BULGARIAN ACADEMY OF SCIENCES

GEORGI NADJAKOV
INSTITUTE OF SOLID STATE PHYSICS

ANNUAL RESEARCH REPORT
2021

Compiled and Edited by J. Genova

Institute of Solid State Physics - BAS

72, Tzarigradsko Chaussee Blvd.

1784 Sofia, BULGARIA

tel: (+359 2) 875 80 61
e-mail: director@issp.bas.bg
http://www.issp.bas.bg

CONTENTS

Foreword

To commemorate the 48th anniversary of the Institute of Solid State Physics an exhibition "Challenges of new materials and applications" was held in the period October 18-22, 2021 at the central lobby of the administrative building of the Bulgarian Academy of Sciences. The exhibition included numerous poster presentations demonstrating the scientific achievements of the Institute in the synthesis of novel materials for optics and advanced optical methods and their industrial applications.

During 2021, scientists of the Institute have been working on a number of scientific projects funded by different Organizations. Some of these projects are: Projects No BG05M2OP001-1.001-0008 of 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. Within this project, two unique set of equipment were purchased to enhance the research and technological potential of the Institute. Three projects, including "ELI-EIC-BG" of the Ministry of Education within the framework of the "National Roadmap for Research Infrastructure (2020-2027)". Moreover, there are also several other scientific projects under contracts with the Ministry of Education and Science through the National Science Fund.

The Institute organized the traditional 24rd Winter Seminar "Interdisciplinary Physics" for doctoral students and young scientists from the Bulgarian Academy of Sciences during the winter of 2021. Furthermore, the organization of the 22nd edition of the traditional International School on Condensed Matter Physics devoted to "State of the Art in Functional Materials & Technologies" has been initiated. This event will be held from August 29th to September 2nd 2022 in Varna, Bulgaria.

During the last year, the scientific personnel of the Institute published 165 papers: 143 printed and 12 at press. 113 articles have been published in internationally recognized journals indexed the international databases for scientific information – Web of Science and/or SCOPUS.

ISSP currently holds 24 BG patents and 3 applications for patents are in procedure. During 2021 two patents: "Method for determination of the laser ablation threshold" and "Optimisation of the cleaning properties of fog, by sensor, operating on the basis of laser-induced photo-charging effect" were approved.

Hassan Chamati

GEORGI NADJAKOV INSTITUTE OF SOLID STATE PHYSICS
Bulgarian Academy of Sciences

72, Tzarigradsko chaussee Blvd., 1784 Sofia, BULGARIA
Tel: (+359 2) 875 80 61, ***http:// www.issp.bas.bg***

Director:
Professor
Hassan Chamati, Ph.D., D.Sc.
tel.: 02 979 5758
director@issp.bas.bg

Deputy Director:
Professor
Albena Paskaleva, Ph.D., D.Sc.
tel.: 02 979 5742
paskaleva@issp.bas.bg

Scientific Secretary:
Associate Professor
Julia Genova, Ph.D.
tel.: 02 979 5725
julia.genova@issp.bas.bg

Chairman of the SC:
Professor
Diana Nesheva, Ph.D., D.Sc.
tel.: 02 979 5686
nesheva@issp.bas.bg

Administrative Director:
Daniel Iliev,
tel.: 974 60 52, 979 5700
diliev@issp.bas.bg

Secretary:
Ljubomila Dedinska, Dipl. Eng.
tel.: 875 80 61, 979 5792
buba@issp.bas.bg

Accountant Office:
Eleonora Popova
tel.: 875 50 59, 979 5744
nora@issp.bas.bg

Administration Office:
Irina Velkova, Dipl. Eng.
tel.: 877 34 92, 979 5780
velkova@issp.bas.bg

Switch board:
02 979xxxx

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

SCIENTIFIC COUNCIL

Chairman: Assoc. Prof. E. Yordanova, Ph.D.
Deputy Chairman: Prof. Y. Marinov, D.Sc.
Secretary: Assoc. Prof. B. Katranchev, Ph.D.

1. Prof. H. Chamati, D.Sc.
2. Prof. A. Paskaleva, D.Sc.
3. Prof. G. Hadjihristov, Ph.D.
4. Prof. P. Rafailov, Ph.D.
5. Prof. K. Temelkov, Ph.D.
6. Prof. V. Vitkova, Ph.D.
7. Assoc. Prof. I. Bineva, Ph.D.
8. Assoc. Prof. B. Blagoev, Ph.D.
9. Assoc. Prof. Z. Dimitrova, Ph.D.
10. Assoc. Prof. K. Esmeryan, Ph.D.
11. Prof. J. Genova, Ph.D.
12. Assoc. Prof. V. Mihailov, Ph.D.
14. Assoc. Prof. A. Stoyanova-Ivanova, Ph.D.,
15. Assoc. Prof. T. Tenev, Ph.D.

THEORY

LABORATORY

THEORY GROUP

HEAD: **Prof. Hassan Chamati, D.Sc.**
tel: 979 5785; e-mail: chamati@issp.bas.bg

TOTAL STAFF: **16**
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

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

RESEARCH ACTIVITIES:

Our research work focuses generally on problems on the quantum origin of the magneto-structural correlations in low-dimensional insulating systems and molecular magnets. This includes investigations on the contribution of the exchange interactions, crystal/ligand field, spin-orbit and Zeeman interactions on the magnetic and spectroscopic properties of the abovementioned systems. One part of the study is devoted to a recently developed theoretical framework based on the molecular orbital theory and the multi-configurational self-consistent field method. Here, the unpaired electrons are viewed as delocalized to a large extent. As a result, the exchange interactions have significant contribution to the fine structure of the energy spectrum. The potential of this method is demonstrated by studying the magnetic behavior of the spin-3/2 single molecule magnets $Na_9[Er(W_5O_{18})_2]$ and $[(Pc)Er\{Pc\{N(C_4H_9)_2\}_8\}]^{\cdot/-}$. The obtained theoretical results show a good agreement with the experimental data for the magnetization, dc and ac low-field susceptibility available in the literature.

Another research features the application of a restricted active space self-consistent field method developed under the principles of the crystal field and Hartree-Fock method. This method describes the unpaired electrons as localized to a large extent around the constituent metal centers and hence it may be very useful in describing the magnetic behavior of $3d^n$ systems, with n = 2, ..., 5. We demonstrate its application by studying the magnetic and spectroscopic properties of the spin-one single-ion magnet $(C_6F_5)_3$trenVCN^{tt}Bu. The calculations find good agreement with the available in the literature experimental data for the magnetization, low-field susceptibility, cw-EPR and photoluminescence. The obtained results clearly demonstrate the dependence of the compound`s magnetic and spectroscopic properties on the existing coordination geometry.

Both aforementioned methods represent multi-configurational approaches that result in a post-Hartree-Fock scheme for constructing an energy spectrum with eigenvalues depending on the type, number and coordinates of the constituent metal ions and the adjacent reactive non-metals

In addition to the investigation on the magneto-structural correlations in solids, we perform a theoretical research on the existence of a discrete dynamics that may underpin the processes of discrete exchange of energy in a quantum system. The study follows the principles of the first quantization formalism and results in a hypothesis that describes the corresponding processes of energy and momentum transfer as a discrete over time. A key aspect in the introduced theory is the presence of a quantum equation for the mechanical power analogous to the Schrodinger equation. This equation includes a constant that has a unit measure of energy and similar to the Planck's constant it plays a fundamental role to all ensued equations of motions. As a result, in addition to the Planck-Einstein and momentum-wavelength relations, we obtain power-frequency and force-wavelength analogs, respectively. Relations for the mechanical power, force and torque in relativistic and non-relativistic cases along with their operator representations are also discussed.

Residential segregation is analyzed via the Schelling model, in which two types of agents attempt to optimize their situation according to certain preferences and tolerance levels. Several variants of this work are focused on urban or social aspects. Whereas these models consider fixed values for wealth or tolerance, here we consider how sudden changes in the tolerance level affect the urban structure in the closed city model. In this framework, when tolerance decreases continuously, the change rate is a key parameter for the final state reached by the system. On the other hand, sudden drops in tolerance tend to group agents into clusters whose boundary can be characterized using tools from kinetic roughening. This frontier can be categorized into the Edward-Wilkinson (EW) universality class. Likewise, the understanding of these processes and how society adapts to tolerance variations are of the utmost importance in a world where migratory movements and pro-segregational attitudes are commonplace.

We characterize sudden increases in the land price of certain urban areas, a phenomenon causing gentrification, via an extended Schelling model. An initial price rise forces some of the disadvantaged inhabitants out of the area, creating vacancies which other groups find economically attractive. Intolerance issues forces further displacements, possibly giving rise to an avalanche. We consider how gradual changes in the economic environment affect the urban architecture through such avalanche processes, when agents may enter or leave the city freely. The avalanches are characterized by power-law histograms, as it is usually the case in self-organized critical phenomena.

We consider random walkers that deform the medium as they move, enabling a faster motion in regions which have been recently visited. This induces an effective attraction between walkers mediated by the medium, which can be regarded as a space metric, giving rise to a statistical mechanics toy model either for gravity, motion through deformable matter or adaptable geometry. In the strong-deformability regime, we find that diffusion is initially described by the porous medium equation, thus yielding subdiffusive behavior of an initially localized cloud of particles. Indeed, while the average width of a single cloud will sustain a $\sigma \sim t^{1/2}$ growth, the combined width of the whole ensemble will grow like $\sigma \sim t^{1/3}$ in a certain time regime. This difference can be accounted for by the strong correlations between the particles, which we explore indirectly through the fluctuations of the center of mass of the

cloud and the expected value of the experienced density, defined as the average density measured by the particles themselves.

Using numerical modeling, the results used in positron annihilation spectroscopy measurements such as the positron lifetime and the electron momentum distributions have been obtained for a number of materials in which a vacancy type defects are induced by neutron or heavy ion irradiation. Numerically the positron lifetime values for a graphene coated metal, in particular, copper, iron, and tungsten substrates were obtained. The resistance of this type of layered structure to the proton accumulation and correspondingly conclusions on the stability of the material to the irradiation were drawn.

A phenomenological model was proposed that describes the complex magnetic phase transitions in the ferromagnetic superconductor UGE_2, meaning the transitions from paramagnetic to low-magnetization phase followed by a transition to new high-magnetization phase with temperature lowering without change of magnetic and crystal structure. For this aim, an n expansion of Landau free energy up to eight order in magnetization is studied which is applied for such type of isostructural transitions. The model describes different phase transitions depending on the relations and values of material parameters in this free energy expansion. Analysis is done and it is shown in which part of the phase diagram it is possible to apply the model of isostructural phase transition at ambient pressure that reflects the experimental data for UGE_2. The relations between the coefficients in free energy expansion has been established, for which second order phase transition occurs from disordered to low-magnetization ferromagnetic phase and with the temperature decrease a crossover transition appears to the high-magnetization phase.

Within this model the strong Ising type anisotropy is considered and the calculation is performed neglecting the other components of magnetization as small. The problem lays in the dual nature of f-electrons coming from U-atoms in UGE_2, this is, a part of them are localized and create strong uniaxial magnetic moment and the other part are itinerant with small magnetic moment in arbitrary direction.

For a more direct comparison with the existing experimental data at ambient pressure, calculations have been performed in the presence of external magnetic field pointing both at easy magnetization axis and perpendicular to it. The experimental data is proven that for magnetic field along the easy magnetization axis, the crossover between the two ferromagnetic phases is not transformed into metamagnetic transition and remains a crossover independent of the external magnetic field magnitude. At the temperature T_c of second order phase transition from disordered to low-magnetization phase in the presence of external field standard change to first order transition occurs. When the magnetic field is applied in direction transverse to the magnetization easy axis, an anomaly occurs in the thermodynamic quantities at the transition between two magnetic phases. This is an important point as in transvers field the response to such field comes mainly from the itinerant f-electrons. The terms on free energy expansion describing the interaction between localized and itinerant f-electrons are derived, as well as the conditions for comparison with experiment. For this aim, the magnetic susceptibility, heat capacity and thermal conductivity are calculated both at crossover temperature and T_c.

Using the capabilities of the LAMMPS package, the process of the mutual thermalization of the spin and lattice subsystems in bcc Fe to T = 300 and 800 K is modeled. It is shown that in the microcanonical ensemble the process of the relaxation of the spin and lattice temperature to T = 800 K lasts about 50 ps. After thermalization, in the canonical ensemble, the dynamic

matrix of the atoms is calculated. The diagonalization of this matrix gave the spectrum of phonons in bcc-Fe in the three main crystallographic directions [100], [110] and [111]. At T = 300 K, there is a very good agreement between the calculated and the experimentally determined phonon dispersion curves. This agreement corresponds to all potentials used, crystallographic directions and small to medium values of the wave number. The difference between the calculated and the experimentally determined dispersion curves for the phonons, observed at the edges of the zones, is due to the anharmonic effects. The pronounced influence of magnons on the phonon spectrum in bcc – Fe is found. There is a significant difference in the frequencies of sound waves propagating in the crystal directions [100], [110] and [111], calculated with and without considering the exchange interaction. The relative difference in these frequencies reaches 14%. At the same time, the frequency of the transverse wave with the wave number q = 0.6 propagating in the [111] direction remains unaffected by the presence of magnons. According to our data and data from other authors, this effect turned out to be dependent on the choice of the mechanical potential.

