25 m/s), as well as between 50-80% of the surface properties after sandpaper abrasion.

AWARDS:

The papers:
(1) K. D. Esmeryan, R. R. Ganeva, G. S. Stamenov, T. A. Chaushev, Superhydrophobic soot coated quartz crystal microbalances: A novel platform for human spermatozoa quality assessment, Sensors 19 (2019) 123.
(2) K. D. Esmeryan, G. S. Stamenov, T. A. Chaushev, An innovative approach for in-situ detection of postejaculatory semen coagulation and liquefaction using superhydrophobic soot coated quartz crystal microbalances, Sensors and Actuators A Physical 297 (2019) 111532.

won the 2-st place in the contest of the Institute of Solid State Physics for best application oriented scientific paper for 2019

PUBLICATIONS:

1. Avramov I. D., Ivanov G. R.,"Langmuir – Blodgett Films from Fluorescently Labeled Phospholipids on Surface Acoustic Wave Devices", 20th International School on Condensed Matter Physics, *Journal of Physics*: Conference Series (JPCS), 2019.
2. K. D. Esmeryan, R. R. Ganeva, G. S. Stamenov, T. A. Chaushev, Superhydrophobic soot coated quartz crystal microbalances: A novel platform for human spermatozoa quality assessment, *Sensors* **19** (2019) 123.
3. K. D. Esmeryan, C. E. Castano, Y. I. Fedchenko, R. Mohammadi, I. K. Miloushev, K. A. Temelkov, Adjustable optical transmittance of superhydrophobic carbon soot coatings by *in-situ* single-step control of their physicochemical profile, *Colloids&Surfaces A* **567** (2019) 325-333.

4. K. D. Esmeryan, G. S. Stamenov, T. A. Chaushev, An innovative approach for *in-situ* detection of postejaculatory semen coagulation and liquefaction using superhydrophobic soot coated quartz crystal microbalances, *Sensors and Actuators A Physical* **297** (2019) 111532.
5. K. D. Esmeryan, C. E. Castano, T. A. Chaushev, R. Mohammadi, T. G. Vladkova, Silver-doped superhydrophobic carbon soot coatings with enhanced wear resistance and anti-microbial performance, *Colloids&Surfaces A* **582** (2019) 123880

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.**
tel: 979 5686; e-mail: nesheva@issp.bas.bg

TOTAL STAFF: ***9***
RESEARCH SCIENTISTS: ***7***
ASSOC. MEMBERS: 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. Prof. R. Dzhurkova; Chemist Z. Ivanova, Eng. V. Dzhurkov, Technologist E. Zaharincheva;

Honorary members: Prof. E. Vateva, D.Sc; Assoc. Prof. K. Kolentsov;
Associated members: Prof. S. Kaschieva, 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.;, Ph.D.; Assoc.Prof. N. Peev, Ph.D.

RESEARCH ACTIVITIES

Equipment and technology are developed for preparation of ZnO layers with spin-coating sol-gel method, which allows deposition of layers with thickness of up to 300-350 nm. The films are deposited either by applying the standard approach, or by using an additional treatment with hot air. After the deposition of the layers, they are heated at 140 °C or 400 °C and then a part of the two types of layers are irradiated with infrared nanosecond laser pulses with an energy fluence of 110 mJ/cm^2. X-ray diffraction measurements show that all layers (heated at 140 °C and 400 °C, as well as laser irradiated) have a wurtzite crystal structure. Raman scattering measurements show presence of C-H vibrations in the spectra of all layers, which indicates that none of the applied treatments results in the complete release from the layers of the organic remains from the precursors. The results obtained by Atomic Force Microscopy (AFM) reveals tightly packed nanocrystals having size of 20-30 nm which is significantly smaller than that in films prepared by deep-coating sol-gel method. The optical micrographs and AFM surface images of the layers prepared by applying the standard approach show existence of fibrous-like surface structures responsible for the high surface roughness of these layers (up to 160 nm). No fiber structure is observed on the surface of the layers deposited by application of the treatment with warm air. The results obtained with a scanning electron microscope show that laser irradiation leads to a decrease in the density and size of the pores on the layers surface. It is concluded from the obtained results that both the layer deposition technology and the laser irradiation provide new possibilities for changing and controlling the properties of the ZnO layers with regard to certain intended application.

The thickness, bandgap and optical constants of ZnO thin layers doped with iron, cobalt, and nickel, deposited by atomic layer deposition (ALD) on silicon and glass substrates are determined by spectroscopic ellipsometry. The work on the optical characterization of thin layers of metal oxides (Al_2O_3, AlZnO, TiO_2, ZnO, etc.) by ellipsometric measurements is

continued, as well. These layers were deposited by atomic layer deposition (ALD) on silicon and glass substrates or by the sol-gel method.

In order to determine the ALD "window" for deposition of layers from AlN, systematic ellipsometric measurements are performed on layers deposited on Si substrates, from which the thicknesses of the layers are obtained. Ellipsometric measurements are also made on graphene layers deposited on SiO_2/Si substrates.

Thin films of ZnSe with a thickness of 50 nm are produced by thermal vacuum evaporation at deposition rates of 0.5, 1.5, and 3 nm/s. The layers are deposited either statically i.e. on substrates fixed above the crucible evaporating ZnSe or dynamically - on rotating substrates which pass periodically above the crucible. Samples from each batch are further annealed at 200 °C in an inert atmosphere for 60 minutes. X-ray diffraction studies show that the layers are nanocrystalline with a cubic structure and the calculated crystallite sizes are in the range of 6-18 nm. Information about the optical absorption coefficient, film thickness, porosity, and surface roughness are obtained by using spectroscopic ellipsometry. From the absorption spectra, the optical bandgap is determined; it is the same (2.73 eV) for all fresh and annealed ZnSe layers. It is also found that the layers deposited dynamically have higher porosity than those deposited statically. The measured Raman spectra confirm that the layers are nanocrystalline and porous and indicate the presence of internal stresses or/and excess selenium in the films. The small size of the nanocrystals and the porosity make the studied ZnSe layers promising for chemical sensor application.

The compositional relationships of the photoluminescence (PL) from Sb_2O_3-PbO-ZnO/ZnS glasses doped with $ErCl_3$ (0.25, 0.5, and 1.0 mol %) are investigated. The fluorescence spectra are measured at room (300 K) and low (4 K) temperatures in the 400-1700 nm range. The effect of the concentration of the alloying element on the emission bands at 660, 855, 980, 1230 and 1530 nm is determined. Particular attention is paid to the most relevant PL band at ~ 1530 nm. The determined parameters of the stimulated emission cross section and quantum efficiency show that the synthesized new glasses can be used as a laser medium and in telecommunications for optical amplification at ~ 1.5 μm.

Complex photoluminescence studies of erbium-doped $(GeS_2)_{100-x}(Ga_2S_3)_x$ chalcogenide glasses are summarized. Based on the obtained knowledge for strong influence of Ga_2S_3 content in the matrix on the erbium ions solubility, samples with high concentrations of Ga_2S_3 (x = 25 and 33 mol %) and Er_2S_3 (1.8-2.7 mol%) are measured. In this way, the optimal composition of these glasses is specified for their application in photonics.

Information is obtained on the morphology, crystalline structure and chemical sensitivity of as-prepared (amorphous) and additionally annealed at 450 ^oC nanotubes of titanium dioxide grown on Ti6Al4V alloy substrates. The observed delayed formation of the anatase phase is related to the inclusion of aluminum atoms coming from the substrate in the nanotubes. It is also found that the amount of anatase phase decreases with decreasing wall thickness and diameter of the nanotubes, which is explained by an increase in the crystallization temperature of the nanotubes with decreasing their size. Examination of the optical response of the samples to ethanol vapor at room temperature revealed relations between the size of the nanotubes and their sensitivity to ethanol vapors.

PUBLICATIONS

1. **Dzhurkov V.**, **Levi Z.**, **Nesheva D.**, **Hristova-Vasileva T.**, Room temperature sensitivity of ZnSe nanolayers to ethanol vapours, Journal of Physics: Conference Series, 1186, 012023 (2019).