The soliton propagation in an anisotropic ferromagnetic chain where the exchange interactions of an impurity spin with its neighbors are modified is investigated. We considered easy-axis anisotropy of the chain which leads to the formation of bright soliton solutions. The character of the soliton-impurity interaction is different when the exchange coupling of the spin is modified in the x,y-plane or in the z-direction. Our results show that the action of the defect depends on the soliton wave number in a complicated manner and for large velocities becomes significant. A comparison with the soliton dynamics in the presence of point defects is made. We have found that for slow solitons the scattering process is similar to this on point defects with the corresponding strength while for fast solitons it is completely different. Then, in addition to the strength of η and $\sim \eta$ the soliton evolution depends considerably on their spatial extension and sign.

We investigate the modifications of the quantum random walk search algorithm on a hypercube. The algorithm uses traversing coins constructed from a generalized Householder reflection and a phase multiplier. Such coins contain two phases – first is the additional one and second is part of the Householder reflection. A study has been made of the probability of finding the searched element of the quantum algorithm at different functional dependences between the two phases (both linear and unlinear). Coins built in such way are optimized with Supervised Machine Learning and Monte Carlo Simulations, in such way to be more robust against inaccuracies in the phases used in the making of the marking coin. The study includes both coins with a coin register composed of qubits and a quid register. Additional study has been done how the probability of finding a solution changes when there are inaccuracies of the additionally imported parameter when the best-found non-linear function is used.

PUBLICATIONS:

1. **Chamati, H**. Scaling behavior of confined O(n) systems involving long-range interaction. Journal of Theoretical and Applied Mechanics (Bulgaria), 51, 2, 2021, ISSN:1314-8710, 105.
2. **Dimitrova, Z.I.**, Vitanov, K.N., Homogeneous balance method and auxiliary equation method as particular cases of simple equations method (SEsM). AIP Conference Proceedings, 2321, AIP, 2021, DOI:10.1063/5.0043070, 030004.

3. **Georgiev, M**, **Chamati, H**. An Exchange Mechanism for the Magnetic Behavior of Er3+ Complexes. 16, 26, Multidisciplinary Digital Publishing Institute, 2021, DOI: 0.3390/molecules26164922.
4. **Georgiev, M**, **Chamati, H**. Molecular magnetism in the multi-configurational self-consistent field method. J. Phys.: Condens. Matter, 33, 7, Institute of Physics, 2021, ISSN:0953-8984, DOI:10.1088/1361-648X/abc802.
5. **Georgiev, M**, **Chamati, H**. Origin of the magnetic exchange in insulators: Localized vs. delocalized electrons. Journal of Physics: Conference Series, 1762, Institute of Physics, 2021, DOI:10.1088/1742-6596/1762/1/012019.
6. **Georgiev, M**. Discrete dynamics of energy and momentum transfer. Journal of Physics: Conference Series, 1762, Institute of Physics, 2021, DOI:10.1088/1742-6596/1762/1/012021.
7. **Kamburova, R. S.**, **Primatarowa, M. T.**, Bound soliton - defect spin states in anisotropic ferromagnetic chains. Journal of Physics: Conference Series, 1762, IOP Science, 2021, ISSN: 1742-6596, DOI: 10.1088/1742-6596/1762/1/012020.
8. **Mishonov, T M**, **Varonov, A M**. Scientific instrument for creation of effective Cooper pair mass spectroscopy. Journal of Physics: Conference Series, 1752, 012013, Institute of Physics, 2021, DOI:10.1088/1742-6596/1762/1/012013, 1-8.
9. **Mishonov, T M**, Dimitrova, I M, **Varonov, A M**. Sound absorption in partially ionized hydrogen plasma and heating mechanism of solar chromosphere. Physica A: Statistical Mechanics and its Applications, 563, 1, Elsevier B.V., 2021, ISSN:03784371, DOI: 10.1016/j.physa.2020.125442, 125442.
10. **Mishonov, Todor M.**, **Dimitrova, Iglika M.**, **Varonov, Albert M.**. On the Influence of the Ionization–Recombination Processes on the Hydrogen Plasma Polytropic Index. The Astrophysical Journal, 916, 1, Institute of Physics, 2021, DOI:10.3847/1538-4357/ac0629.
11. **Mishonov, Todor M.**, **Dimitrova, Iglika M.**, Serafimov, Nikola S., Petkov, Emil G., **Varonov, Albert M.**, Q-factor of the resonators with Frequency Dependent Negative Resistor. IEEE Transactions on Circuits and Systems II: Express Briefs, (Early Access), IEEE, 2021, ISSN:1558-3791, DOI:10.1109/TCSII.2021.3111488.
12. **Mishonov, Todor M.**, Petkov, Emil G., **Dimitrova, Iglika M.**, Serafimov, Nikola S., **Varonov, Albert M.**, Probability distribution function of crossover frequency of operational amplifiers. Measurement, 179, Elsevier, 2021, ISSN:02632241, DOI: 10.1016/j.measurement.2021.109509, 109509.
13. **Mishonov, Todor M**, Andreoni, Matteo, Mihaylova, Nelly Zh, **Varonov, Albert M**. Determination of effective magnon mass of neodymium magnet by temperature dependence of spontaneous magnetization. European Journal of Physics, 42, 045502, Institute of Physics, 2021, DOI:10.1088/1361-6404/abf6ec, 1-14.
14. **Paskaleva, A**, **Chamati, H**, **Genova, J**. Progress and Perspectives in Functional Materials. physica status solidi a, 218, 17, Wiley, 2021, ISSN:1862-6319, DOI:10.1002/pssa.202100548, 2100548.
15. **Primatarowa, M. T.**, **Kamburova, R. S.**, Soliton Scattering on Impurities with Modified Exchange Interactions in Anisotropic Ferromagnetic Chains. Journal of Physics: Conference Series, 1762, IOP Science, 2021, ISSN: 1742-6596, DOI:doi:10.1088/1742-6596/1762/1/012014.
16. **Slavkova, Z.**, **Drinova, N.**, **Chamati, H.**, **Genova, J.**, Influence of sucrose on the phase behaviour of phospholipid model systems. Journal of Physics Conference Series, 1762, 2021.
17. **Tonchev H.**, Comparison between XY spin chains with spin 1/2 or 1 interacting with quantized electromagnetic field by one and two photon Jaynes-Cummings model. Magnetochemistry, 7, 1, MDPI, 2021, DOI: 10.3390/magnetochemistry7010004, 1-4.

18. **Tonchev, N.S.**, ON THE RELATION BETWEEN THE MONOTONE RIEMANNIAN METRICS ON THE SPACE OF GIBBS THERMAL STATES AND THE LINEAR RESPONSE THEORY. Journal of Theoretical and Applied Mechanics (Bulgaria), 51, 2, 2021, 154-186.
19. **Tonchev, N.S.**, Statistical Mechanics of Thermal Fluctuations of Nearly Spherical Membranes: The Influence of Bending and Stretching Elasticities. Physics of Particles and Nuclei volume, 52, Springer Nature, 2021, DOI:10.1134/S1063779621020064, 290-314.
20. **Varbev, S**, **Boradjiev, I**, **Chamati, H**. Single-photon generation of entangled triplet state in an atomic spin dimer. Journal of Physics: Conference Series, 1762, Institute of Physics Publishing, 2021.
21. **Varbev, S**, **Boradjiev, I**, **Kamburova, R**, **Chamati, H**. Interaction of solitons with a qubit in an anisotropic Heisenberg spin chain with first and second-neighbor interactions. Journal of Physics: Conference Series, 1762, Institute of Physics Publishing, 2021, ISSN: 1742-6596, DOI:https://doi.org/10.1088/1742-6596/1762/1/012018.
22. Demir, E., Mirzayev, M.N., **Popov, E.**, Horodek, P., Genov, I.G., Siemek, K., Mirzayeva, D.M., Turchenko, V.A., Bulavin, M., Beskrovnyi, A.I., Valizade, A.H., Akhundzada, H.V., Karaaslan, S.I., Effects of high-energetic $3He^{+}$ ion irradiation on tungsten-based composites. Vacuum, 184, Elsevier, 2021, DOI:10.1016/j.vacuum.2020.109934, 109934.
23. Gerdjikov, V. S., Mladenov, D. M., Stefanov, A. A., **Varbev, S. K.**, The mKdV-type equations related to A (1)5 and A (2)5 Kac-Moody algebras. Theoretical and Mathematical Physics, 207, 2, 2021, DOI:10.1134/S0040577921050068, 604-625.
24. Ivanova, N, **Genova, J**, **Chamati, H**. Physical properties of SOPC lipid membranes containing cholesterol by molecular dynamics simulation. Advances in Biomembranes and Lipid Self-Assembly, Academic Press, 2021, ISBN:9780323914994, 1.
25. Lajusticia-Costan, C, Santalla, S.N., Rodríguez-Laguna, J, **Korutcheva, E**. Random walkers on a deformable medium. Journal of Statistical Mechanics: Theory and Experiment, 2021, DOI:10.1088/1742-5468/ac1261, 073207.
26. Mifune, Toshiro, **Mishonov, Todor M.**, Serafimov, Nikola S., **Dimitrova, Iglika M.**, Popeski-Dimovski, Riste, Velkoska, Leonora, Petkov, Emil G., **Varonov, Albert M.**, Barone, Alberto. Tunable high-Q resonator by general impedance converter. Review of Scientific Instruments, 92, American Institute of Physics, 2021, DOI:10.1063/5.0041136, 025123-1-025123-3.
27. Minkov, I.L., **Dimitrova, I.M.**, Arabadzhieva, D, Mileva, E, Slavchov, R.L., The cause of accelerated desorption of sparingly soluble dodecanol monolayers: Convection or leakage? Colloids and Surfaces A: Physicochemical and Engineering Aspects, 629, Elsevier, 2021, DOI: 10.1016/j.colsurfa.2021.127414, 127414.
28. Mirzayev, M.N., Abdurakhimov, B.A., Demir, E, **Donkov, A.A.**, **Popov, E**, Tashmetov, M.Yu., Genov, I.G., Thabethe, T.T., Siemek, K., Krezhov, K, Mamedov, F, Mirzaeva, D.M., Bulavin, M.V., Turchenko, V.A., Thang, T.X., Abdurakhmonov, T.Z., Horodek, P. Investigation of the formation of defects under fast neutrons and gamma irradiation in 3C–SiC nano powder. Physica B: Physics of Condensed Matter, 611, Elsevier B.V., 2021, DOI:10.1016/j.physb.2021.412842, 412842.
29. Ortega, D, Rodríguez-Laguna, J, **Korutcheva, E**. A Schelling model with a variable threshold in a closed city segregation model. Analysis of the universality classes. Physica A: Statistical Mechanics and its Applications, 574, Elsevier, 2021, DOI: https://doi.org/10.1016/j.physa.2021.126010, 126010.
30. Ortega, D, Rodríguez-Laguna, J, **Korutcheva, E**. Avalanches in an extended Schelling model: An explanation of urban gentrification. Physica A: Statistical Mechanics

and its Applications, 573, Elsevier, 2021, ISSN:0378-4371, DOI:10.1016/j.physa.2021.125943, 125943.

31. Rzayev, R.F., Dashdemirov, A.O., Akhundzada, H.V., **Popov, E.**, Mirzayeva, D.M., Mirzayev, M.N., Surface binding energy and erosion coefficient on the nanoyttrium oxide under ionization irradiation. International Journal of Modern Physics B, 35, World Scientific, 2021, DOI:10.1142/S0217979221503094, 2150309.

32. Vitanov, K.N., **Dimitrova, Z.I.**, Simple equations method (SEsM) and its particular cases: Hirota method. AIP Conference Proceedings, 2321, AIP, 2021, DOI: https://doi.org/10.1063/5.0040410, 030036.

33. Vitanov, N.K., **Dimitrova, Z.I.**, Vitanov, K.N., Simple Equations Method (SEsM): Algorithm, Connection with Hirota Method, Inverse Scattering Transform Method, and Several Other Methods. Entropy, 23, 3, MDPI, 2021, DOI:10.3390/e23010010.

34. Vitanov, N.K., Vitanov, K.N., **Dimitrova, Z.I.**, Study of a Flow of Reacting Substances in a Channel of Network. Studies in Computational Intelligence, 961, Springer Nature, 2021, DOI:10.1007/978-3-030-71616-5_36.

35. **Ivanov, P.Ch.**. The New Field of Network Physiology: Building the Human Physiolome. Frontiers in Network Physiology, 1, Frontiers Media, 2021, DOI:10.3389/fnetp.2021.711778, 711778.

36. **Mishonov, Todor M.**, Petkov, Aleksander P., Andreoni, Matteo, Petkov, Emil G., **Varonov, Albert M.**, **Dimitrova, Iglika M.**, Velkoska, Leonora, Popeski-Dimovski, Riste. Problem of the 8-th Experimental Physics Olympiad, Skopje, 8 May 2021 Determination of Planck constant by LED. Обучение по природни науки и върхови технологии, 30, 3, Аз-буки, 2021, ISSN:2738-7143, DOI:10.53656/nat2021-3.02.

37. **Mishonov, T. M.**, Petkov, A. P., Andreoni, M., Petkov, E. G., **Varonov, A. M.**, **Dimitrova, I. M.**, Velkoska, L., Popeski-Dimovski, R., Problem of the 8th Experimental Physics Olympiad, Skopje, 8 May 2021 Determination of Planck constant by LED. 2021, DOI: arXiv:2106.01337 [physics.ed-ph]

38. **Mishonov, Todor M.**, Zahariev, Nedelcho I., **Varonov, Albert M.**, Hot and cold spots along the Fermi contour of high-Tc cuprates in the framework of Shubin-Kondo-Zener s-d exchange interaction. 2021, DOI: arXiv:2111.06716 [cond-mat.supr-con].

39. **Shopova, Diana V.** Thermodynamic analysis of magnetic phase transitions in the ferromagnetic superconductor UGe2 at ambient pressure. arXiv:2108.09512 [cond-mat.supr-con], 2021.

40. **Ivanov, P.Ch.**, Bartsch, R.P. Physiologic systems dynamics, coupling and network interactions across the sleep-wake cycle. Methodological Approaches for Sleep and Vigilance Research, Elsevier, 2022, DOI:10.1016/B978-0-323-85235-7.00006-5, 59-100

41. **Angelova, E**, **Chamati, H**. Dynamic simulation of the energy spectrum of phonons in the magnetic bcc iron. Comptes Rendus de l'Academie Bulgare des Sciences, Accedpted.

42. **Tonchev, H. S.**, Danev, P. M.. High robustness quantum walk search algorithm with qudit Householder traversing coin, machine learning study. приета за печат: 2021, arxiv

43. **Tonchev, H. S.**, Danev, P. M.. Optimizing the walk coin in the quantum random walk search algorithm through machine learning, 2021, arxiv.

ONGOING RESEARCH PROJECTS:

- Quantum effects in low-dimensional and nanostructured magnetic systems
- Synthesis and theoretical studies of graphene nanostructures – Ministry of Sciences – Bulgaria & JINR Dubna - Russia

- Magnetic quantum effects in low-dimensional and nanostuctured spin systems – Bulgarian National Science Fund
- Dynamics of low dimensional spin systems – Post doctoral
- Exchange interactions in nanomagnetic systems

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

TEACHING ACTIVITIES:
Latex Basics
Computer modeling of complex systems

DEPARTMENT FUNCTIONAL MATERIALS AND NANOSTRUCTURES

LABORATORY

PHYSICS OF MATERIALS AND LOW TEMPERATURES

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

TOTAL STAFF: **17**
RESEARCH SCIENTISTS: **12**
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

Associated member: Prof. M.M. Gospodinov, D.Sc.

RESEARCH ACTIVITIES:

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

Highly conductive Al-doped ZnO (AZO) films are deposited on transparent and flexible muscovite mica substrates by using the atomic layer deposition (ALD) technique. The obtained structures possess high optical transmittance in the visible and near-infrared spectral range and retain low electric resistivity, even after continuous bending of up to 800 cycles. AZO films on mica are implemented as transparent conductive electrodes in flexible polymer dispersed liquid crystal (PDLC) devices. The measured electro-optical characteristics and response time of the proposed devices reveal the higher potential of AZO-mica for future ITO-free flexible optoelectronic applications.

We studied an innovative group of materials: dichalcogenides of transition metals, such as WSe2, PtSe2 and WTe2. They are obtained in different structural forms: as two-dimensional (nano)layers (WSe2 and PtSe2) and single crystals (WTe2). The nanolayers were obtained by gas-phase deposition. A series of experiments for elemental analysis were performed: X-ray photoelectron spectroscopy (XPS), UV-VIS-NIR spectrophotometry and Raman spectroscopy in order to qualitatively monitor the formation of nanolayers at different stages of synthesis.

Layers of ZnO doped with transition metals (Ni, Co and Fe) were obtained by ALD. The effect of doping on structure, morphology and optical properties was investigated using X-ray diffraction, XPS, ellipsometry, UV and visible optical spectroscopy and infrared Fourier spectroscopy. The influence of the substrate type (glass, Si with different orientation and type) on the morphology of the layers was also studied. Doping with Ni impairs the transparency of the layer, while doping with Co improves it. Based on experiments with Kerr effect microscopy, a strong magnetic response and high values of coercitivity were found. These

results, as well as the synthesis technology, make it possible to use these layers in a new type of electronic, magnetic and optical devices.

25 nm thick AlN layers were deposited by 550 ALD cycles at 330 ° C on Si (111) substrates using TMA (trimethylaluminum) and NH3 as precursors. X-ray diffraction analysis shows an amorphous structure of the layers. The presence of AlN was found by XPS in all obtained layers with Al 2p and N 1s peaks at 73.6 and 396.8 eV, respectively. The analysis showed that an Al / N ratio closest to the stoichiometric one (1: 1) was obtained at pulse durations of 180 and 90 ms for TMA and NH3 precursors, respectively. Atomic force microscopy (AFM) shows roughness of the order of 1 nm. The presented results are promising for application of AlN layers in surface acoustic-wave devices.

The photocatalytic activity of ZnO layers grown by ALD on porous anodized aluminum (AAO) substrates with hexagonal pore symmetry was studied. The ZnO layers are grown in Al2O3 pores with diameters in the range 93–134 nm and pore distance in the range 185–286 nm. The photocatalytic activity of the ZnO / Al2O3 composite was measured for different intensities of UV radiation and different pore sizes. The interesting results obtained prove the possibility of using AAO-based substrates as a testbed for studying the photocatalytic properties of ALD-deposited photocatalysts on porous structures. The obtained results can be used as guidelines for the design of photocatalysts with porous structure and tubular geometry.

Ellipsometric studies of single-crystal samples of WTe2 were performed - a material with a variety of topological, dielectric and magnetoresistive properties. It has a strong triaxial anisotropy, which is reflected in complex optical properties, high refractive index and birefringence.

We monitored the phase evolution of Bi2Se2.1Te0.9 under high pressure up to 30 GPa using angular dispersion X-ray diffraction (ADXRD) and Raman spectroscopy. Consecutive structural phase transitions from rhombohedral structure to a seven- and eight-fold monoclinic structure and finally to a body-centered structure have been identified, occurring at pressures of 10.5 GPa, 18.8 GPa, and 23.0 GPa, respectively. The rhombohedral phase shows an even more pronounced electronic topological transition in the low-pressure mode than those previously observed in Bi2Te3 and Bi2Se3. Observations show that doping Bi2Se3 with Bi2Te3 leads to deeper effects in the electronic and structural properties of the resulting system than expected by Vegard's law. This may be mainly due to the stoichiometrically dependent preferred occupation of Se and Te atoms in the five-fold structural units.

II. Carbon-nanostructure research

CVD-grown graphene was transferred to polished bismuth silicate crystalline substrates with subsequent characterization of the samples by optical absorption and Raman spectroscopy. The influence of photoinduced phenomena in the crystalline substrate on the graphene layer manifested by increased graphene absorption and shift of the G-peak position is explained by optically induced doping of graphene by transient photoinduced fields of spatial charge.

The process of synthesis of multilayer graphene by the atmospheric-pressure chemical vapor deposition technique (APCVD) is demonstrated. Graphene quality assessments are performed by Raman analysis and optical spectroscopy. Graphene was then transferred to polyethylene terephthalate (PET) substrates and applied as a transparent conductive electrode in flexible PDLC devices. Their electro-optical properties, such as voltage-dependent permeability and flexibility behavior, were studied. Sheet stability has been demonstrated after 1200 bending tests of the graphene / PET structure.

III. High-temperature superconductors

The fluctuation conductivity in the normal state of Fe-based superconductors has been studied. These studies provide information on various phenomena and stages in the formation of the superconducting state, for example, the existence of uncorrelated Cooper pairs above the critical temperature.

Newly discovered correlations in the behavior of one of the most basic phenomena in superconductors - double peak effect in magnetic hysteresis in the FeSeTe system - have been extensively analyzed. A universal relationship has been established between this phenomenon and various relaxation processes in the vortex matter in many superconducting systems.

PUBLICATIONS:

1. Rafailov, P. M., Marinova, V., Todorov, R., Boyadjiev, S., An Optical Excitation Study of Pure and Ru-doped Bi12SiO20 Crystals with Graphene Coating. Journal of Physics: Conference Series, 1762, 2021, 012024. DOI:10.1088/1742-6596/1762/1/012024.

2. Dimitrov, D. Z., Chen, Z. F., Marinova, V., Petrova, D., Ho, C. Y., Napoleonov, B., Blagoev, B., Strijkova, V., Hsu, K. Y., Lin, S. H., Juang, J-Y. ALD Deposited ZnO:Al Films on Mica for Flexible PDLC Devices. Nanomaterials, 11, 2021, 1011. DOI:https://doi.org/10.3390/nano11041011.

3. Buchkov, K, Todorov, R, Terziyska, P, Gospodinov, M, Strijkova, V, Dimitrov, D, Marinova, V. Anisotropic Optical Response of WTe2 Single Crystals Studied by Ellipsometric Analysis. Nanomaterials, 11, 2021, 2262. DOI:https://doi.org/10.3390/nano11092262.

4. Minev, N., Buchkov, K., Dikov, H., Videva, V., Avramova, I., Rafailov, P., Dimitrov, D.. Properties Analysis of 2D PtSe2 Layers Grown by Thermally Assisted Conversion of Chemical Vapor Deposition. Institute of Electrical and Electronics Engineers Inc., IEEE, 2021. DOI:10.1109/ET52713.2021.9579921, 9579921.

5. Blagoev, B., Terziyska, P., Tzvetkov, P., Kovacheva, D., Ivanov, P., Mehandzhiev, V., Dimitrov, D.. Low Temperature ALD Films On Transparent And Flexible Substrates. Proc. XXX International Scientific Conference Electronics - ET2021, September 15 - 17, 2021, Sozopol, Bulgaria, 2021. DOI: 10.1109/ET52713.2021.9580070.

6. Buchkov, K, Galluzzi, A, Blagoev, B, Paskaleva, A., Terziyska, P., Stanchev, T, Mehandzhiev, V, Tzvetkov, P, Kovacheva, D, Avramova, I. Magneto-optical characterization of ZnO / Ni nano-laminate obtained via Atomic Layer Deposition. Journal of Physics: Conference Series, 1762, 2021, 012041. DOI:10.1088/1742-6596/1762/1/012041.

7. Galluzzi, A., Buchkov, K., Tomov, V., Nazarova, E., Leo, A., Grimaldi, G., Polichetti, M.. High pinning force values of a Fe(Se, Te) single crystal presenting a second magnetization peak phenomenon. Materials, 14, 2021, 5214. DOI:10.3390/ma14185214.

8. Polichetti, M., Galluzzi, A., Buchkov, K., Tomov, K., Nazarova, E., Leo, A., Grimaldi, G., Pace, S.. A precursor mechanism triggering the second magnetization peak phenomenon in superconducting materials. Scientific Reports, 11, 2021, 7247. DOI:10.1038/s41598-021-86728-8.

9. Solovjov A. L., Petrenko E. V., Omelchenko L. V., Nazarova E., Buchkov K., Rogacki K.. Fluctuating Cooper pairs in FeSe at temperatures exceeding double Tc. Supercond. Sci and Technol., 34, 2021, 015013. DOI:https://doi.org/10.1088/1361-6668/abc2ac.

10. Paskaleva, A., Blagoev, B. S., Terziyska, P. T., Mehandzhiev, V., Tzvetkov, P., Kovacheva, D., Avramova, I., Spassov, D., Ivanova, T.,, Gesheva, K.. Structural, morphological and optical properties of atomic layer deposited transition metal (Co, Ni or Fe)- doped ZnO layers. Journal of Materials Science: Materials in Electronics, 32, 2021, 7162-7175. DOI:https://doi.org/10.1007/s10854-021-05425-4.

11. Dionisiev, I., Minev, N., Dimitrov, D., Videva, V., Buchkov, K., Dikov, H., Rafailov, P., Marinova, V.. 2D WSe2 films synthesized by thermally assisted conversion method. Institute of Electrical and Electronics Engineers Inc., IEEE, 2021. DOI:10.1109/ET52713.2021.9580033, 9580033.

12. Beshkova, M., Blagoev, B. S., Mehandzhiev, V., Yakimova, R., Avramova, I., Terziyska, P., Kovacheva, D., Strijkova, V.. Optimization of AlN films grown by atomic layer deposition. Journal of Physics: Conference Series, 1762, 012035, 2021. DOI:doi:10.1088/1742-6596/1762/1/012035.

13. Stefanov, B.I., Blagoev, B.S., Österlund, L., Tzaneva, B.R., Angelov, G.V.. Effects of anodic aluminum oxide substrate pore geometry on the gas-phase photocatalytic activity of zno/al2o3 composites prepared by atomic layer deposition. Symmetry, 13, 2021, 1456. DOI:https://doi.org/10.3390/sym13081456.

14. Koduru, H.K., Marinov, Y.G., Kaleemulla, S., Rafailov, P.M., Hadjichristov, G.B., Scaramuzza, N.. Fabrication and characterization of magnesium—ion-conducting flexible polymer electrolyte membranes based on a nanocomposite of poly(ethylene oxide) and potato starch nanocrystals. Journal of Solid State Electrochemistry, 25, 2021, 2409-2428. DOI:10.1007/s10008-021-05018-5.

15. Marinova, V., Petrov, S., Napoleonov, B., Mickovski, Y., Petrova, D., Dimitrov, D., Hsu, K.-Y., Lin, S.-H.. Multilayer Graphene for Flexible Optoelectronic Devices. Materials Proceedings 4, 2021, 65. DOI: 10.3390/IOCN2020-07900.

16. Tseng, Y.-C., Lin, C.-M., Jian, S.-R., Lee, P.H., Gospodinov, M.M., Marinova, V., Dimitrov, D.Z., Luo, C.-W., Wu, K.-H., Zhang, D.-Z., Juang, J.-Y.. Structural and electronic phase transition in Bi2Se2.1Te0.9 under pressure. Journal of Physics and Chemistry of Solids, 156, 2021, 110123. DOI:10.1016/j.jpcs.2021.110123.