2. **Hristova-Vasileva T.**, **Bineva I.**, Todorov R., Dinescu A., Romanitan C., In-depth evolution of tellurium films deposited by frequency assisted thermal evaporation in vacuum (FATEV), Journal of Physics: Conference Series, 1186, 012026 (2019).
3. **Manolov E.**, Paz-Delgadillo J., **Dzhurkov V.**, Nedev N., **Nesheva D.**, Curiel-Alvarez M., Valdez-Salas B., Investigation of resistive switching in SiO_2 layers with Si nanocrystals, Journal of Physics: Conference Series, 1186, 012022 (2019).
4. **Nesheva D.**, Babeva Ts., Vasileva M., Valdes-Salas B., **Dzhurkov V.**, Grujić-Brojčin M., Šćepanović M., Perez O., Nedev N., Curiel M., Srećković T., Phase characterization and ethanol adsorption in TiO_2 nanotubes anodically grown on Ti_6Al_4V alloy substrates, Journal of Alloys and Compounds, 798, 394-402 (2019).
5. **Nesheva D.**, Petrik P., **Hristova-Vasileva T.**, Fogarassy Z., Kalas B., Šćepanović M., **Kaschieva S.**, Dmitriev S.N., **Antonova K.,** Changes in composite nc-Si-SiO_2 thin films caused by 20 MeV electron irradiation, Nuclear Instruments and Methods in Physics Research, Section B: Beam Interactions with Materials and Atoms, 458, 159-163 (2019).
6. Curiel M., Nedev N., Paz J., Perez O., Valdez B., Mateos D., Arias A., **Nesheva D.**, **Manolov E.**, Nedev R., **Dzhurkov V.,** UV sensitivity of MOS structures with silicon nanoclusters, Sensors, 19, 1-7 (2019).
7. Dikovska A., **Tzonev L.**, Avramova I., **Terziiska P.**, **Bineva I.**, Avdeev G., Valcheva E., Angelov O., Mladenoff J., Kolev S., Milenov T., Ellipsometric study of thin carbon films deposited by pulsed laser deposition, Proc. SPIE, 11047, 110470N (2019).
8. Kolaklieva L., Chitanov V., **Szekeres A.**, **Antonova K.**, **Terziyska P.**, Fogarassy Z., Petrik P., Mihailescu I.N., Duta L., Pulsed laser deposition of aluminum nitride films: Correlation between mechanical, optical, and structural properties, Coatings, 9, 195 (2019).
9. Kostka P., **Ivanova Z.G.**, Nouadji M., Cernoskova E., Zavadi, J., Er-doped antimonite Sb_2O_3-PbO-ZnO/ZnS glasses studied by low-temperature photoluminescence spectroscopy, J. Alloys Compounds, 780, 866-872 (2019).
10. Milanova M., Donchev V., **Terziyska P.**, Valcheva E., Georgiev S., Kirilov K., Asenova I., Shtinkov N., Karmakov Y., Ivanov I.G., Investigation of LPE grown dilute nitride InGaAs(Sb)N layers for photovoltaic applications, AIP Conference Proceedings, 2075, 140004 (2019).
11. Milanova M., Donchev V., Kostov K.L., Alonso-Álvarez D., **Terziyska P.**, Avdeev G., Valcheva E., Kirilov K., Georgiev S., Study of GaAsSb:N bulk layers grown by liquid phase epitaxy for solar cells applications, Materials Research Express, 6, 075521 (2019).
12. Milenov T., Dikovska A., Avdeev G., Avramova I., Kirilov K., Karashanova D., Terziyska P., Georgieva B., Arnaudov B., Kolev S., Valcheva E., Pulsed laser deposition of thin carbon films on SiO_2/Si substrates, Applied Surface Science, 480, 323-329 (2019).
13. Avramova I., Dikovska A., Valcheva E., **Terziiska P.**, Mladenoff J., **Tzonev L**, Kolev S., Milenov T., X-ray photoelectron spectroscopy characterization of amorphous and nanosized thin carbon films, Proceedings of SPIE - The International Society for Optical Engineering, 11047, 110470D (2019).
14. Mladenoff J., **Tzonev L.**, Kirilov K., Avramova I., Avdeev G., Valcheva E., Russev S., Arnaudov B., **Terziiska P.**, Kolev S., Milenov T., Study of the initial stages of deposition of graphene-like films by sublimation of amorphous carbon, AIP Conference Proceedings, 2075, 160029 (2019).
15. Guziewicz E., Krajewski T.A., Przezdziecka E., Korona K.P., Czechowski N., Klopotowski L., **Terziyska P.**, Zinc oxide grown by ALD – from heavily n-type to p-type material, 257, 2, 1900472 (2020).

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.

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.

DEPARTMENT SOFT MATTER PHYSICS

LABORATORY

LIQUID CRYSTALS AND BIOMOLECULAR LAYERS

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

RESEARCH ACTIVITIES:

The electro-optical (EO) response of nematic liquid crystal (NLC) nanocomposite doped with a photoactive NLC was studied. The basic nanocomposite was NLC with nanosilica fillers. The host compound of the investigated nanocomposite was the nematogen 4-n-heptyl cyanobiphenyl (7CB). This NLC was filled (3 wt.%) with hydrophilic silica nanoparticles (Aerosil 300) of size ~7 nm. To obtain a photoresponsive nanofilled NLC, the photoinsensitive aerosil/7CB nanogel was doped (3 wt.%) with azobenzene NLC 4-(4'ethoxyphenylazo)phenyl hexanoate (EPH). By illumination with UV light with wavelength of 375 nm, a large reduction of the threshold voltage takes place for the voltage-dependent optical transmittance of thin (25 μm) optical films of the produced EPH-doped aerosil/7CB NLC. The photo-induced depression of the threshold of the LC reorientation upon AC electric field occurs due to trans-cis photoisomerization of EPH molecules that decorate the network of the aerosil/7CB nanogel. Our explanation of this effect involves a model consisting of uniform distributed capacitances related to LC domains confined in the gel structure that are connected in series. Based on this model the term Confined Freedericksz Transition (CFT) is coined.

The bending rigidity and capacitance of lipid bilayers were measured in aqueous solutions of aspartame and sorbitol, which are non-saccharide sweeteners with wide application in the food industry. Our interest in these compounds is motivated by the existing issues on their influence on the human organism raising questions about the impact of these molecules at membrane level. Deformation of lipid vesicles in AC fields was employed to obtain the electrical capacitance of palmitoyl-oleoyl phosphatidylcholine bilayers in sorbitol solutions. Analysis of the thermal shape fluctuation of lipid vesicles was applied to determine the bending elasticity modulus of POPC membranes in the presence of aspartame or sorbitol in the aqueous

solution. Their influence on the studied membrane properties is found to be different from the effect of sugars reported earlier.

As vital components of all membranes, intimately concerned in protein-protein, lipid-lipid and protein-lipid interactions in cells, cations may alter the structural organization of chloroplast membranes. For elucidation of molecular mechanisms underlying divalent cation interactions with chloroplasts, microelectrophoresis and light scattering of thylakoid preparations were combined at fixed pH values of 7.5 and of 6.3 upon addition of calcium or magnesium cations. In their presence the net negative membrane charge density and aggregation of thylakoids are obtained to increase upon illumination. The secondary ion-exchange (proton gradient formation) across the membrane is enhanced by divalent cations at pH 7.5. Our results indicate a strong effect of Mg^{2+} and Ca^{2+} on thylakoid aggregation and primary ion-exchange processes across the membrane at pH 6.3.

Using the methods differential scanning calorimetry (DSC) and Fourier transform infrared spectroscopy (FTIS), the effect of hydrophobic coated gold nanoparticles and single-walled carbon nanotubes (nonfunctionalized and amide-functionalized) on the phase behavior and the spectral response of the synthetic lipid stearoyl-oleoyl-phosphatidylcholine was studied. The used nanoparticles were 4nm in size and have been synthesized by colleagues from the University of Chemical Technology in Moscow. The results from differential scanning calorimetry showed that the addition of hydrophobic nanoparticles in the concentration range of 0.5 - 5 wt% strongly influenced the lipid phase transitions and at the highest studied concentration (5 wt%) blurred the transition from gel (L_β) to liquid crystalline phase (L_α).

The results from the obtained infrared spectra showed an increase in the intensity of some of the absorption lines (C-O; P-O; C = O and C = H) with increasing nanoparticle concentration in the system. The FTIS results showed that the addition of both functionalized and non-functionalized carbon nanotubes (at concentrations 0.5-1 mg) resulted in a strong increase in the ratio $A_{C=Obonded} / A_{C=Ofree}$. However, the further increase in the carbon nanotube content showed a negligible effect on the population of hydrogen-bounded C = O conformations. The data obtained from DSC analysis demostrated that the enthalpy values, respectively, the entropy of the lipid and non-functionalized nanotubes bio-nanocomposite are smaller compared to those of the mixtures of lipid and functionalized ones. The obtained results demonstrated a better ability of the functionalized nanotubes to form hydrogen bonds with carbonyl C = O and polar P = O groups compared to non-functionalized ones.