ONGOING RESEARCH PROJECTS:

- National Scientific Research Fund: Projects КП-06-ПН58/12, КП-06-Н38/10 and Н28/8;

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

- Inter-academic cooperation with:

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

(ii) University of Salerno, Italy

“Investigation of superconducting and multiferroic materials”

INTERNATIONAL COLLABORATION:

- Institute of Low Temperature and Structure Research, PAS, Wroclaw, Poland;
- National Ciao Tung University, Hsinchu, Taiwan;
- Department of Physics ‘E.R. Caianiello’, University of Salerno, Salerno, Italy
- CNR-SPIN Salerno, via Giovanni Paolo II, 132, Fisciano (SALERNO), I-84084, Italy

DEPARTMENT FUNCTIONAL MATERIALS AND NANOSTRUCTURES

LABORATORY

PHYSICAL PROBLEMS OF MICROELECTRONICS

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

TOTAL STAFF: **15**
RESEARCH SCIENTISTS: **7**
ASSOC. MEMBERS: **0**

Prof. D.Sc. A. Paskaleva, Assoc. Prof. Ph.D. D. Spassov, Assoc. Prof. Ph.D. Ts. Ivanov, Assoc. Prof. Ph.D. E. Manolov, assist. T. Stanchev, physicist E.Gajdarzhieva, technologist S. Tsvetanov, technologist M. Stoicheva, technologist Ch. Petkanov, technologist M. Atananasov.
Electromagnetic group: Assist. Prof. L. Mihailov, assist. P. Todorov, mechanical eng. N. Mihaylov, technician V. Altynova, technician N. Ilieva

RESEARCH ACTIVITIES:

The research activities of the Laboratory in the recent years have been focused on nanoelectronics and cover the investigations of thin and ultra-thin nanolaminated and doped high-*k* dielectrics and semiconducting oxides for advanced non-volatile memories. The dedicated Electromagnetic sensor group is mainly engaged in experimental investigations of the Electromagnetic Echo Effect (EMEE) and development of sensors for rapid and contactless analysis of solids, liquids and gases. The research work conducted in 2021 can be summarized as follows:

The electrical (current-voltage (I-V) and capacitance-voltage (C-V)) characteristics of thin homogeneous ZnO layers doped with transition metal atoms (Ni, Co or Fe), prepared by atomic layer deposition (ALD) were studied. Metal-oxide-metal (MOM) structures with lower electrode - TiN and upper electrode - Pt were prepared for the electrical measurements. It was found that the shape of the C-V curves differs depending on the dopant element. C-V curves for Fe: ZnO and Ni: ZnO show a pronounced peak and strong frequency dependence, which implies that the doped ZnO layers have a semiconductor behavior. The concentration of the dopant (majority current carriers) N_D, the barrier height, Φ_b and the built-in potential -V_{bi} are determined: $N_D = 6.83x10^{17}$ cm^{-3} ; Vbi=1.29 V, $\Phi_b = 1.24$ eV in case of Fe doping and $N_D = 3.63x10^{18}$ cm^{-3}; V_{bi}=3.43 V, $\Phi_b = 3.4$ eV – for Ni doped films. The higher concentration of the dopant in the case of Ni: ZnO compared to Fe:ZnO is in a good agreement with the results of structural studies. The unrealistically high value of Φ_b for Ni doping is most likely due to surface defects or barrier inhomogeneities. The capacitance-voltage characteristics of Co:ZnO layers suggest possible presence of ferro- and antiferroelectric phenomena in the layers. A strong frequency dependence of the capacity of the structures was observed, which is associated with the processes of capture and emission of current carriers from defective states in zinc oxide.

The electrical characteristics and charge trapping were investigated for MIS (metal-dielectric-semiconductor) capacitors with charge trapping layer of HfO_2/Al_2O_3 nanolaminates and Al doped HfO_2 layers. The charge trapping layer is sandwiched between upper blocking oxide (Al_2O_3) and bottom tunnel oxide (SiO_2 or Al_2O_3) films. The employed dielectric structures based on HfO_2 an Al_2O_3 were fabricated by atomic layer deposition (ALD). To

achieve effect of doping the thickness of Al_2O_3 was reduced to 1 ALD cycle while maintaining the overall thickness of the doped and nanolaminated stacks the same. The dielectric constant of HfO_2-based stacks obtained from capacitance measurements at different frequencies does not depend on the way Al is introduced into HfO_2 (lamination or doping). Both types of HfO_2-Al_2O_3 structures show a negative initial oxide charge, but in nanolaminated layers its density is higher. Al doping of HfO_2 has been found to decrease the leakage currents compared to the case of nanolaminated HfO_2-Al_2O_3. The initial analysis of the characteristics of the charge trapping in the studied stacks shows a stronger capture of positive charges in the doped layers.

A model for processing of data from ellipsometric measurements of multilayer dielectric structures was proposed. Applying the model, the composition distribution in the depth of the stacks and the thickness of the sublayers were estimated. The possibility to obtain some of the dielectric parameters of the sublayers building the stack from the ellipsometric data based on the developed algorithms is demonstrated. The method appears as a valuable tool complementing the electrical characterization of the structures, allowing to bypass some of the difficulties in capacitance measurements of multilayer dielectric structures.

A number of investigations have been conducted to detect the presence of various viruses, to determine the effect of chemicals on the microphysical properties of fog, as well as to optimize its cleaning properties for various types of air pollutants. The detection of the different virus species was performed using the *Electromagnetic Echo Effect* to discern the specific antigen-antibody reactions. The purpose of the experiments was to demonstrate the applicability of the effect for rapid diagnosis and in the future to proceed to the development of a sensor for Covid-19.

The effect of a superstrong magnetic field on the crust of magnetars has been studied. The composition of the crust and the limit beyond which atomic nuclei decay by neutron radiation are quantified for different strengths of the magnetic field. Experimental measurements of atomic mass are used, supplemented by theoretical masses calculated from Hartree-Fock-Bogolyubov nuclear models. An optimized calculation procedure is employed to reduce the calculation time by several orders.

The reflection of some aspects of the theories of unification of interactions on the properties of nuclei has been studied. The energies of the ground state electron, the mass correction, and the mass polarization of low- and high-charged helium-like ions are calculated analytically and numerically. The Schrödinger two-electron equation is solved with a perturbation approach based on explicitly correlated wave functions. Adjustments due to additional dimensions are examined and different approaches to the minimization procedure are considered.

A detailed analysis of the influence of the isotopic characteristics of the nucleus on the ground energy of the helium-like electron-nuclear system and its corresponding components within the classical quantum mechanics for the synthesized 3833 isotopes is made. The research is within the framework of classical quantum theory without any additional assumptions. The relationships between these energies and their components for different isotopes have been determined using staggering analysis. The obtained results correspond to all physical and mathematical principles and measurements.

Activities for support of implemented models: “Optimal Distribution of Locomotives” and “Dynamic Traction Integrator”, and their algorithms, which continue to be included in railway systems of national importance, covering a large number of tasks

PUBLICATIONS:

1. Spassov, D., Paskaleva, A., Guziewicz, E., Davidović, V., Stanković, S., Djorić-Veljković, S., Ivanov, T., Stanchev, T., Stojadinović, N.. Radiation Tolerance and Charge Trapping

Enhancement of ALD HfO_2/Al_2O_3 Nanolaminated Dielectrics.. Materials, 14(4), 2021, 14(4), 84.
2. Paskaleva, A., Blagoev, B. S., Terziyska, P. T., Mehandzhiev, V., Tzvetkov, P., Kovacheva, D., Avramova, I., Spassov, D., Ivanova, T.,, Gesheva, K.. Structural, morphological and optical properties of atomic layer deposited transition metal (Co, Ni or Fe)-doped ZnO layers. Journal of Materials Science: Materials in Electronics, 32, 2021, 7162-7175.
3. Gegova-Dzhurkova, R., Nesheva, D., Dzhurkov, V., Scepanovic, M., Grujić-Brojčin, M., Bineva, I., Mihailov, V., Levi, Z., Manolov, E., Popovic, Z.V.. Modification of surface morphology and lattice order in nanocrystalline ZnO thin films prepared by spin-coating sol–gel method. Journal of Sol-Gel Science and Technology, 100(1), 2021, 55-67.
4. Spassov, D., Paskaleva, A., Guziewicz, E, Wozniak, W, Stanchev, T, Ivanov, Tz., Wojewoda-Budka, J., Janusz-Skuza, M. Effect of blocking and tunnel oxide layers on the charge trapping properties of MIS capacitors with ALD HfO2/Al2O3 nanolaminated films,. Journal of Physics: Conference Series, 1762, 2021, 012038.
5. Buchkov, K, Galluzzi, A, Blagoev, B, Paskaleva, A., Terziyska, P., Stanchev, T, Mehandzhiev, V, Tzvetkov, P, Kovacheva, D, Avramova, I. Magneto-optical characterization of ZnO / Ni nano-laminate obtained via Atomic Layer Deposition. Journal of Physics: Conference Series, 1762, 2021, 012041.
6. Gegova-Dzhurkova, R., Nesheva, D., Mihailov, V., Dzhurkov, V., Terziyska, P., Manolov, E.. Effect of infrared laser irradiation on electrical conductivity and ethanol sensitivity of sol gel ZnO thin films. Journal of Physics: Conference Series, 1762, 012037.
7. Spassov, D., Paskaleva, A. Optimization of HfO_2/Al_2O_3 Dielectric Stacks for Charge Trapping Memories. Proc. IEEE 32st International Conference on Microelectronics, MIEL 2021,, IEEE, 2021, 149-152.
8. Danković, D, Mitrović, N, Veljković, S, Davidović, V, Djorić-Veljković, S, Prijić, Z, Paskaleva, A., Spassov, D., Golubović, S. A Review of the Electric Circuits for NBTI Modeling in P-Channel Power VDMOSFETs. Proc. IEEE 32st International Conference on Microelectronics, MIEL 2021,, IEEE, 2021, 55-62.
9. Skeparovski, A, Novkovski, N, Paskaleva, A., Spassov, D.. "Reduction of Interface States Stress Generation by Oxygen Annealing of ALD Nanolaminated HfO2/Al2O3 Dielectric Stacks for Charge Trapping Devices. Proc. IEEE 32st International Conference on Microelectronics, MIEL 2021,, IEEE, 2021, 153-156.
10. Veljković, S., Mitrović, N, Djorić-Veljković, S, Davidović, V, Manić, I., Golubović, S, Paskaleva, A., Spassov, D., Prijić, Z, Prijić, A., Stanković, S, Danković, D. Effects of Bias Temperature Stress and Irradiation in Commercial p-Channel Power VDMOS Transistors. Proc. IEEE 32st International Conference on Microelectronics, MIEL 2021,, IEEE, 2021, 345-348.
11. Ivanov O., Simeonov K., Todorov P., Stoyanov Z., Antonova D., Kostadinov K.. Registration approach of viruses by using the electromagnetic echo effect. 2021 IEEE International Conference on Manipulation, Manufacturing and Measurement on the Nanoscale (3M-NANO), 2021, 296-300.
12. Ivanov O., Todorov P., Simeonov K., Vaseashta A., Experimental Control of a Reaction Occurring during the Interaction between Chicken Anemia Virus (CAV) and Its Corresponding Antibodies, bioRxiv, 2021.02.12.430950, 2021, DOI: 10.1101/2021.02.12.43095

Patents: O. Ivanov P. Todorov, J. L. Pérez-Díaz, "Optimization of the cleaning properties of fog through a sensor operating on the basis of laser induced photo-charge effect by measurement of electrical response, patent № 67262B1, issued on 26.02.2021 by the Patent Office of the Republic of Bulgaria.

ONGOING RESEARCH PROJECTS:

Funded by Bulgarian Science foundation:

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

Funded by Bulgarian Academy of Sciences:

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

INTERNATIONAL COLLABORATION:

1. Fraunhofer Inst. of Integrated Systems and Device Technology, Erlangen, Germany.
2. Institute of Electronic Engineering, Slovak Academy of Sci., Bratislava, Slovakia.
3. Insitute of Physics, St.St. Cyril and Methodius Universty, Skopie, Macedonia.
4. University of Nish, Serbia.
5. Institute of Physics, Polish Academy of Sci. Warsaw, Poland.
6. Universidad Autonoma de Baja California, Mexicale, Mexico.

DEPARTMENT FUNCTIONAL MATERIALS AND NANOSTRUCTURES

LABORATORY

ACOUSTOELECTRONICS

HEAD: **Assoc. Prof. Karekin Esmeryan, PhD**
tel: 02 979 58 11; e-mail: karekin_esmerian@abv.bg

TOTAL STAFF: **8**
RESEARCH SCIENTISTS: 4
ASSOC. MEMBERS: 2

Prof. Ivan Avramov, DsC, Assoc. Prof. Karekin Esmeryan, PhD, Assist. Prof. Yuliyan Lazarov, PhD, chemist Ivana Ilievska, PhD, chemist Yulian Fedchenko, MsC, chemist Teodor Grakov, BsC, eng. Lazar Vergov, MsC, eng. Stefan Staykov, BsC

Associated members: Cor. Mem. Lozan Spassov, Assoc. Prof. Ekaterina Radeva Ph.D.

RESEARCH ACTIVITIES:

A highly sensitive method for direct detection of respiratory viruses has been developed, using a quartz surface microbalance (QSM) operating with Rayleigh surface acoustic waves (RAS) as a resonant gravimetric sensor element. Such a QSM has been shown to have a mass sensitivity of 19.7 KHz / ng and a detection limit of 11 fg, which is on the order of 22 viral particles of the SARS-Cov-2 virus. When functionalizing the active surface of the QSM with a layer of aptamer with high affinity to a respiratory virus, an express check for the presence of such a virus in the human breath is possible. Thus, the method can be applied in widely available personal diagnostic tools to check for the presence of SARS-Cov-2 and other respiratory viruses, which when infected dominate over all other substances in the human breath.

A method has been developed to increase the gas sensitivity of QSs functionalized with plasma polymer layers of hexamethyldisiloxane (HMDSO) and triethylsilane (TES) to ammonia vapor. By further modification of the polymer layers with NH3, in the same process of plasma polymerization used in the synthesis of functionalizing layers, a significant increase in the affinity of the layers to ammonia vapor is achieved and their sorption properties are improved accordingly. An increase in the gas sensitivity of real working CPMs by 74 to 82% and by 8%, respectively, in the layers of HMDSO and TES under the influence of ammonia vapor with concentrations from 50 to 500 ppm. High reproducibility of the sensor parameters was obtained during repeated measurements over time.

For the first time, the tolerability of the RWMP QSM to functionalization by repeated layer-by-layer application of Langmuir Blodget (LB) layers for chemical and biosensor applications was studied. It has been shown that 430 MHz QSMs tolerate up to 15 LB-monohydric acid monolayers suitable for such applications, while maintaining low imported attenuation and high load Q-factor. High sensitivity to chloroform, hexane, methanol, ethanol and acetone vapors and low sensitivity to water vapor have been demonstrated, which creates prerequisites for applicability in sensors for volatile organic compounds (VOC).

New thin polymer layers have been synthesized by the plasma polymerization method. Triethyl borate, titanium butoxide, tetrabutyl 1-methyl-2-propynyl ether and triethylsilane (TES) were used as monomers. The variation of the main parameters of the process - the gas

phase pressure, the discharge current density and the synthesis time led to the production of polymers of different thickness, structure and morphology. The thin layers of TES obtained on surfactant resonators were used as a sensitive layer for determining the concentration of ammonia in the air.

Within 2021, a thorough literature review on the possibilities for developing non-wettable functional coatings based on industrial soot wastes was performed. The first-of-its kind experiments, related to the impact of the overall physicochemical profile of superhydrophobic carbon soot coatings on their icephobic properties were conducted. The results showed that the current perceptions of the international scientific community that the morphology, roughness and wetted area at the solid-liquid contact interface are the main parameters controlling the freezing time and temperature of icing are not universal and do not fully apply to carbon soot-based surfaces. It was found that the condensation icing and the freezing dynamics of static water droplets on carbon soot are governed by the chemical composition, thickness and porosity of the material. It is of significant practical importance that the soot defrosting is up to 35 times faster compared to a hydrophilic substrate, which means that the coatings maintain extremely weak ice adhesion, making the soot a material with high potential for passive icing protection of various cryogenic facilities. New methods have also been developed for detecting the various modes of water freezing and for complex biochemical analysis of human urine, using a superhydrophobic quartz crystal microbalance.

AWARDS:
IOP Trusted reviewer certified to Dr. Karekin Esmeryan

PUBLICATIONS 2021:
(1) **K. D. Esmeryan**, S. D. Gyoshev, C. E. Castano, R. Mohammadi, Anti-frosting and defrosting performance of chemically modified super-nonwettable carbon soot coatings, *Journal of Physics D Applied Physics* **54** (2021) 015303. (IF = 3.207) Category Q1
(2) **K. D. Esmeryan**, T. A. Chaushev, Complex characterization of human urine using super-nonwettable soot coated quartz crystal microbalance sensors, *Sensors & Actuators A Physical* **317** (2021) 112480. (IF = 3.407) Category Q1
(3) **K. D. Esmeryan**, Y. I. Fedchenko, G. P. Yankov, K. A. Temelkov, Laser irradiation of super-nonwettable carbon soot coatings – physicochemical implications, *Coatings* **11** (2021) 58. (IF = 2.881) Category Q2
(4) **K. D. Esmeryan**, Critical aspects in fabricating multifunctional super-nonwettable coatings exhibiting icephobic and anti-biofouling properties, *Coatings* **11** (2021) 339. (IF = 2.881) Category Q2
(5) **K. D. Esmeryan**, N. I. Stoimenov, Studying the bulk and contour ice nucleation of water droplets via quartz crystal microbalances, *Micromachines* **12** (2021) 463. (IF = 2.891) Category Q2
(6) A. Baldelli, **K. D. Esmeryan,** O. Popovicheva, Turning a negative into a positive: Trends, guidelines and challenges of developing multifunctional non-wettable coatings based on industrial soot wastes, *Fuel* **301** (2021) 121068. (IF = 6.609) Category Q1
(7) **K. D. Esmeryan**, C.E. Castano, S. D. Gyoshev, Y. Lazarov, N. I. Stoimenov, R. Mohammadi, On the dynamics of contact line freezing of water droplets on superhydrophobic carbon soot coatings, *Current Applied Physics* **31** (2021) 74-86. (IF = 2.48) Category Q2
(8) **I. D. Avramov**, "The Quartz Surface Microbalance - a Possible Candidate for Rapid Respiratory Virus Detection", 2021 IEEE Int. Symp. *ISAF-2021*, published in IEEE Explore, Aug. 11, 2021, https://ieeexplore.ieee.org/document/9477383

(9) **Ivan Avramov, Ekatherina Radeva, Yuliyan Lazarov, Teodor Grakov** and **Lazar Vergov**, "Sensitivity Enhancement in Plasma Polymer Films for Surface Acoustic Wave Based Sensor Application", *Coatings* 2021, 11, 1193. https://doi.org/10.3390/coatings11101193, (IF = 2.881) Category Q2

PATENT APPLICATIONS 2021:

(1) **K. D. Esmeryan, T. A. Yordanov, Y. V. Lazarov** and **L. G. Vergov**, A metal holder for quartz crystal resonators functioning at sub-zero temperatures, submitted on 26.02.2021г, Sofia Bulgaria, №113331.

(2) **K. D. Esmeryan** and T. A. Chaushev, Superhydrophobic carbon soot nanoparticles as a functional activator of human spermatozoa, submitted on 30.11.2021г, Sofia Bulgaria, №113453.

ONGOING RESEARCH PROJECTS:

(1) Studying the impact of physicochemical characteristics of super-nonwetting carbon soot coatings on their icephobic properties, **КР-06-Н37/7/06.12.2019.**

(2) An innovative engineering approach for cryopreservation of human gametes, **КР-06-Н57/1/15.11.2021.**

INTERNATIONAL COLLABORATION:

(1) Department of Mechanical and Nuclear Engineering, Virginia Commonwealth University, USA, collaborators: Dr. Reza Mohammadi, Dr. Carlos Castano

(2) Department of Mechanical Engineering, University of British Columbia, Canada, collaborator: Dr. Alberto Baldelli

(3) Skobelstin Instute of Nuclear Physics, Lomonosov Moscow State University, Russia, collaborator: Dr Olga Popovicheva

(4) Chemical Engineering and Chemical Technology, Imperial College London, England

(5) Research Center Karlsruhe, Germany

DEPARTMENT NANOPHYSICS

LABORATORY
PHOTOELECTRICAL AND OPTICAL PHENOMENA IN WIDE BAND GAP SEMICONDUCTORS

HEAD: **Assoc. Prof. Irina Bineva, PhD**
tel: .979 5743; e-mail: irka@issp.bas.bg

TOTAL STAFF: ***8***
RESEARCH SCIENTISTS: ***5***
ASSOC. MEMBERS: ***4***
HONORARY MEMBER: ***1***

Assoc. Prof. Z. Levi, PhD, Assoc. Prof. P. Terziyska, PhD, Assoc. Prof. T. Hristova-Vasileva, PhD, Prof. D. Nesheva, D.Sc., Eng. R. Dzhurkova, Eng. V. Dzhurkov;
Technologist: E. Zaharincheva.
Associated members: Assoc. Prof. Z. Ivanova, PhD, Assoc. Prof. A. Szekeres, PhD, Prof. S. Alexandrova, D.Sc, Assoc. Prof. S. Simeonov, PhD.
Honorary member: Prof. E. Vateva, D.Sc.

RESEARCH ACTIVITIES:

Two groups of sol-gel films of ZnO prepared using the spin-coating technique were investigated. A new element in the preparation of the first group of samples was application of hot air flow as a first step in the drying procedure, followed by conventional heating in a furnace at 140^{o}C. The second group of samples was produced by applying only conventional furnace heating at 140^{o}C. Part of the films from both groups were further annealed at 400°C. The films had been characterized by X-ray diffraction (XRD), Scanning Electron Microscopy (SEM), Atomic Force Microscopy (AFM), Raman scattering, optical microscopy and spectroscopic ellipsometry (SE). It has been established that due to the use of monoethanolamine, all films are nanocrystalline, and drying with hot air flow has a significant effect on their properties. The films produced by using hot air flow, have a smooth, homogeneous surface, while the surface of those obtained by conventional furnace annealing is "wrinkled". The application of hot air also leads to a larger size of nanocrystals and better crystallinity, reduces the internal stress in the layers, gives assistance to the effusion of organic remains and leads to a lower defect density.

As an alternative to the standard furnace annealing nanosecond infrared laser irradiation was applied to modify the ZnO sol-gel thin films. Laser irradiation leads to reduction in the size and the density of small cracks and pores on the film surface as well as to decrease of the number of defects acting as non-radiative recombination centers for electrons. It has also been found that laser irradiation improves the crystal structure, slightly increases the size of the crystallites, however it also causes an increase of the the micro stresses in the films.

The study of the influence of drying procedures on the rate of photocatalytic reaction of sol-gel ZnO films irradiated with ultraviolet and visible light has shown that in both types of irradiation, all samples dried with hot air flow demonstrate significantly higher photocatalytic activity and better stability (up to 6 photocatalytic cycles) than those of the second group. The study was performed in collaboration with colleagues from the Institute of General and Inorganic Chemistry of the Bulgarian Academy of Sciences.

Experiments on sensitivity of ZnO sol-gel films to ethanol vapors at room temperature have revealed that the films prepared by applying drying with hot air flow have the best sensitivity. Laser beam irradiation has also increased the sensitivity, which has been related to the better crystallinity of the irradiated films. ZnO films, annealed at 400°C have not shown good sensitivity. This may be due to the reduction of the porosity and the significant increase in the size of the nanocrystals in the films as a consequence of annealing.

Single layers of ZnSe with thickness of 50 nm were deposited by vacuum thermal evaporation on Corning 7059 glass substrates at room temperature with three deposition rates (0.5, 1.5 and 3.0 nm/sec). The layers were prepared by applying two deposition manners: continuous or periodically interrupted. The influence of the manner of deposition and the deposition rate on the crystallinity and porosity of as-deposited ZnSe nanolayers had been investigated. Information about the porosity and optical properties of the layers was obtained by spectroscopic ellipsometry. From the X-ray diffraction and micro-Raman scattering data conclusions about the crystal structure were made. The results obtained by both methods were in very good agreement with each other and showed that all layers are crystalline, but the nanocrystals size and the crystal lattice ordering are strongly influenced by the deposition conditions - the size is larger in continuously deposited films and at a higher deposition rate. At all deposition rates, the porosity of the films, obtained by periodically interrupted deposition is higher than that of the continuously deposited and at each deposition manner the porosity decreases with increasing the deposition rate. Periodically interrupted layers deposited at 0.5 nm/s have the highest porosity (25%) and smallest nanocrystals size (~8 nm from XRD), while continuously deposited layers at 3.0 nm/s are not porous and have an average grain size of 19 nm.

In order to investigate the influence of TiO_2 nanotubes (NTs) obtained by anodic oxidation of titanium on the process of thermally induced crystal phase formation in NTs, three types of samples have been prepared by colleagues from the Autonomous University of Southern California in Mexicali, Mexico, by varying oxidation time and applied voltage. SEM studies of the sample surface have shown that ensembles of parallel nanotubes with an internal diameter of about 20 nm (and a wall thickness of 8-11 nm), about 45 nm (and wall thickness of 13-16 nm) and 80-100 nm (and wall thickness of 13-16 nm) have been prepared. Some of the samples were annealed in air at 450^{o}C for 2 hours by applying slow heating to the desired temperature and slow cooling to room temperature after heating.

Homogeneous films of SiO_x ($x = 1,2$) and composite films of a (nc)-Si-SiO_x containing amorphous Si nanoparticles (Si nanocrystals) were irradiated with fast neutrons at a flow of $3{,}96.10^{17}$ neutrons/cm^2. The irradiation effect on the properties of the layers was investigated with XPS, HRTEM, AFM, IR transmission, SE and Raman scattering. It has been found that the applied irradiation does not cause significant changes in the surface roughness of the layers, it remains very smooth. The irradiation of homogeneous layers causes phase separation, in which the oxygen content increases (from $x = 1,2$ to $x = 1,5$ in the matrix of the irradiated layers) and a significant amount of pure amorphous silicon phase is formed (a filling factor of ~0,15 has been estimated).

The neutron irradiation of the composite films with amorphous nanoparticles causes a decrease in the filling factor of the pure amorphous silicon phase, which is related to a decrease in the size of the nanoparticles. It has been assumed that neutron irradiation causes a reduction of part of SiO_2 to SiO_x and the released oxygen reduces the size of Si nanoparticles by their surface oxidation and SiO_x formation. High radiation resistance has been observed in the layers containing Si nanocrystals.

Spectroscopic ellipsometry with Woollam M2000D (193-1000 nm) ellipsometer was used to determine the thicknesses and/or the optical constants of thin metal oxide films (Al_2O_3,

ZnO, AZO, TiO_2 etc.) deposited on silicon and glass substrates by atomic layer deposition (ALD).