In the frameworks of a joint research work with the Institute of Engineering Chemistry at the Bulgarian Acaemy of Sciences the implementation of tasks on contract with Bulgarian National Science Fund on the topic "Method for estimation of the transfer efficiency in integrated processes in a bioreactor with membrane separation" was performed. Experiments on membrane separation of biologically active substances from the group of polyphenols and flavonoids from plant materials were performed. A series of cross-current micro- and nano-filtration experiments were carried out with a MaxiMem membrane filtration system (PS Prozesstechnik GmbH), equipped with an NF membrane "Microdyn Nadir NP030P". The filtration and concentration processes were optimized using a membrane with MWCO ~ 400. It was shown that the used membrane had a low threshold. In order to recover the biologically active compounds in the plant extract for further utilization and for obtaining purified glucose solution and concentrated solution of polysaccharides and polyphenols a series of fractionation experiments via nanofiltration were conducted. For the purposes of the membrane separation a watery weed extract of Myriophyllum spicatum with an initial glucose concentration of 6 g/l and 10 g/l was used. The filtration was performed at the following operating parameters: transmembrane pressure (5, 10, 20 bar), tangential flow (0.8, 1.2, 1.6, 2 l/min) and room temperature.

Ceramic multifunctional materials were synthesized and characterized in order to be used in the practice. Through solid state synthesis, bulk samples were obtained from the systems: Y-Ba-Cu-O (with nominal composition: 123; 134; 156; 13-20-33) and the same doped with Ag_2O and Fe_3O_4 and Bi-Sr-Ca-Cu-O (nominal composition: 2201; 2212). Various methods such as scanning electron microscopy (SEM), X-ray diffraction analysis (XRD), energy dispersive spectroscopy (EDS), determination of oxygen content by spectrophotometric technique and magnet measurements (AC / DC) were used to study them. Doping of Y-Ba-Cu-O samples with additives (Ag_2O and Fe_3O_4) in low concentration, based on literary data, improves their superconducting properties and increases their critical temperature and critical current density. The synthesized Bi-Sr-Ca-Cu-O ceramics can be added to the electrode mass of the zinc electrode in nickel-zinc batteries in order to enhance its electrochemical properties.

The structure, morphology, chemical composition, thermal behavior and mechanical properties of as-received or used in-vivo (clinical practice) orthodontic archwires made of the following alloys were studied: nickel-titanium, copper-nickel-titanium and titanium-niobium. When selecting the appropriate archwire for a particular stage of the fixed technique orthodontic treatment, information on physicochemical characteristics, thermal phase transitions and mechanical properties is of utmost importance to the treating orthodontists. Modern methods such as X-ray diffraction (XRD), scanning electron microscopy (SEM), energy-dispersion analysis (EDS) and X-ray photoelectron spectroscopy (XPS), differential scanning calorimetry (DSC) and nanoindentation (Nanoententation) were used. The qualitative and quantitative elemental analysis revealed no significant changes in the Ni:Ti ratio (1:1). Respectively, Ni 51.21wt% and Ti 48.79wt% for archwires used up to 6 weeks and Ni 50.36wt% and Ti 49.64wt% for archwires used more than 8 weeks. The surface analysis of the clinically rertieved TriTanium archwires showed surface defects and scratches in all regions and the archwires used for more than 8 weeks have greater porosity. The thermal phase transitions in the temperature range from -50 °C to + 50 °C correspond to different transition temperatures of the austenitic, martensitic and R phases of the as-received and clinically retrieved TriTanium archwires in the three regions. Due to the increasing cases of Ni allergy in patients, especially in children, the Ti-Nb archwire was investigated as a good alternative. The X-ray diffraction analysis of as-received and used for 4 and 6 weeks Ti-Nb archwires (ORMCO Company, CA, USA) showed a Ti-Nb alloy with austenitic structure and β-phase lattice. The content of Ti and Nb in the as-received archwire, respectively 57.47wt% and 42.52wt% did not change significantly after use for treatment up to 6 weeks as obtained from SEM analysis. The XPS analysis of clinically retrieved Ti-Nb orthodontic archwires revealed the presence of Si, P, C, and O on the sample surface.

The study of Ti-Nb, Cu-Ni-Ti and Tritanium orthodontic archwires is a joint scientific activity with the Department of Orthodontics, Medical University – Sofia. This research is essential for optimization of the usage of orthodontic archwires in the clinical practice, and will be beneficial for the patient's health.

Ni-Zn batteries are battery systems with high energy density, high work potential and wide working temperature ranges. They have significant advantages such as low toxicity, low cost and abundant resources, stability in aqueous electrolyte and low equilibrium potential. The main disadvantage of this type of battery is the poor electrical conductivity of ZnO and the limited life, expressed in cycles, which is mainly due to passivation, change in the shape of the Zn electrode and the formation of dendrites. The zinc electrodes were characterized through scanning electron microscopy (SEM), X-ray diffraction analysis (XRD), energy dispersive X-ray spectroscopy (EDX), electrochemical impedance spectroscopy (PEIS), chronopotentiometry (CP) and cyclic voltammetry (CV). The conducted electrochemical studies with Bio-logic SP-200 potentiostat-galvanostat confirmed the positive effect of the two types of ceramic additives B(Pb)SCCO 2201 ($Bi_{1.7}Pb_{0.3}Sr_2CuO_x$) and B(Pb)SCCO 2212

($Bi_{1,7}Pb_{0,3}Sr_2CaCu_2O_x$) on the electrochemical properties – over 30% higher discharge capacity during prolonged cycling as a result from the increase of the conductivity and homogeneity of the electrode mass in the presence of additives, on one hand, and the formation of highly conductive network between the ZnO particles, on the other. The positive effect of B(Pb)SCCO 2201 on the zinc anode is not due to the internal conductivity but due to the reduction products of the ceramic formed during the charging of the electrode. For the first time, structural and morphological changes in ceramics B(Pb)SCCO 2212 and B(Pb)SCCO 2201 were investigated before and after their electrochemical treatment (CV and CP measurements) in a Ni-Zn battery-like medium (7M KOH, 25 ^oC). After CV, various reduction products are found, such as CuO, Bi_2O_3, Bi_2CuO_4, $Ca(OH)_2$ and $Sr(OH)_2$ and the CV curves show that at higher negative potentials the Cu and Bi compounds are further reduced to metallic Cu and Bi. This can lead to the formation of metal particles that improve the overall conductivity of the electrode and the contact between the particles of the active ZnO. On the other hand, the Ca- and Sr- products in the case of the B(Pb)SCCO 2212 modification do not participate in the redox processes. Under the conditions of the experiment, hydroxides are formed, which form insoluble compounds with Zn, which reduce the solubility of ZnO in the electrolyte and suppress the shape change of the electrode. Therefore, B(Pb)SCCO 2212 could have an additional positive effect on the performance of the Zn electrode compared to B(Pb)SCCO 2201. Ultrasound assisted mixing is used in order to achieve a better homogenization of the additives with the zinc active mass. The composition of the active mass is preserved during the ultrasound mixing. The ultrasound irradiation further improves the effect of the ceramics on the properties of the electrode. Because of all this we conclude that the better homogenization of the additives with the ZnO could improve the conductivity and stability; therefore, prolonging the life of the battery. The obtained results provide a base for further studies of the newly prepared Zn electrodes in Ni-Zn electrochemical cell.

AWARDS:

Best achievement of ISSP-BAS in applied science, 2019: "Na^+ ion-conducting polymer-based electrolyte containing nanoparticles or liquid crystal",
Y.G. Marinov, G.B. Hadjichristov and T.E. Vlakhov

Certificate of Excellence: V. Petrova, P. Lilov, O. Petkov, G. Ivanova, A. Stoyanova, V. Mikli, A. Stoyanova-Ivanova,, "B(Pb)SCCO ceramics with potential application as additives in rechargeable Ni-Zn batteries", **Best poster award:** G. B. Hadjichristov, **T. E. Vlakhov**, Y. G. Marinov, H. K. Koduru, N. Scaramuzza "Impedance spectroscopy study of novel electrolytic systems composed from polymer polyethylene oxide (PEO) and liquid crystal E8", VIII National Student Scientific Conference on Physics and Engineering Technologies with international participation (31 October - 1 November 2019), Plovdiv, Bulgaria

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3. Mitkova, D., Antonova, K., Vitkova, V., Mechanical and electrical properties of biomimetic membranes in the presence of sweeteners. AIP Conference Proceedings, 2075, 1, AIP Publishing, 2019, ISSN:0094243X, 170009. SJR (Scopus):0.18 https://doi.org/10.1063/1.5091374

4. Genova, J., Chamati, H., Slavkova, Z., Petrov, M.. Differential scanning calorimetric study of the effect of cholesterol on the thermotropic phase behaviour of phospholipid SOPC, Journal of Surfactants and Detergents, 22, 2019, 1229-1235. DOI: 10.1002/jsde.12289 IF: 1.672 https://aocs.onlinelibrary.wiley.com/doi/abs/10.1002/jsde.12289