Layers of graphene deposited on Cu foil as well as multilayer structures of Al_2O_3 on graphene on Cu foil (Al_2O_3/graphene/Cu foil) were investigated. In the investigated fresh samples, copper oxide was not found, while in samples stored in air for six months, copper oxide with thickness ~ 6 nm was detected around the boundaries of graphene regions. The Al_2O_3 layer deposited on the graphene impedes the penetration of oxygen toward the Cu foil. (This work was performed in collaboration with the laboratory Physics of materials and low temperatures at ISSP-BAS)

Ellipsometric measurements were performed to determine the thickness of graphene-like thin films (a-C:H, ta-C:H, a-C), deposited on SiO_2/Si substrates by pulsed laser deposition and irradiated by UV-C light. This work was done in collaboration with colleagues from the Institute of Electronics-BAS.

PUBLICATIONS:

1. Buchkov, K., Todorov, R., Terziyska, P.**,** Gospodinov, M.**,** Strijkova, V.**,** Dimitrov, D.**,** Marinova, V. Anisotropic Optical Response of WTe_2 Single Crystals Studied by Ellipsometric Analysis. Nanomaterials, 11, 9, MDPI, 2021, 2262 https://doi.org/10.3390/nano11092262, SJR (Scopus):0.919, JCR-IF (Web of Science):5.076, Q1 (Web of Science).
2. Nesheva**,** D., Fogarassy, Z., Fabian, M., Hristova-Vasileva**,** T**.**, Sulyok, A., Bineva**,** I., Valcheva, E., Antonova, K., Petrik, P. Influence of fast neutron irradiation on the phase composition and optical properties of homogeneous SiOx and composite Si–SiOx thin films. Journal of Materials Science, 56, Springer Nature, 2021, 3197-3209, ISSN: 1573-4803, https://doi.org/10.1007/s10853-020-05338-3, SJR (Scopus):0.8, JCR-IF (Web of Science):4.22, Q1 (Web of Science).
3. Milenov, T.I., Avramova, I.A., Dikovska, A., Karaivanova, A., **Terziyska, P.**, Kolev, S.K., Karashanova, D., Georgieva, B, Dimov, D., Atanasov, V., Valcheva, E.P. Modification of graphene-like, hydrogenated amorphous, hydrogenated tetrahedral amorphous carbon and amorphous carbon thin films by UV-C light. Surfaces and Interfaces, 24, 2021, 101073, https://doi.org/10.1016/j.surfin.2021.101073, SJR (Scopus):0.71, JCR-IF (Web of Science):4.837, Q1 (Scopus).
4. Gegova-Dzhurkova, R.**,** Nesheva, D.**,** Dzhurkov, V.**,** Scepanovic, M., Grujić-Brojčin, M., Bineva, I.**,** Mihailov, V.**,** Levi, Z.**,** Manolov, E.**,** Popovic, Z.V. Modification of surface morphology and lattice order in nanocrystalline ZnO thin films prepared by spin-coating sol–gel method. Journal of Sol-Gel Science and Technology, 100, 1, 55-67, Springer, 2021, ISSN: 0928-0707, https://doi.org/10.1007/s10971-021-05635-6, JCR-IF (Web of Science): 2.326, Q2 (Web of Science).
5. Paskaleva, A.**,** Blagoev, B.S.**,** Terziyska, P.T.**,** Mehandzhiev, V.**,** Tzvetkov, P., Kovacheva, D., Avramova, I., Spassov, D.**,** Ivanova, T., Gesheva, K. Structural, morphological and optical properties of atomic layer deposited transition metal (Co, Ni or Fe) - doped ZnO layers. Journal of Materials Science: Materials in Electronics, 32, 7162-7175, Springer, 2021, https://doi.org/10.1007/s10854-021-05425-4, SJR (Scopus):0.49, JCR-IF (Web of Science):2.478, Q2 (Web of Science).

6. Buchkov, K**,** Galluzzi, A, Blagoev, B**,** Paskaleva, A.**,** Terziyska, P.**,** Stanchev, T**,** Mehandzhiev, V**,** Tzvetkov, P, Kovacheva, D, Avramova, I., Nazarova, E., Polichetti, M. Magneto-optical characterization of ZnO / Ni nano-laminate obtained via Atomic Layer Deposition. Journal of Physics: Conference Series, 1762, IOP, 2021, 012041, DOI:10.1088/1742-6596/1762/1/012041, SJR (Scopus):0.21, Q4 (Scopus).

7. Dzhurkov, V.**,** Levi, Z.**,** Nesheva, D.**,** Hristova-Vasileva, T.**,** Terziyska, P. Properties of ZnSe nanocrystalline thin films prepared by thermal evaporation. Journal of Physics: Conference Series, 1762, IOP, 2021, 012036, ISSN: 1742-6588, DOI: 10.1088/1742-6596/1762/1/012036, SJR (Scopus):0.21, Q4 (Scopus).

8. Gegova-Dzhurkova, R.**,** Nesheva, D.**,** Mihailov, V.**,** Dzhurkov, V.**,** Terziyska, P.**,** Manolov, E**.** Effect of infrared laser irradiation on electrical conductivity and ethanol sensitivity of sol gel ZnO thin films. Journal of Physics: Conference Series, 1762, IOP Publishing, 2021, 012037, ISSN: 1742-6588, DOI: 10.1088/1742-6596/1762/1/012037, SJR (Scopus):0.21, Q4 (Scopus).

9. Beshkova, M., Blagoev, B. S.**,** Mehandzhiev, V.**,** Yakimova, R., Avramova, I., Terziyska, P.**,** Kovacheva, D., Strijkova, V. Optimization of AlN films grown by atomic layer deposition. Journal of Physics: Conference Series, 1762, 2021, 012035, DOI: 10.1088/1742-6596/1762/1/012035, SJR (Scopus):0.21, Q4 (Scopus).

10. Milenov, T. I., Dikovska, A., Avramova, I. A., Karaivanova, A., Andreev, G., Terziyska, P.**,** Dimov, D., Karashanova, D., Georgieva, B., Kolev, S.K., Valcheva, E.P. Modification of thin carbon films by UVC light. Journal of Physics: Conference Series, 1859, 1, IOP Publishing, 2021, 012008, DOI:10.1088/1742-6596/1859/1/012008, SJR (Scopus):0.21, Q4 (Scopus).

11. Rabadzhiyska, S., Ormanova, M., Valkov, S., Ivanov, N., Terziyska, P., Ivanov, K., Petrov, P. Study optical properties of the thin HfO2 coatings deposited by DC reactive magnetron sputtering. Journal of Physics: Conference Series, 1859, IOP, 2021, 012066, https://doi.org/10.1088/1742-6596/1859/1/012066, SJR (Scopus):0.21, Q4 (Scopus).

12. Todorov R., Hristova-Vasileva T**.**, Atanasova A., Katrova V., Milushev G. Preparation and optical characterization of Au – In films for plasmonic applications. Journal of Physics: Conference Series, 1762, IOP Publishing, 2021, 012022, ISSN:1742-6596, DOI:10.1088/1742-6596/1762/1/012022, SJR (Scopus):0.21, Q4 (Scopus).

13. Todorov R., Hristova-Vasileva T**.**, Atanasova A., Katrova V., Strijkova V., Milushev G., Milanov E. Optical properties of thin Ag - In films prepared by interdiffusion in bimetallic nanolayered stacks. Journal of Physics: Conference Series, 1762, IOP Publishing, 2021, 012023, ISSN: 1742-6596, DOI:10.1088/1742-6596/1762/1/012023, SJR (Scopus):0.21, Q4 (Scopus).

14. Blagoev, B.**,** Terziyska, P.**,** Tzvetkov, P., Kovacheva, D., Ivanov, P.**,** Mehandzhiev, V.**,** Dimitrov, D**.** Low Temperature ALD Films on Transparent and Flexible Substrates. Proc. XXX International Scientific Conference Electronics - ET2021, September 15 - 17, 2021, Sozopol, Bulgaria, 2021, SJR (Scopus):0.11.

15. Ganchev, M., Gergova, R., Terziyska, P., Popkirov, G., Vitanov, P. Direct thermal evaporation of thin films copper (I) bromide. Materials Today (Proceedings), 37, 4, 2021, A16-A20, ISSN: 2214-7853, https://doi.org/10.1016/j.matpr.2021.05.244, SJR (Scopus):0.341.

16. Katrova V., Atanasova A., Hristova-Vasileva T., Todorov R. Ultraviolet plasmonic properties of thin Ag-Sb films for optical biosensing application. OSA Nonlinear Optics 2021,

OSA Technical Digest (Optical Society of America, 2021), 2021, ISBN: 978-1-943580-97-2, NTh3A.2, https://doi.org/10.1364/NLO.2021.NTh3A.2.

17. Todorov R**.,** Hristova-Vasileva T**.,** Katrova V., Atanasova A. Optical properties and UV Plasmon-Enhanced Fluorescence activity of thin Ag-In films. OSA Advanced Photonics Congress 2021, OSA Technical Digest (Optical Society of America, 2021), 2021, JTu1A.36, ISBN: 978-1-943580-94-1, DOI:10.1364/IPRSN.2021.JTu1A.36.

18. Atanasova A., Katrova V., Hristova-Vasileva T**.**, Todorov R. Synthesis, microstructure and optical properties of Ag_3Sn nanoparticles for plasmonic sensing applications. European Conferences on Biomedical Optics 2021 (ECBO), OSA Technical Digest (Optical Society of America, 2021), 2021, EW4A.13, ISBN: 978-1-943580-95-8.

19. Dzhurkov, V**.,** Levi, Z**.,** Nesheva, D**.,** Hristova-Vasileva, T. Effect of Layer Thickness and Preparation Conditions on the Properties and Ethanol Sensitivity of ZnSe Thin Films. Newest Updates in Physical Science Research, v. 3, Book Publisher International, 2021, 125-134, ISBN: 978-93-90768-16-5 (Print), ISBN: 978-93-90768-29-5 (eBook), https://doi.org/10.9734/bpi/nupsr/v3/8080D.

PATENTS:

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

ONGOING RESEARCH PROJECTS:

Financed by the Bulgarian Academy of Sciences:
"Preparation and investigation of nanostructured thin films suitable for environmental protection"

Financed by the Bulgarian Ministry of Education and Science:
"Preparation, characterization, and laser modification of nanocrystalline ZnO films", National program "Young scientists and postdoctoral researchers" approved by DCM N 203, 19.09.2018, beneficient eng. Chem. Radka Dzhurkova, adviser Prof. D. Nesheva, D.Sc.

"Preparation and investigation of ZnSe thin films suitable for chemical sensors", National program "Young scientists and postdoctoral researchers" approved by DCM N 203, 19.09.2018, beneficient Eng. Chem. Valeri Dzhurkov, adviser Assoc. Prof. Z. Levi, PhD.

"Development and application of spectrophotometric methods for determination of thin films optical constants" (NSF - КП-06 ПН57/5). Project coordinator: Assoc. Prof. Tihomir Tenev. Assoc. Prof. I. Bineva, Assoc. Prof. P. Terziyska, Eng. V. Dzhurkov, Eng. R. Dzhurkova-team members.

“Effects of resistive switching and magnetoresistance in transition metal (Co, Ni, Fe) doped ZnO layers for multifunctional applications” (NSF - КП-06-Н28/9). Project coordinator: Prof. Albena Paskaleva. Assoc. Prof. P. Terziyska-team member.

“Controlled hybrid ALD/CVD synthesis of 2D transition metal dichalcogenides” (NSF - КП-06 ПН58/12). Project coordinator: Prof. Dimitre Dimitrov. Assoc. Prof. P. Terziyska-team member.

“Study of the possibilities for deposition of two- or multi- layred structures of type: graphene-buffer layer- single crystalline Si substrate” (NSF - КП-06-Н58/2). Project coordinator: Assoc. Prof. Teodore Milenov, Institute of Electronics, BAS. Coordinator of ISSP team: Assoc. Prof. Tihomir Tenev. Assoc. Prof. P. Terziyska-team member

Funded by the Operational Programme Science and Education for Smart Growth, co-financed by the European Union through the European Regional Development Fund

Project BG05M2OP001-1.001-0008 "National Center of Mechatronics and Clean Technologies", Operational Program: Science and Education for Smart Growth, Creation and Development of Centers of Excellence.
Team members : Prof. D. Nesheva, Assoc. Prof. I. Bineva, Eng. V. Dzhurkov.

INTERNATIONAL COLLABORATION:

- Centre for Energy Research, Konkoly Thege Miklos ut 29-33, 1121 Budapest, Hungary.
- Center for Solid State Physics and New Materials, Institute of Physics, SASA, Belgrade, Serbia.
- Institute of Engineering, Autonomous University of Baja California, Mexicali, Mexico.

DEPARTMENT SOFT MATTER PHYSICS

LABORATORY

LIQUID CRYSTALS AND BIOMOLECULAR LAYERS

HEAD: **Prof. Victoria Vitkova, Ph.D.**
tel: +3592 979 5796; e-mail: victoria@issp.bas.bg

TOTAL STAFF: **15**
RESEARCH SCIENTISTS: **9**
HONORARY MEMBER: **2**
ASSOC. MEMBERS: **1**

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

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

RESEARCH ACTIVITIES:

Complex impedance and dielectric spectroscopy were applied to study the dielectric relaxations and their thermal behavior in ion-conducting composites/complexes from polymer poly(ethylene oxide) (PEO) and E8 nematic liquid crystals (LCs), at the compositional ratio PEO:E8 = 70:30 wt%. The relaxation and polarization of dipole formations in PEO/E8 and PEO/E8/NaIO4 were evidenced and compared in terms of both electrical impedance and dielectric response depending on temperature. The results obtained for molecular organization, molecular relaxation dynamics, and electric polarization are attractive for applications in flexible organic electronics, energy storage devices, and mechatronics.