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9. Y. G. Marinov, G. B. Hadjichristov, A. G. Petrov, S. K. Prasad “UV light enhanced confined Freedericksz transition in photoisomerizable nematic nanocomposite with photoactive molecules of azobenzene nematic liquid crystal”, AIP Conference Proceedings 2075 (2019) 020020. DOI: 10.1063/1.5091137, ISSN: 0094243X, ISBN: 9780735418035

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ONGOING RESEARCH PROJECTS:

1. Research Project: “Investigations of Photostimulation Effects in Nano-Structured Liquid Crystals”, Indo-Bulgarian intergovernmental programme, contract DNTS/ India 1/04, NSF, (2014-2019), coordinator: Assoc. Prof. Dr Y. Marinov
2. 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
3. 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
4. Research Project “A mechanistic approach to revealing the molecular mechanism of how oxidized lipids alter the 2D and 3D lipid organization in model membranes” National Science Fund, Bulgaria – Grant DN18-15/15.12.2017), Coordinator, principal investigator: Professor Dr G. Staneva, IBPBME-BAS; ISSP-BAS /partner organization/ Coordinator: Assoc. Prof. Dr V. Vitkova
5. 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
6. Research Project “New effects in nano-thin ordered organic films (Langmuir and Langmuir-Blodgett) and their use for conceptual development of a new generation of biosensors for working in a fluid environment at ambient conditions and real-time monitoring of hard-to-find water pollutants (anti-terrorism) or early diagnosis by tumor markers (acronym NanoBioSensors)” (contract № KP-06-OPR 03/9), 2019 – 2021, ISSP-partner coordinator Assoc. Prof. Dr Y. Marinov
7. Research Project “Model membrane systems in the presence of biologically active macromolecules: physical and physicochemical parameters in norm and pathology”

National Science Fund, Bulgaria – Grant KP-06-N38/14/2019), Coordinator, principal investigator: Assoc. Prof. Dr V. Doltchinkova, Sofia University "St. Kliment Ohridski"; Coordinator from ISSP-BAS /partner organization/: Assoc. Prof. Dr V. Vitkova

8. 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
9. Bilateral Research Project /ISSP – BAS and Wallonie Bruxelles International – Belgium/ 2018-2020: "Développement et application de la microscopie holographique pour la visualisation tridimensionnelle et l'étude de la dynamique d'objets biomimétiques", coordinator Assoc. Prof. Dr. V. Vitkova
10. Bilateral Research Project /ISSP-BAS and Tallinn University of Technology, Estonian Academy of Science (Estonian projects TAR16016 and IUT-T4)/ coordinator Assoc. Prof. Dr Angelina Stoyanova-Ivanova

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DEPARTMENT PHYSICAL OPTICS AND OPTICAL METHODS

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RESEARCH SCIENTISTS: **12**
ASSOC. MEMBERS: ***5***

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

RESEARCH ACTIVITIES:

Ion-conductive solid polymer electrolytes composed from blends of poly-(ethylene oxide) (PEO) and poly(vinylpyrrolidone) (PVP), as complexed with the ionic compound sodium periodate ($NaIO_4$), are inspected for the presence of electric charge trapping (CT) and ionic space charge polarization (SCP) under static electric field. Thin films (110 μm-thick) of these materials are produced at a ratio of the polymers PEO:PV =70:30 wt%, the concentration of $NaIO_4$ is 5, 7.5, or 10 wt%. The electrical current at room temperature, as well as the charging/discharging in the films are studied as depending on applied voltage and time. At a detectable level, no SCP and CT processes in PEO-PVP-$NaIO_4$ are evidenced, in contrast to identical experiments by PEO film under the same experimental conditions. The largely reduced SCP and CT are of importance for electrochemical applications of the considered ion-conducting PEO-PVP-$NaIO_4$ ion-polymer coupled system. The samples of solid polymer electrolytes PEO-PVP-$NaIO_4$ are characterized also by means of optical spectroscopy - diffuse reflectance from the surface of these electrolytes. With this experimental technique, it is found that the addition of $NaIO_4$ leads to an increase in the percentage of the amorphous fraction in the polymeric matrix of PEO-PVP-$NaIO_4$, which is very important for the electrolytic function of this material.

Graphene oxide (GO) nano-sheets incorporated PEO/PVA composite membranes complexed with $NaIO_4$ salt at different concentrations were prepared using the solution casting technique. The nanocomposite GO/PEO/PVA membranes demonstrated improved mechanical tensile strength and Young's modulus in comparision to pure PEO/PVA blends. Impedance measurements were performed in the frequency range of 0.1 Hz – 3 MHz and at temperature in the range of 30 – 70 °C. The blend electrolyte PEO/PVA complexed with 20 wt.% of $NaIO_4$ salt demonstrated Na^+ ion conductivity of 1.03×10^{-7} S/cm at room temperature. As a result of

incorporation of 0.9 wt% GO nanosheets, the room temperature ionic conductivity of GO/PEO/PVA/$NaIO_4$ is enhanced by one order of magnitude. The effect of introducing GO nanosheets in the matrix of PEO/PVA blend electrolyte membranes was noticed by means of increment in charge carriers, diffusivity and mobility of the ions

The structural, electrical and dielectric properties of electrolytic system composed of polymer poly(ethylene oxide) (PEO) and nematic-type liquid crystals (LC) E8 (at composition ratio PEO:E8 = 70:30 wt.%), being of interest for practical applications in rechargeable mini-batteries and organic electronics. Flexible thin films of this organic electrolyte with a thickness of ~ 0.1 mm were characterized by frequency spectra of complex electrical impedance and dielectric function. As compared to the host polymer PEO, a significant improvement of both electrical transport and dielectric properties of PEO-E8 composite electrolyte was achieved. The obtained results were compared with the corresponding values and characteristics measured for advanced metal-organic solid-state polymer electrolytes based on PEO or blends of PEO with polyvinylpyrrolidone (PVP) - ionic polymer electrolyte complexes from PEO/PVP doped with inorganic ionic compound and currently trending nanoparticles. The effect from the inclusion of nematic LC E8 into the polymer PEO was inspected by studying of structural and electrical properties of PEO-E8 composites at weight percentage of E8 ranging from 10 % to 50 %. PEO-E8 films were structurally characterized by X-ray diffraction (XRD) and X-ray photo-electron spectroscopy (XPS). The results obtained by analyses indicate that a polymer- LC intermolecular complex is formed by inclusion of E8 LC molecules in the PEO host at a certain their concentration level. The structural properties of PEO-E8 composites were correlated with their electro-conducting properties as depending on the E8 LC concentration. By the amount of the LC fraction one can achieve a controlled modification of the structural and electro-conducting properties of the PEO-E8 material. As compared to PEO, the inclusion of E8 LC in the PEO polymer matrix can lead to a considerably enhanced electrical conductivity of PEO-E8 composites.

Novel electrolytic systems composed from polymer PEO, the mesogenic liquid crystal (LC) mixture E8 and the salt sodium metaperiodate ($NaIO_4$) as ions dopant, were studied by electrical measurements upon temperature variation. Free-standing films (thickness from 0.1 to 0.25 mm) of flexible composite electrolytes were produced by solution casting technique from PEO and E8LC at a ratio PEO:E8LC 70:30 wt.%, with addition of $NaIO_4$ at weight percentage ranging from 2 to 10 wt.%. Being of importance for electrochemical and other applications, the complex electrical impedance spectra and current-voltage characteristics of sodium ion-conductive PEO/E8LC/$NaIO_4$ electrolyte films were analyzed and interrelated to their structural properties and thermal behaviors. The composite-salt complexations were examined by X-ray diffraction (XRD), Fourier transform infrared (FTIR) spectroscopy, micro-Raman and X-ray photoelectron spectroscopy (XPS) studies. Differential scanning calorimetry (DSC) studies confirmed the decrease of percentage of crystalline portion in the matrix of electrolyte membranes upon that addition of $NaIO_4$. The EIS studies evidenced for the increase of ionic conductivity of the electrolytes upon increase of $NaIO_4$ concentration. PEO/E8 electrolyte complexed with 10 wt% of $NaIO_4$ demonstrated an enhanced ionic conductivity of 1.05×10^{-7} S/cm at room temperature. Compared to another advanced Na^+-conducting solid polymer-blend electrolyte, namely $NaIO_4$-complexed PEO/PVP/$NaIO_4$ at equal concentration of the salt, the studied PEO/E8LC/$NaIO_4$ electrolytes exhibit similar value of ionic conductivity. Such flexible composites incorporating LC soft matter are ionic conductors that can combine the advantages of solid polymer electrolytes with the unique properties of the LC soft matter included in plastic materials. They are promising polymer-LC combination and are attractive for sensorics, mechatronics and soft electronics applications.