We studied the photo-thermal effect in liquid-crystalline nanocomposites (NCs) of tris(*keto*-hydrozone) discotic liquid crystals (DLC) doped with single-walled carbon nanotubes (SWCNTs) at concentration 1 wt.%. The mean size of SWCNTs was 1.5 nm. Thin films with a thickness of 3 μm formed from the NCs were illuminated with a low-intensity (~ 1 mW/cm^2) continuous light. The light-induced thermo-effect in the SWCNTs/DLC NC films was correlated with the change in their electrical conductivity, as determined by complex electrical impedance spectroscopy. The observed effect is pottentially interesting for photo-control of the liquid-crystalline state of DLC-based NC materials doped with SWCNTs, in order to achieve their enhanced functionality.

We performed an experimental study on phospholipid Langmuir-Blodgett (LB) films for detection of vapors of volatile organic compounds such as acetone and methanol, at room temperature. For that purpose, LB molecular monolayers of phospholipid dipalmitoyl-phosphatidyl-ethanolamine (DPPE) were deposited on Surface Acoustic Wave Resonator (SAWR) thus forming a sensor element. To test the suitability of the investigated DPPE LB

films on SAWRs for practical gas sensing applications, an electrical impedimetric approach in the frequency range 0.1 Hz – 1 MHz was applied. As a result of vapor sorption on the film, the impedance response of the DPPE LB films is considerably changed that is proper for detection of acetone and methanol vapors.

Flexible and free-standing electrolyte membranes of nanocomposite 'poly(ethylene oxide) (PEO)/starch-nanocrystals (SNCs)' complexed with magnesium bromide ($MgBr_2$) salt at various concentrations (5, 10, 15, 20, and 25 *WT.%*) were prepared using conventional solution casting technique. Concerning pure PEO/SNCs (10 *WT.%*), the electrolyte membrane of the composition 'PEO/SNCs (10 *WT.%*)/$MgBr_2$ (25 *WT.%*)' demonstrated more than three orders of magnitude in the room temperature ionic conductivity, as measured by complex electrochemical impedance spectroscopy (EIS). It was estimated by dielectric spectroscopy that the values of the diffusion coefficient (*D*) and the total ion concentration (*n*) for the studied nanocomposite electrolyte membranes were increased in proportion to the doping salt concentrations.

In order to elucidate the molecular mechanisms involved in the interaction of mono- and disaccharides with biomimetic membrane models composed of 1-palmitoyl-2-oleoyl-sn-glycero-3-phosphocholine (POPC) and 1-stearoyl-2-oleoyl-sn-glycero-3-phosphocholine (SOPC), we studied their dielectric properties, degree of hydration, lipid packing and dipole potential. Fluorescence spectroscopy measurements reported increased lipid packing in sucrose solutions. The alteration of the rotational diffusion and the degree of hydration for the corresponding fluorophore is more pronounced in sucrose compared to glucose and fructose solutions. Qualitatively different behaviours were found in the two types of phosphatidylcholine bilayers studied, namely POPC and SOPC, with increasing sucrose concentration in the bulk phase. The data reported support the hypothesis of the effect of alignment of lipid molecules near the glycerol residue in the presence of the sucrose. The disaccharide has been found to induce greater changes in the alignment of lipid molecules at the glycerol level compared to the hydrophobic part of the bilayer. A slight increase in dipole potential for POPC and SOPC membranes with the addition of sodium chloride, glucose, fructose and sucrose is reported. The specific electrical capacitance of membranes in aqueous solutions of sucrose, glucose and fructose was determined by two independent methods: analysis of the deformation of quasispherical lipid vesicles in an alternating electric field and rapid electrochemical impedance spectroscopy of flat suspended POPC and SOPC bilayers. Both methods report increase in the specific electrical capacitance of the membranes in solutions of 0.2 mol/L sucrose and higher. Measurements show that the presence of monosaccharides (glucose or fructose) in the aqueous phase does not change the dielectric properties of the lipid bilayer. The obtained results could underlie developments based on bilayer lipid structures exposed to external physical stimuli such as temperature changes and electric fields. The results were achieved in cooperation with the Institute of Biophysics and Biomedical Engineering, BAS (Bulgarian Science Fund, DN18-15/2017).

Surface and mechanical properties of synaptosomes and biocompatible model systems were determined in the presence of neurotransmitter molecules. Morphologically and functionally identical to brain synapses, the nerve endings of synaptosomes are biochemically derived membrane structures responsible for transmitting neural information. Their superficial and mechanical properties, measured *in vitro*, provide useful information about the functional activity of synapses in the brain *in vivo*. Glutamic and kainic acids are of particular interest due to their role in brain pathology (including seizures, migraines, ischemic stroke, aneurysmal subarachnoid hemorrhage, intracerebral hematoma, etc.). The effects of the excitatory neurotransmitter L-glutamic acid and its agonist kainic acid on the activity of Na^+, K^+-ATPase and $Mg2^+$-ATPase were studied. The electrokinetic and surface properties of synaptosomes were probed by microelectrophoresis. Neurotransmitters were obtained to significantly

increase the electrophoretic motility and surface electrical charge of synaptosomes 1-4 hours after their isolation. In the presence of L-glutamate, a decrease in the bending modulus of model bimolecular membranes of the monounsaturated lipid 1-palmitoyl-2-oleoyl-sn-glycero-3-phosphocholine was measured. The agonist does not affect the membrane curvature elasticity even at an order of magnitude higher concentration. Data on the inhibition of acetylcholinesterase activity by both L-glutamic and kainic acid are also reported. The results were achieved within a research project with national funding, implemented jointly with Sofia University "St. Kliment Ohridski" and the Medical University, Sofia (KP-06-N-38/14/2019).

The latest generation of multi-force orthodontic arches Bio-active was studied. By X-ray diffraction (XRD), scanning electron microscopy (SEM), energy dispersion analysis (EDX), laser-induced emission spectroscopy (LIBS), X-ray photoelectron spectroscopy (XPS), differential scanning calorimetry (DSC), nanoindentation and statistical analysis examined the structure, morphology, chemical composition, thermal behavior and mechanical properties of unused and used in-vivo arcs. Bio-active orthodontic arches are made of Ni-Ti alloy with austenitic crystal structure, which is preserved during orthodontic treatment. The surface roughness of the studied arches decreases after clinical use and their elemental composition does not change significantly during treatment. In addition to Ni and Ti, traces of Fe and Cr were also found. The elemental composition is important to be determined with regards to patients' health issues related to Cr and Ni allergic reactions. In addition, knowing the rate of Ni reduction in arches (or the rate at which Ni may be absorbed into the patient's body) is necessary for orthodontists in order to determine the optimal prolongation of treatment. With increasing usage time of the arches in the oral cavity, their hardness decreases, probably due to changes in morphology. The bicuspid region used for 6 weeks had the smallest decrease of all other samples tested, probably due to the lowest Ti concentration in this region. It can be concluded that the reduction in the hardness of the arches is limited to the first 6 weeks of use. The main result of this study is the obtained model of the dynamics of nickel release during the stay in the patient's mouth. The novelty of the approach is based on the idea of taking into account differences in the lengths of intraoral use. The obtained model can become a tool for determining the optimal duration of use of orthodontic arches specifically for each patient. The current results will provide orthodontists with important information about the physicochemical and mechanical properties of Bio-active multi-force arches during their clinical use. It can help in choosing the optimal duration of use of arches depending on the specific goals of treatment and the needs of the patient. This scientific research is a joint development of the teams of the Institute of Solid State Physics "Academician Georgi Nadjakov", BAS and the Faculty of Dental Medicine of the Medical University, Sofia.

Samples were obtained by solid-phase phase synthesis from the systems: Y-Ba-Cu-O (with nominal composition: 123; 134; 156; 13-20-33), Dy-Ba-Cu-O (nominal composition 123) and the same doped with Ag_2O and nanosized Fe_3O_4 and Bi-Pb-Sr-Ca-Cu-O (nominal composition: 2201; 2212). Scanning electron microscopy (SEM), X-ray diffraction (XRD), energy dispersion analysis (EDS) and magnetic measurements (AC / DC) were applied for their characterization. The introduction of additives (Ag_2O and Fe_3O_4) with low concentrations to Y-Ba-Cu-O samples according to literature data improves their superconducting properties by increasing the critical temperature and critical current density, observed as well in our obtained polycrystalline samples with inhomogeneous composition and homogeneous distribution on the surface of iron and silver, respectively. It was also found that the value of cell volume (V) for Dy123 and Dy123 with the addition of Fe3O4 is the same. XRD analysis was performed on the entire surface of the samples and did not detect phases less than 4%. SEM micrographs reveal a multiphase structure with elongated grains for DyBCO ceramics. The introduction of Fe_3O_4 into the composition of the studied multiphase DyBCO sample does not interfere with the formation of the Dy123 superconducting phase, as well as the formation of the $BaCuO_2$

and CuO phases. The results of EDX and cartographic analyzes show the presence of small amounts of Fe on the surface scattered around Dy123, CuO and $BaCuO_2$ crystals, which led us to conclude that Fe does not react with other elements and does not form phases and enter the Dy123 cell lattice. The calculated oxygen content of the samples did not vary significantly between the Fe_3O_4 sample and the pure one, therefore the addition of 2 wt% Fe_3O_4 nanopowder to DyBCO ceramics does not affect the amount of oxygen, which plays an important role in the superconducting properties of the material. This research is part of the bilateral projects between the Bulgarian Academy of Sciences and the Estonian Academy of Sciences, the Technical University of Tallinn and the Institute for Low Temperature and Structural Studies, the Polish Academy of Sciences and the Institute of Electronics at BAS.

Studies were conducted to determine the effect of different methods of preparation on the electrochemical properties of active zinc mass with conductive cuprate ceramic additives. 3 methods of preparation (ball mill, ultrasound and mechanical mixing) were studied. Three electrodes with different compositions were prepared: zinc electrodes with carbon addition in two of which there is also added conductive ceramics from the system B (Pb) SCO 2201 and B (Pb) SCCO 2212, respectively. The samples were examined by X-ray diffraction, scanning electron microscopy and electrochemical impedance spectroscopy. In B (Pb) SCCO 2212 ceramics it was found that the best homogenization of the additive in the active mass is achieved by ultrasonic treatment and improvement of the already known effects of the ceramic additive is observed. Better homogenization of ZnO additives can improve conductivity, stability and thus extend battery life. The results obtained so far also determined future research related to the study of the influence of the amount of ceramic additive on the performance of the zinc electrode in a Ni-Zn electrochemical cell. This scientific research is a joint development of the Institute of Solid State Physics "Academician Georgi Nadjakov" at BAS and the Institute of Electrochemistry and Energy Systems "Academician Evgeni Budevski" at BAS.

We continued with our research work on the influence of various organic and inorganic impurities on the physicochemical properties of the synthetic lipid steroyl-oleoyl phosphatidylcholine (SOPC) membrane. During the reporting year we completed the started analyzes of SOPC systems in the presence of aqueous solutions with sucrose concentration of 100; 200; 300 and 400 mM. Also, through our joint work with colleagues from different institutes, we were able to successfully synthesize silver nanoparticles with hydrophobic coating. We compared their effect on the chemo-physical properties of SOPC model lipid membrane with that of hydrophobic gold nanoparticles in the same concentration. By the means of differential scanning calorimetry, it was established that pure SOPC lipid system (without the presence of sugar in the aqueous solution), undergoes transition from gel to liquid-crystalline at approximately 3.34 ˚C. The peak is very pronounced and corresponds to a first order phase transition. Measurements reveal slight shift of this temperature to about 4.73 ℃ with the addition of sucrose to the aqueous solution. The results show that the addition of 100 mM sucrose strongly affects the phase behavior. The shape of the transformation peaks is similar for all samples containing sucrose. There is also a clear tendency of enthalpy values decrease the with the disaccharide increase untill about 300 mM sucrose. At this concentration, the system is saturated and the subsequent sugar addition has practically no effect on the values of the parameters. A connection between these results and the results for the bending elasticity modulus-k_c of the SOPC membrane in the presence of sucrose could be made. According to these data, there is a drastic reduction in k_c with the addition of sucrose to a concentration of about 300 mM. At higher sucrose concentrations, saturation is observed and the value of the elastic parameters remains practically unchanged. SOPC systems in aqueous solutions with a concentration of 100; 200; 300 and 400 mM sucrose were also examined by Fourier transform infrared spectroscopy (FTIR). As a result of the signal substraction, due to the water absorption

of the studied systems spectra, no SOPC or sugar IR bands are observed in the fallowing intervals: 3600-3200 cm-1; 1700–1500 cm-1. Below 3200 cm^{-1}, two stretching oscillations are detected, caused by the C – H bond (2936 cm^{-1}-asymmetric and 2885 cm^{-1}-symmetric stretching). They originate, both, from the lipid and sucrose in the the aqueous sample. The rest of the spectrum is dominated by the stretching IR bands of C – O and C – C of the sugar, being most pronounced at 1138, 1113, 1056, 1018 and 998 cm^{-1}. In general, the intensity of the spectra increases proportionally to the amount of sucrose in the aqueous phase. There is no shift in the location of the IR bands themselves. On the other hand, a certain decrease of the intensity ratio for the bands at 1056 and 998 cm^{-1}, corresponding to C-O stretching vibrations of the sugar molecules, was detected i.e. the relative intensity of the band at 998 cm^{-1} increases in respect to that at 1056cm^{-1} when the amount of sugar in the solutions is higher. This phenomenon indicates the presence of at least two types of sucrose hydrate in the studied systems - sucrose pentahydrate and aqueous sucrose solution. Due to the significant overlap of the sugar and SOPC IR bands, the phospholipid sample with the addition of 300 mM sucrose was subjected to analysis of the second derivative in the region 1500-800 cm^{-1} and subsequent spectra analysis. This content was chosen because of previously established effect of sugar on the k_c of the SOPC lipid. After comparing the spectra of pure sucrose, it was found that the vibrational motions at 1249 cm^{-1} and 1260 cm^{-1} stem only from the asymmetric valence bonds of the phosphate groups. The position of these bands is highly dependent on hydrogen bonds and ionic interaction. Having in mind the simultaneous presence of bands at both, 1260 and 1249 cm^{-1} in the spectrum of SOPC and sugar (300 mM) in water it could be concluded that not all of the phosphate groups in the SOPC molecules are associated to hydrogen bonds