Thin (7 μm) planar layers of nanocomposites from graphene nanoflakes (GrFs) dispersed at concentrations of 10^{-3} wt.% into the nematic liquid crystal (NLC) E7 were

characterized by various investigation techniques, such as optical spectroscopy (UV-Vis absorbance and Raman spectroscopy), impedance measurements and dielectric spectroscopy, as well as by electro-optical measurements (optical transmittance of the NLC layers versus the voltage of the applied external AC electric field). Their responses were compared to those of films of pure LC E7 measured under identical experimental conditions. Being nematic nanocomposite material, such graphene-doped LC material is of interest for electro-optics and organic electronics. Conducting behaviour, dielectric permittivity and electric energy loss of the prepared planar-aligned NLC layers at room temperature were analysed as a function of frequency in the range from 0.5 Hz to 1 MHz. It was found that graphene nanodopants lead to a change of both electrical transport and dielectric function of the LC E7 which should render improved electro-optic response of the considered room-temperature nanocomposite nematic films. The analysis of experimental data indicates that the molecular alignment through GrFs/NLC surface interactions is responsible for the reduction of the ionic conductivity of E7 NLC in the presence of GrFs. As compared to pure LC E7, this leads to improved characteristics for the studied nanocomposites, necessary in their practical applications in electro-optics.

Being of practical importance for photo-controllable electro-optical (EO) applications based on nematic liquid crystals, the photo-stimulated EO response of photoactive nematic nanocomposites was studied by thermo-optical and EO measurements. Strong photo-induced effect upon alternating-current electric field was obtained by thin (25 μm) optical films of nematic nanocomposites illuminated with UV light at the wavelength of 375 nm. The investigated nematic nanocomposites were produced from nematic liquid crystal 4-n-heptyl cyanobiphenyl (7CB) filled with 3 wt.% aerosil nanoparticles of size ~ 7 nm, and further doped with 3 wt.% azobenzene nematogenic liquid crystalline molecules. In a certain temperature range, the electric-field driven optical transmittance of azo-doped aerosil/7CB films can be efficiently controlled by light through *trans-cis* photoisomerization of azobenzene nanodopants. The photo-induced effect on the electrically-controlled optical transmittance of photoactive azobenzene-doped nematic nanocomposites, was studied by electro-optical measurements. Upon alternating-current electric field, the photo-induced effect on the voltage-dependent light transmittance of aerosil/7CB/EPH is well pronounced, rather strong and reversible. The effect from UV light intensity and the role of the photoisomerizable photochromic EPH nanodopants for photo-controllable electro-optics of the nematic aerosil/7CB/EPH nanocomposite, were elucidated.

We estimate the fundamental thermodynamic quantities, such as enthalpy and entropy, of the bilayer phosphatidylcholine using the differential scanning calorimetric (DSC) technique. The thermal properties of SOPC (stearoyl-2-oleoyl-sn-glycero-3-phosphocholine) phospholipid and its mixture with cholesterol, in the range between 10 and 50 mol% were investigated. 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_β) to liquid crystals (L_α) 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. It is found that the gel-liquid crystal phase transition is driven by the van't Hoff enthalpy, revealing the occurrence of an intermediate phase transition. We discuss the influence of the heating rate on the enthalpy and on the gel ↔ liquid crystal phase transition temperature by introducing the adequate thermodynamic Gibbs potential. The effect of hydrogen bonding of the water molecules with the polar head and polar-apolar interface on the

energetics of the bilayer membrane matrix is analysed. The obtained transition temperature was found to vary between 3 and 4°C depending on the hydration level.

The microstructure of glasses with composition of $Ge_xSb_{40-x}Se_{60}$ (x= 40, 35, 32, 27, 20, 15 at. %) is investigated. The results are explained with formation of $GeSe_4$ and $SbSe_3$ structural units, which correlate with the Ge/Sb ratio. For all the studied compositions, the Ge-Se, Sb-Se, Ge-Ge, and Se-Se bonds are significant. Far infrared Fourier Transform spectroscopic measurements in the range of 50-450 cm^{-1} at oblique (75^0) incidence radiation reveal clear dependences of the IR band's shift and intensity on the glassy composition, showing features around x=27 at.% supporting the topological phase transition to a stable rigid network consisting mainly of $SbSe_3$ pyramidal and $GeSe_4$ tetrahedral clusters.

The electrooptic and dielectric properties and the phase transitions of a group of thermotropic liquid crystals announcing a nematic "twist-bend" phase, are analysed. The methods of the polarisation microscopy and the impedance spectroscopy are applied. The samples under investigation demonstrate an ability for application in the liquid crystal displays production.

A large number of spectrophotometric measurements are carried out for different customers as a service:

- Measurements of the optical quality of Si wafers, used in the manufacturing of the optical elements working in the infrared spectrum, for Optix JSC.
- Measurements of the infrared spectral characteristics of antireflection coatings on Ge substrates, for Cimcoop Holding Ltd.
- Measurements of the infrared spectral characteristics of multilayer systems of bio-destructive materials having anti-oxide properties, deposited on poly-lactose substrate, for the University of Plovdiv.
- Measurements of the UV-VIS spectral characteristics of antireflection coatings and of narrow-band filters on glass substrates, for Cimcoop Holding Ltd.

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 SiO_2 were deposited on UV grade fused silica by ion-assisted electron beam evaporation under various technological conditions in order to prove possibility of hard and durable coatings in deep UV spectral range.

A theoretical analysis of the generation of time solitons or Ker frequency frequency combs in a microresonator with inhomogeneity was performed and the homoclinic bifurcation structure was constructed. A new extended field of stability of a one-peak soliton is demonstrated.

The dynamics of a photon optical fiber ring resonator in the framework of the Luzhato-Lefever model is investigated and it is shown that it is well described near the transition from mono- to bi-stability with a generalized Swift-Hohenberg equation with real coefficients. The motion of dissipative solitons in this system is characterized by a weak nonlinear analysis.

A model has been developed describing the dynamics of electric and optically pumped vertical-cavity surface-emitting lasers (VCSELs) and a mirror incorporating a saturable absorber. The dynamics of linear and folded resonator geometry and the possibility of mode locking of colliding pulses are investigated.

The debugging of the working version of the computer code for the propagating constants and the electric and the magnetic fields obtained by introducing of local coordinate systems in the Galerkin method for modes along Bragg photonic crystal fibers (PCFs) and PCFs consisting of a host medium with holes covered by concentric layers with different

refractive indices to increase their sensitivity when used as gas and chemical sensors started during the year.

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 with an emphasis 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 approach used allows evaluation of the technological parameters influence on the phase formation mechanism. The combination of methods contributes to the more accurate analysis of the phase composition and phase sublayers' thicknesses in this type of optical waveguides.

An overview on the laser methods for the study of materials used in easel painting - binders, pigments, vanishes - is made. The main spectroscopic methods with laser equipment that allow *in situ* analysis with high accuracy are considered. Holographic interferometry methods for the structural analysis of painting layers, as well as the use of laser-based microclimate sensors in painting exposition and storage halls have been described.

The megalithic sites are in principle difficult to be dated by means of classical methods. Most suitable dating method for them is the optically induced luminescence (OSL). In 2019, the range of archeological sites where luminescent dating can be extremely useful was expanded by adding two new groups: medieval Christian and Ottoman tombstones.

AWARDS:

Assoc. Prof. M. Kuneva, Ph.D - Acknowledgment letter from UPB and MES for the contribution to the organization and holding of the National Essay Contest, dedicated to the 150th anniversary of the creation of the Periodic Table of the Elements by D.I. Mendeleev

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11. **Hadjichristov, G. B.**, Ivanov, Tz. E., Marinov, Y. G., Koduru, H. K., Scaramuzza, N. "PEO-PVP-NaIO4 Ion-Conducting Polymer Electrolyte: Inspection for Ionic Space Charge Polarization and Charge Trapping". Physica Status Solidi (A) Applications and Materials Science, 216, 13, 2019, 1800739-1–1800739-11.
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with single wall carbon nanotubes. AIP Conference Proceedings, 2075, 2019, 020019-1–020019-4.

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32. **Цонев, Л.** "Сакрални обекти от Древна Тракия, оцелели в християнството". THRACIA, XXIV, Издателство на БАН "Марин Дринов", 2019, 435-455, ISSN:0204-9872.
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34. **Цонев, Л.** "Взаимодействия между християнство и ислям в дизайна на надгробия и култови сгради". Памет, наследство, култура (етноложката перспектива), РОД, София 2019, 376-392, ISSN:1311-493X.

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36. **М. Кънева**. Лазерни методи при реставрация и консервация на кавалетна живопис (част I). Светът на физиката, 17, 3, 2019, ISSN:0861–4210, 220-239.
37. **М. Кънева**. Лазерни методи при реставрация и консервация на кавалетна живопис (част II). Светът на физиката, 17, 4, 2019, ISSN:0861–4210, 376-382.
38. **Кънева М.**, **Тончев Св.**, **Караколева Е.** "Сензорни елементи на основата на протонно-обменени вълноводи в литиев ниобат", Светът на физиката, **17**, (1), 18-28, 2019.

CITATIONS FOR 2019: 274

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:

Participation in three-year (2016-2019) project "Liquid crystal approach for model lipid membrane functions optimization by nanoparticles insertion" (FNI-DH08/48) head: Assoc. prof. J. Genova, ISSP-BAS (Assoc. Prof. B. Katranchev and Assoc. Prof. G. Hadjihristov – team members)

Bulgaria-India International Cooperation Project (2013–2015, continued until 2019) "Investigation of photo-stimulated effects in nanostructured liquid crystals", (DNTS / In-01/4/2013) , Head: Assoc. Prof. Y. Marinov, IFTT-BAS. Funded by the NSF.

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

INTERNATIONAL COLLABORATION:

1. Department of Applied Physics and Photonics (TW-TONA), Vrije Universiteit Brussel, B-1050 Brussels, Belgium
2. Institute for Theoretical Physics, University of Münster, Wilhelm-Klemm-Str. 9, D-48149 Münster, Germany
3. Center for Nonlinear Science (CeNoS), University of Münster, Corrensstr. 2, D-48149 Münster, Germany
4. Faculté des Sciences, Université Libre de Bruxelles, Campus Plaine, C.P. 231, Brussels B-1050, Belgium
5. Departamento de Fisica and Millennium Institute for Research in Optics, FCFM, Universidad de Chile, Casilla 487-3, Santiago, Chile
6. Université des Sciences et de la Technologie Houari Boumediene (USTHB), Bab Ezzouar, Algeria
7. Department of Electronic Engineering, University of York, York YO10 5DD, UK

TEACHING ACTIVITIES:

Prof. K. Panayotov, D.Sc. - Supervisor of Gaëlle BREVALLE “Etude des boites quantiques pour la réalisation d’un laser VECSEL bifréquence cohérent” Thèse présentée et soutenue à Rennes, le 09/12/2019 Unité de recherche: INSTITUT FOTON (UMR 6082 / CNRS)

Assoc. Prof. M. Kuneva, Ph.D - 120 hours laboratory exercises in physics, bachelor program, Technical University, Sofia, 2019

Assoc. Prof. E. Karakoleva, Ph.D - have been conducting physics seminars at the Technical University - Sofia since the beginning of the 2019/2020 academic year.

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:**8**
RESEARCH SCIENTISTS: **7**
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 Ph.D

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

RESEARCH ACTIVITIES:

In 2019 the research activities of Atomic Spectroscopy laboratory have been focused in the field of quantum optics and in analytical atomic spectroscopy.

In the field of quantum optics and quantum-optical analogies, the work on the theoretical development of new composite impulses and their application for control in optical technologies has continued.

New composite pulses have been developed that allow (admit/permit) errors in the relative phases. This is a step towards overcoming one of the most serious drawbacks of the composite pulse technique: the need for precise phase manipulation. The work has been completed on: 1) development of twin composite impulses allowing greater flexibility over the total pulse area and 2) quantum control method based on “detuning pulses”, which are a generalization of the composite pulses and can be used in physical systems where it is impossible or difficult to make a jump in the field phase.

In the field of application of composite control methods in optical technologies, tunable composite linear polarization wide-band rotators have been created. Using the formal analogy between the evolution of the state vector in quantum mechanics and the Jones vector in polarization optics, we have designed and experimentally proved the action of tunable composite wide-field polarization rotators on linear polarization in two models:

1. system of even number half-wave plates having a spectral bandwidth of 50 nm
2. combination of achromatic half-wave plates and Fresnel rhombus, with a spectral bandwidth of about 400 nm.

The analogy used has also been applied to the creation of composite narrow-band polarization retarders (CTPs) and their application to selectively rotate linear polarization into a light beam according to the wavelength. A key point in the last study is theuse of the properties of the created composite narrow-polarized polarization retarder. It is made up of a set of multilinear $\lambda/4$ wave plates (λ = 780nm, WPMQ10M-780, Thorlabs) arranged one after the other, with the optical axes of each of the plates at a pre-estimated angle to each other (similar in sequence of impulses with definite phases). The resulting CTSD works for several wavelengths determined by the specific features of the single wavelength plate. The created

composite narrow-band polarization retarder can be used as a rotator for the plane of linear polarization of light with a selected wavelength. This allows in a beam consisting of light with two different wavelengths of 532 nm and 780 nm, respectively, to manipulate selectivelythe linear polarization of one light beam (532 nm), while the composite narrow-band polarization retarder influences the beam with the other wavelength. 780nm).

We continue the work on the construction of experimental apparatus and methodology for the manipulation of laser-cooled rubidium atoms. Several LabView programs have been created for the different degrees of control and detection of the states of atoms. Theexperimentaltestanddetectionsystemhas beenimproved.

In the field of analytical atomic spectroscopy the studies have beena focused on determining the elemental composition of a number of archaeological artefacts.Ceramics from the Early Chalcolithic period, discovered in two regions in Bulgaria - Vrachanski and Starozagorsko – have been investigated. The aim is to determine by LIBS the elemental composition of the white pigment in the inlays. On the basis of the obtained results and the results by other methods (FTIR and XRD), the studied objects are classified into different groups according to the composition of the pigment - calcite, gypsum and bioapatite.

Elemental spectral analyzes of bronze weapons (copies and axes) from the collection of the National Archaeological Institute with Museum at the BAS have been carried out. The aim is to determine the concentration of antimony in the alloy, on the basis of which conclusions can be drawn about the production processes and the origin of the artefacts. For some of the objects studied, antimony content between 1% and 3% has been found, which is assumed to be an indication that the antimony has been added to the alloy and is not an impurity from the ore. The addition of antimony to bronze has been characteristic of eastern Central Europe during the Late Bronze Age and has not been practiced in the Balkans. The results obtained can be a confirmation of the assumption of the origin of the objects. Ancient lead anchors are being investigated to determine the content of impurity elements.

We continue the work to develop a plasma source combining laser ablation for introduction and a hollow cathode discharge to excite the spectrum of solid materials. The performed emission spectral analyzes of silver have demonstrated enhanced analytical characteristics of the combined source in comparison to the hollow cathode discharge and laser-induced plasma separately. Two mechanisms have been identified leading to an increase in the intensities of the analytical spectral lines - the increased excitation and the spatial confinement of the plasma and their role at different experimental conditions has been evaluated.

PUBLICATIONS:

1. Composite pulses with errant phases: BT Torosov and NV Vitanov, Physical Review A, vol.100 iss. 2, 023410, 2019
2. Robust high-fidelity coherent control of two-state systems by detuning pulses: BT Torosov and NV Vitanov, Physical Review A, vol. 99 iss. 1, 013424, 2019
3. Arbitrarily accurate variable rotations on the Bloch sphere by composite pulse sequences: BT Torosovand NVVitanov, Physical Review A, vol. 99 iss. 4, 013402, 2019
4. Elena Stoyanova, Mouhamad Al-Mahmoud, HristinaHristova, Andon Rangelov , EmiliyaDimova and Nikolay V Vitanov “Achromatic polarization rotator with tunable rotation angle”, Journal of Optics. 21 105403 (5pp), (2019),
5. E. Dimova, “Individual selective rotation of the linear polarization of single light beam in a bundle”, Rev. Sci. Instrum. 90, 086102 (2019)

6. HristinaHristova, Stefano Ognyanski, Andon Rangelov and EmiliyaDimova, „A different optical composition for a broadband linear polarization rotator“, Journal of Physics: Conference Series, 1186 (1), 012018 (2019)
7. Zhechev, D. Z.; Steflekova, V. K., „On Self-aligning of Atomic States in a Segmented Hollow Cathode Discharge“, AIP Conference Proceedings 20175, 060011, 2019, DOI:10.1063/1.5091189.
8. .HristoKisov, GeorgiDyankov, Valery Serbezov, Vani Tankova, "DYE Doped Polymer Medium for Photonics Applications", AIP Conference Proceedings, 2075, DOI:10.1063/1.5091155, 030011-1-030011-5. SJR:0.182, (2019).
9. S. Karatodorov and V. Mihailov, "Spectroscopic characteristics of hollow cathode discharge with sample introduction by laser ablation", AIP Conference Proceedings, 2075, art. No. 060006, 2019
10. Vani Tankova, Georg Nekhrizov, Galina Malcheva, VasilkaSteflekov, KirilBlagoev, "Application of Laser Induced Breakdown Spectroscopy for Elemental Analysis of Archaeological Artefacts", Comptesrendus de l'Academiebulgare des Sciences, 72, 5, SJR:0.205, ISI IF:0.321, Q2, (2019).
11. Angelina Pirovska, KrassimiraAntonova, Galina Malcheva, Vani Tankova, KirilBlagoev, "Nature and physicochemical features of the incrusted white decoration on pottery from two sites in Bulgaria, dated to the chalcolithic period (IV mill BC)", J. Archaeol. Science: Reports, 29, 102142, Q1 (2020).

PATENTS

Maintained patents:

Inventors: P. M. Pramatarov, M. S. Stefanova, Kudryavtsev, A. I.

Invention: "Methodandionizationdetectorforanalysisofimpuritiesingases"

Patent № 66623, Int. Cl. G 01 N 27/62 (2006.01)

Patents in procedure:

Inventors: Ognian Ivanov, Valentin Mikhailov, Stefan Karatodorov, Jose Louise Perez Diaz

Invention: "Method for determining the ablation threshold of solid materials"

Patent № 112446, from 2017

ONGOING RESEARCH PROJECTS:

- Composite and adiabatic methods for control in quantum and optical technology. (ДН 18/14, National Science Fund),

- Laser ablation applications for the study of traditional cultural heritage materials(under the Academy's bilateral agreements with INOE-2000, Magurele, Romania)

- Atomic and Plasma Physics (funded by the budget subsidy of BAS),

- "Application of Laser Plasma Spectroscopy (LIBS) in Archeometry" (Program for Supporting Young Scientists – BAS)

- "Adiabatic control and quantum-optical analogies"(Program for Supporting Young Scientists – BAS).

INTERNATIONAL COLLABORATION:

- ✓ National Institute for Research and Development of Optoelectronics, Magurele, Romania
- ✓ New Technologies – Research Centre (NTC), University of West Bohemia, Pilsen, Czech, Republic
- ✓ French National Centre for Scientific Research CNRS, Institut de physique,
- ✓ Faculty of Physics, University of Belgrade, Serbia,

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TEACHING ACTIVITIES:

Vani Tankova - PhD student in the laboratory, successfully defended a thesis "Application of Laser Plasma Spectroscopy (LIBS) in Archeometry"

DEPARTMENT - LASER, ATOMIC, MOLECULAR AND PLASMA PHYSICS

LABORATORY

METAL VAPOUR LASERS

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

TOTAL STAFF: **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 Atanassova, PhD; Physicist Klaoyan Zlatanov, PhD; Assist. Ivan Kostadinov, Assist. Krassimir Dimitrov; Assist. Yu. I. Fedchenko, Physicist Danka Iordanova; Physicist Blagovela Blagoeva

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

RESEARCH ACTIVITIES:

Strontium vapour laser, oscillating at atomic and ionic strontium lines in the middle infrared spectral range, was investigated. A record average output power of 29 W, which is two-time higher than the average laser power achieved with single tube so far, was obtained. The highest laser pulse energy of 2.9 mJ was also achieved. Master oscillator–power amplifier strontium vapour system with record high-beam quality at the 6.45-μm laser line ($M^2 \approx 1.0$) was developed and studied. In a stationary sealed-off regime, an average output power of 3 W was measured.

Radial gas temperature distribution in the four laser tubes, which had been experimentally investigated, was calculated by determining the following parameters: thermal conductivity of the tubes confining the discharge zone and the used thermal insulations; density of the average electrical power deposited in the gas-discharge plasma, i.e. heat source. Temporal and radial distribution of electron temperature $T_e(r, t)$ in DUV Cu^+ Ne-H_2-CuBr and Sr^+ recombination lasers was also calculated at bi-Maxwellian electron energy distribution function by the new theoretical method based on solving of the nonstationary heat conduction equation for the electron gas.

Glasses doped with Ag and Au nanoparticles were irradiated with femtosecond laser radiation. Samples with various concentrations of the silver nanoparticles, such as 0, 1, 5 and 10 %, were used. 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; laser pulse energies – from 20 to 60 μJ; wavelength of laser radiation – 800 nm. Analyses of the samples, which had been and not been doped with gold particles, were made in the laboratories of National Institute for Laser, Plasma & Radiation Physics and Center for Advanced Laser Technologies. Methods and techniques,

which were applied to analyze the samples irradiated, were: terahertz spectroscopy for determination of the transmittance, refraction and reflection coefficients; SEM analysis.

A modified *z*-scan method with femtosecond laser radiation was developed and used to study nonlinear properties and effects of three-dimensional ensembles of noble metal nanoparticles, which had been doped in optical material. The method was calibrated with fused quartz samples. Samples, which had been made of borosilicate glass and doped with gold ions with concentrations of 0.1 and 1 wt%, were investigated. Filamentous structure in the investigated material volume was obtained and studied in the spectral range 260 – 1600 nm. Focusing the laser radiation with achromatic lens, second harmonic oscillation was obtained at the following wavelength: 266, 400, 532, 600, 800, 1064, 1500 and 1600 nm.

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

Laser ablation with subpicosecond and femtosecond laser pulses was experimentally investigated for micro- and nanoprocessing of various materials, such as Al, Zn, Cu, brass, stainless steel, polypropylene, and nylon.

PUBLICATIONS:

1. N. Nedyalkov, N. E. Stankova, M. E. Koleva, R. Nikov, L. Alexandrov, R. Iordanova, **E. Iordanova**, **G. Yankov**, "Laser processing of noble metal doped glasses by femto- and nanosecond laser pulses", *Applied Surface Science*, **475**, pp. 479-486, 2019 **IF = 5.155 Q1**;
2. 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 = 5.155 Q1**;
3. P. Koelman, **D. Yordanova**, W. Graef, S. T. Mousavi, J. van Dijk, "Uncertainty analysis with a reduced set of input uncertainties selected using pathway analysis", *Plasma Sources Sci. Technol.*, **28**, art. No. 075009 (13pp), 2019 **IF = 4.128 Q1**;
4. T. Milenov, A. Nikolov, G. Avdeev, I. Avramova, S. Russev, D. Karashanova, **I. Kostadinov**, B. Georgieva, J. Mladenoff, I. Balchev, N. Stankova, S. Kolev, E. Valcheva, "Synthesis of graphene-like phases in a water colloid by laser ablation of graphite", *Material Science & Engineering B*, **247**, art. No. 114379 (7pp), 2019 **IF = 3.507 Q1**;
5. K. D. Esmeryan, C. E. Castano, **Y. I. Fedchenko**, R. Mohammadi, I. K. Miloushev, **K. A. Temelkov**, "Adjustable optical transmittance of superhydrophobic carbon soot coatings by in-situ single-step control of their physicochemical profile", Colloids and Surfaces **A**, **567**, pp. 325–333, 2019 **IF = 3.131 Q2**.
6. L. Vála, R. Medlín, M. Koštejn, **S. Karatodorov**, V. Jandová, V. Vavruňková, T. Křenek, "Laser-Induced Reactive Deposition of Nanostructured CoS_2- and Co_2CuS_4-Based Films with Fenton Catalytic Properties", European Journal of Inorganic Chemistry, 9, pp. 1220-1227, 2019 **IF = 2.578 Q2**.
7. **D. Yordanova**, **M. Grozeva**, D. Mihailova, J. van Dijk, "FLUID MODELLING OF HOLLOW CATHODE COPPER ION LASER WITH CATHODE SPUTTERING",

Comptes Rendus de L'Académie Bulgare des Sciences, **72(12)**, pp. 1634-1640, 2019 **IF = 0.321 Q2**.

8. **K. D. Dimitrov**, **I. K. Kostadinov**, **N. V. Sabotinov**, "Infrared Strontium Vapor Laser", *International Journal of Photonics and Optical Technology*, **5(2)**, pp. 4-6, 2019, JCR-IF (Web of Science): 0.001.
9. **I. K. Kostadinov**, **S. I. Slaveeva**, **K. A. Temelkov**, "Powerful High-Beam-Quality Sealed-Off Laser System Oscillating in Middle Infrared Spectral Range on Strontium Atomic Transitions for Medical Applications", *in Proceedings of SPIE*, **11047**, art. No. 110471K (6pp), 2019 (print ISSN 0277–786X), SJR (Scopus): 0.234.
10. I. Balchev, A. Nikolov, N. Stankova, I. Avramova, E. Valcheva, S. Russev, D. Karashanova, **I. Kostadinov**, J. Mladenoff, S. Kolev, T. Milenov, "Ablation of graphite in water by Nd:YAG laser", *in Proceedings of SPIE*, **11047**, art. No. 110470E (6pp), 2019 (print ISSN 0277–786X), SJR (Scopus): 0.234.
11. A. Nikolov, I. Balchev, N. Stankova, I. Avramova, E. Valcheva, S. Russev, D. Karashanova, B. Georgieva, **I. Kostadinov**, J. Mladenoff, S. Kolev, T. Milenov, "Synthesis of submicron-dispersed carbon phases in water by ND:YAG laser ablation of graphite", *in Proceedings of SPIE*, **11047**, art. No. 110470K (6pp), 2019 (print ISSN 0277–786X), SJR (Scopus): 0.234.
12. **V. Atanassova**, P. Penkova, **I. Kostadinov**, **S. Karatodorov**, G. V. Avdeev, "Laser removal of chlorine from historical metallic objects", *in Proceedings of SPIE*, **11047**, 2019, DOI:10.1117/12.2516813 (print ISSN 0277–786X), SJR (Scopus): 0.234.
13. N. Nedyalkov, M. E. Koleva, N. E. Stankova, R. Nikov, P. A. Atanasov, **E. Iordanova**, **G. Yankov**, L. Aleksandrov, R. Iordanova, G. Sliwinski, M. Sawczak, K. Grochowska, M. Terkawa, "Direct laser writing of Ag nanoparticle-composed structures in glass", *in Proceedings of SPIE*, **11047**, 2019 (print ISSN 0277–786X), SJR (Scopus): 0.234.
14. **K. A. Temelkov**, **S. I. Slaveeva**, **Yu. I. Fedchenko**, T. P. Chernogorova, "A Comparative Theoretical Study on Electron Temperature in Nanosecond Pulsed Longitudinal Discharge for Maxwellian and Druyvesteyn Electron Energy Distribution Functions", *AIP Conference Proceedings*, **2075**, art. No. 060010 (4pp) 2019, SJR (Scopus): 0.182, JCR-IF (Web of Science): 0.001.
15. **S. Karatodorov** and V. Mihailov, "Spectroscopic characteristics of hollow cathode discharge with sample introduction by laser ablation", *AIP Conference Proceedings*, **2075**, art. No. 060006, 2019 SJR (Scopus): 0.182, JCR-IF (Web of Science): 0.001;
16. **V. Atanassova**, **I. Kostadinov**, P. Penkova, "Selective laser cleaning of corroded metal objects", *AIP Conference Proceedings*, **2075**, 2019 SJR (Scopus): 0.182, JCR-IF (Web of Science): 0.001.
17. **N. V. Sabotinov**. "Metal vapor lasers and Bulgarian contribution for their development", *AIP Conference Proceedings*, **2075**, art. No. 190002, 2019 SJR (Scopus): 0.182, JCR-IF (Web of Science): 0.001;
18. **V. Atanassova**, **I. Kostadinov**, **G. Yankov**, **P. Zahariev**, **M. Grozeva**, "Laser treatment of contaminations on paper: a preliminary study", *Proceedings of APLAR*, **6**, pp. 433-445, 2019 (ISBN:978-88-404-0090-7), JCR-IF (Web of Science): 0.001;
19. K. Garasz, M. Kocik, **T. Petrov**, "Experimental investigations on ultrashort laser ablation for micro and nanomachining of materials", *Journal of Physics: Conference Series*, **1186** art. No. 012028, 2019.
20. **Н. Съботинов**, "Ролята на Българска академия на науките за развитието на лазерната наука и технологиите", *Наука*, 4, стр. 54-59, 2019.

PATENTS:

Maintained patents:

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

Patents in procedure:

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

ONGOING RESEARCH PROGECTS:

- Basic research and development of high-beam-quality high-power laser system oscillating in visible spectral range (funded by BSF KP-06-H37/2 06.12.2019).
- Functionalization of 3D printed fibrous matrixes by femtosecond laser modelling (funded by BSF KP-06-PH-38/4 06.12.2019).
- Basic research and development of high-beam-quality high-power laser system oscillating in middle infrared spectral range (funded by BSF KP-06-H27/5 08.12.2018).
- Experimental and theoretical investigation on ultrafast dynamics of processes, induced by subpicosecond laser nanomachining of wide gap semiconductors (funded by BSF DN 18/07 2017).

- Nonlinear interaction and effects of ultrafast laser pulses in dielectric media (funded by BSF DN 18/11 2017).
- Laser induced formation of three-dimensional structures of nanoparticles and study of their optical properties, (funded by NFS №.H08/25 01.09.2016).
- Lasers, laser technologies and applications (funded by the budget subsidy of BAS).
- Femtosecond laser applications (under the Academy's bilateral agreements with IFFM, Gdansk, PAS, Poland).
- Material processing and analysis by ultrashort laser pulses (under the Academy's bilateral agreements with National Institute for Lasers, Plasma and Radiation Physics, RAS, Romania).

INTERNATIONAL COLABORATION:

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

TEACHING ACTIVITIES:

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

The young scientists of the laboratory participated in the traditional 22th Winter Seminar of PhD Students and Young Scientists in Physics, 06-08 December, Vitosha, Bulgaria, 2019.

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

Assoc. Prof. Dr. K. Temelkov gave an invited lecture at 12th Spring Seminar of PhD Students and Young Scientists in Chemistry, 19-21 April, Vitosha, Bulgaria, 2019 and an invited lecture at 22th Winter Seminar of PhD Students and Young Scientists in Physics, 06-08 December, Vitosha, Bulgaria, 2019.

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

SCIENTIFIC RESULTS:

Peter Maria Schuster passed away on the age of eighty (26.10.1939–26.12.2019). He was President of the History of Physics Group at the European Physical Society (2007-2016). He made many significant things for history of physics in Europe. During that time, he came and visited Bulgarian Academy of Sciences, Institute of Solid State Physics, Georgi Nadjakov Museum (17–18 October 2011). We felt his unquenchable enthusiasm in his welcome speech. Georgi Nadjakov's cabinet was selected for European Physical Society historic site with his large backing (23 May 2014) [1-2].

Eugene Leyarovski (05.07.1933–23.04.1999) has valuable contributions to Bulgarian physics. He had excellent experimental skills, and innovative scientific ideas. His results in high temperature superconductivity, Van-Vleck paramagnetism, methods for low temperatures below 1 K, and separation of gas mixtures have Bulgarian and international recognition [3].

Rashko Zaycoff **(**10.12.1901–25.11.1982**)** is the first Bulgarian physicist joined to the theory of relativity (1925–1935). His work has commemorated on the occasion of Albert Einstein (1879–1955) 140th anniversary. Sofia University Departments of German and Scandinavian Studies, and the Austrian Dr. Wolfgang Kraus Library organized the celebration. One report, and two interviews about Rashko Zaycoff have given [4-6].

Bulgarian State Television, Second Channel created documentary film entitled "Students and professors invented security sensors for public places" using the Georgi Nadjakov's Cabinet. It was broadcasted as a TV show "Young Innovators" on 10 February 2019 (27:46 minutes long).

The exhibition about Georgi Nadjakov has several visitors in 2019 (11 January 2019, 16 May 2019, and 8 November 2019). Two documentary inquires have made (28 August 2019, and 10 September 2010) about physicist Stayka Dimitrova. Fourteen donations have given by Prof. Valentina Petkova, BAS member, Prof. B. Kovachev, Prof. T. Mishonov, Assoc. Prof. N. Bogdanova, and A. Karastoyanov during 2019.

PUBLICATIONS:

1. P. M. Schuster, Welcoming Speech, Dissemination and development physics and mathematics on the Balkans, ISSP, Sofia, 2012, p. 1.
2. Г. Камишева, Разпространение и развитие на физико-математическите знания на Балканите, Светът на физиката (1) 93-96 (2012).
3. E. Nazarova, G. Kamisheva, Eugene Leyarovski founder of the contemporary low temperature physics in Bulgaria, Proceedings of 10 Jubilee Conference of the Balkan Physical Union (2019).
4. Г. Камишева, Айнщайн и проф. Рашко Зайков, по повод 140 годишнината от рождението на Айнщайн – геният на века (1879–2019), Зала 1 на Ректората на Софийския университет, 5 юни 2019 година (доклад)

5. Г. Камишева, Българският гений до Айнщайн – проф. Рашко Зайков, в предаването на Валерия Николова "Хоризонт до обед", Българско национално радио, 5 юни 2019 (интервю)
6. Г. Камишева, в предаването на Диана Цанкова, Гениален български физик работи редом с Айнщайн, Радио България, Българско национално радио, 28 юни 2019 (интервю)