The thermograms of the SOPC systems and 0.5 wt. % gold (AuNPs) and silver nanoparticles (AgNPs) with hydrophobic coating show a significant and similar effect of the two types of nanoobjects on the phase transition from gel to liquid crystal state. The presence of nanoparticles causes the transformation to shift to lower temperatures. This effect is more pronounced for AgNPs. The transition itself for SOPC-AuNPs systems is notably more hindered and difficult to identify, leading to a lower enthalpy value of about one order of magnitude compared to the sample containing AgNPs. The resulting thermograms show that AuNPs inhibit phase transformation more intensely than their gold counterparts for the studied concentration. The experimental results reveal a change in the phase transition from homogeneous (all molecules rearrange into another phase simultaneously) to inhomogeneous and the appearance of an intermediate state (pre-transition state) with the addition of nanoparticles. IR bands of SOPC molecules in the SOPC-AgNPs system were observed at the same positions as those found for SOPC-AuNPs: 2962, 2930, 2877, 2860 cm^{-1} (CH valence vibrations of the methyl and methylene groups of alkyl chains), 1463 , 1414, 1394, 1381, 1360 cm^{-1} (CH bending vibrations), 1217 cm^{-1} (asymmetric valence (bending) motion of phosphate groups) and 1046 cm^{-1} (stretching vibrations of CO). Only the C = O valence vibration band of the lipid ester carbonyl groups appears to be slightly shifted from 1730 cm^{-1} (SOPC-AuNPs) to 1735 cm^{-1} (SOPC-AgNPs), but corresponds to the position for fully hydrated diacyl phosphatidylcholines. The position of the band for the asymmetric stretching vibration of the phosphate groups - at 1217 cm^{-1} is also a sign of effective hydration of the phosphate groups. Obviously, hydration is not affected by the presence of hydrophobic metallic impurities. On the other hand, in the SOPC-AgNPs system the relative intensity of the SOPC bands is much higher than in the SOPC-AuNPs system. This is most likely due to the stronger plasmon effect of AgNPs compared to AuNPs

A series of nanofiltration experiments were carried out with a MaxiMem filtration system (PS Prozesstechnik GmbH), equipped with a nanomembrane "Microdyn Nadir NP030P" (MWCO 500 Da). Nanofiltration experiments were performed in a diafiltration mode for separation between phenolics and saccharides from a hydrolysate of Myriophyllum

spicatumcompared and compared to a model sugar solution. Diafiltration shows essential advantages over concentration mode of nanofiltration. Transfer of disaccharides through the membrane is twice more effective. Opportunity for a continuous removal by diafiltration provides substantially higher sugar recovery from the initial feed solution. Mass transfer rate of all sugars in diafiltration is higher. It is found that diafiltration ensures the appropriate conditions in the concentration polarization layer of the membrane in a way to favor the sugar diffusion but prevent a critical deposition and fouling. Ethanol-water model solutions with different ethanol concentration in the range of 0 to 80% were subjected to nanofiltration. Dry red wine Mavrud was used in preliminary set of experiments to check the separation ability in presence of a complex composition systems and a number of biologically active substances. Water-ethanol separation of model solutions showed lower permeate flux as compared to water and a retention tendency, slightly increased with the ethanolic content. In presence of higher viscosity and complex multicomponent composition systems, the permeate flux is essentially reduced. However, it can be significantly improved by applying higher pressure and/or cross-flow velocity. The former has stronger effect on both permeate flux and ethanol retention.

AWARD:

Ognyan Krasimirov Petkov, scholarship holder of the EUREKA Foundation for 2021/2022 for achievements in the mastery of knowledge in the field of physics in the name of Aademician Georgi Nadjakov.

PUBLICATIONS:

1. Vitkova, V, Yordanova, V., G. Staneva, Petkov, O., Stoyanova-Ivanova, A., Antonova, K., Popkirov, G.. Dielectric properties of phosphatidylcholine membranes and the effect of sugars. Membranes, 2021, ISSN:20770375, DOI:DOI:https://doi.org/10.3390/membranes11110847, JCR-IF (Web of Science):4.106 **Q1** (Web of Science)

2. Hadjichristov, G. B. , T. E. Vlakhov, Y. G. Marinov, N. Scaramuzza. Ion-conducting fexible thin films of composites from poly(ethylene oxide) and nematic liquid crystals E8—characterization by impedance and dielectric relaxation spectroscopy. Polymers, 13, 24, MDPI, 2021, ISSN:2073-4360, DOI:10.3390/polym13244465, 4465-1-4465-27. JCR-IF (Web of Science):4.329, **Q1** (Scopus)

3. Doltchinkova, V., Mouleshkova, N., Vitkova, V. Surface properties of synaptosomes in the presence of L-glutamic and kainic acids: in vitro alteration of the ATP-ase and acetylcholinesterase activities. Membranes, 11, 12, 2021, DOI:https://doi.org/10.3390/ membranes11120987, 987. JCR-IF (Web of Science):4.106, **Q1** (Web of Science)

4. Yordanova, V., Staneva, G., Angelova, M., Vitkova, V., Kostadinova, A., Benkova, D., Veleva, R., Hazarosova, R.. Modeling of molecular mechanisms of membrane domain formation during the oxidative stress: effect of palmitoyl-oxovaleroyl-phosphatidylcholine. Comptes rendus de l'Académie bulgare des Sciences, 74, 1, 2021, DOI:10.7546/CRABS.2021.01.10, 78-87. SJR (Scopus):0.22, JCR-IF (Web of Science):0.378, **Q2**

5. Koduru, H.K., Marinov, Y.G., Kaleemulla, S., Rafailov, P.M., Hadjichristov, G.B., Scaramuzza, N.. Fabrication and characterization of magnesium—ion-conducting flexible polymer electrolyte membranes based on a nanocomposite of poly(ethylene oxide) and potato starch nanocrystals. Journal of Solid State Electrochemistry, 25, 8, 2021, ISSN:14328488, DOI:10.1007/s10008-021-05018-5, 2409-2428. SJR (Scopus):0.58, JCR-IF (Web of Science):2.647, **Q2** (Scopus)

6. Koduru, H.K., Marinov, Y.G., Scaramuzza, N.. Review on Microstructural and Ion-conductivity Properties of Biodegradable Starch-Based Solid Polymer Electrolyte Membranes.

STARCH, WILEY, 2021, DOI:doi.org/10.1002/star.202100170, SJR (Scopus):0.62, JCR-IF (Web of Science):2.741 **Q2** (Scopus)

7. Paskaleva, A, Chamati, H, Genova, J. Progress and Perspectives in Functional Materials. physica status solidi a, 218, 17, Wiley, 2021, ISSN:1862-6319, DOI:10.1002/pssa.202100548, 2100548. SJR (Scopus):0.53, JCR-IF (Web of Science):1.981 **Q2** (Scopus)

8. Vlakhov, T.E., Hadjichristov, G.B., Marinov, Y.G.. Photo-thermal effect by discotic liquid crystals doped with single-walled carbon nanotubes. Comptes Rendus de L'Academie Bulgare des Sciences, 74, 9, 2021, ISSN:13101331, DOI:10.7546/CRABS.2021.09.03, 1289-1295. SJR (Scopus):0.24, JCR-IF (Web of Science):0.378 **Q2** (Scopus)

9. Vlakhov, T.E., Ivanov, G.R., Marinov, Y.G., Hadjichristov, G.B.. Phospholipid langmuir-blodgett films and impedance spectroscopy for detection of acetone and methanol vapours. Compt. Rend. Acad. Bulg. Sci., 74, 6, 2021, ISSN:13101331, DOI:10.7546/CRABS.2021.06.04, 828-834. SJR (Scopus):0.24, JCR-IF (Web of Science):0.378 **Q2** (Scopus)

10. Georgieva, M., Angelina Stoyanova-Ivanova, Sabina Cherneva, Valeri Petrova, Laura Andreeva, Valentin Mihailov, Alexander Petkov, Valdek Mikli. Characterization and comparison of as received and clinically retrieved Bio-active™ orthodontic archwires. Biotechnology & Biotechnological Equipment, VOL. 35, NO. 1, 2021, ISSN:13102818, DOI: https://doi.org/10.1080/13102818.2021.1964381, 1301-1311. JCR-IF (Web of Science):1.632 **Q3** (Web of Science)

11. Martinov, B.L., Staneva, A.D., Vlakhov, T.E., Slavov, S., Dimitrov, D., Marinov, Y.G., Hadjichristov, G.B.. Synthesis and characterization of nanosized ZnTiO3doped with reduced graphene oxide (RGO). Journal of Physics: Conference Series, 1762, 2021, ISSN:17426588, DOI:10.1088/1742-6596/1762/1/012031, 012031. SJR (Scopus):0.21 **Q4** (Scopus)

12. Santhosh, P. Gold nanoparticles: Phospholipid membrane interactions. 1, 34, Elsevier, 2021, ISBN:9780323914994, DOI:10.1016/bs.abl.2021.11.006, SJR (Scopus):0.276 **Q4** (Scopus)

13. Slavkova, Z., Drinova, N., Chamati, H., Genova, J.. Influence of sucrose on the phase behaviour of phospholipid model systems. Journal of Physics Conference Series, 1762, 2021, SJR (Scopus):0.23 **Q4** (Web of Science)

14. Stoyanova-Ivanova, A., G. Ivanova, E. Leffterova, V. Petrova, O. Petkov, A. Stoyanova. "Influence of various preparation methods on the electrochemical properties of the active Zn mass with conductive cuprate ceramics as additives". CURRENT TOPICS IN ELECTROCHEMISTRY, vol. 23, 2021, ISSN:0972-4443, 25-32. SJR (Scopus):0.12 **Q4** (Scopus)

15. Stoyanova-Ivanova, A., Petrov, V., V. Petrova, Andreeva, L., Ilievska, I., Zaleski, A., Mikli, V.. PHYSICOCHEMICAL RESEARCH OF CLINICALLY RETRIEVED Cu-Ni-Ti ORTHODONTIC ARCHWIRES. Acta Medica Bulgarica, 48, 1, 2021, ISSN:0324-1750, DOI:10.2478/amb-2021-0011, 68-74. SJR (Scopus):0.122 **Q4** (Scopus)

16. Hadjichristov, G.B., Exner, G.K., Marinov, Y.G., Vlakhov, T.E.. Photo-electrical response of nanocomposites of single-walled carbon nanotubes incorporated in tris(keto-hydrozone) discotic mesogen. Journal of Physics: Conference Series, 1762, 2021, ISSN:17426588, DOI:10.1088/1742-6596/1762/1/012011, 012011. SJR (Scopus):0.21 **Q4** (Scopus)

17. Kostadinov, I. K., Astadjov, D. N., Yankov, G. P., Popova, L. T., Slaveeva, S. I., Fedchenko, Yu. I., Temelkov, K. A.. High-beam-quality sealed-off master oscillator–power amplifier system oscillating in the visible spectral range on atomic copper transitions for micromachining in research and technology. Journal of Physics: Conference Series, 1859, 1, IOP Publishing, 2021, 012056. SJR (Scopus):0.21 **Q4** (Scopus)

18. Kostadinov, I. K., Yankov, G. P., Popova, L. T., Slaveeva, S. I., Fedchenko, Yu. I., Temelkov, K. A.. High-power high-beam-quality sealed-off master oscillator–power amplifier system oscillating in the middle infrared spectral range on strontium atomic transitions. Journal of Physics: Conference Series, 1859, 1, IOP Publishing, 2021, 012054. SJR (Scopus):0.21 **Q4** (Scopus)

19. Vlakhov, T.E., Marinov, Y.G., Hadjichristov, G.B., Scaramuzza, N.. Complex electrical impedance and dielectric spectroscopy of Na+-conducting PEO/PVP/NaIO4 solid polymer electrolyte with incorporated nano-sized Graphene Oxide. Journal of Physics: Conference Series, 1762, 2021, ISSN:17426588, DOI:10.1088/1742-6596/1762/1/012010, 012010. SJR (Scopus):0.21 **Q4** (Scopus)

20. Hadjichristov, G. B., Marinov, Y. G., Vlakhov, T.E., Scaramuzza, N.. Phospholipid Langmuir-Blodgett nano-thin monolayers: electrical response to Cadmium ions and harmful volatile organic compounds. Advances in Biomembranes and Lipid Self-Assembly, 34, Chapter 5, 2021, DOI:10.1016/bs.abl.2021.11.005, 129-172. SJR (Scopus):0.28 **Q4**

21. Iliev, M.T., Koduru, H.K., Marino, L., Marinov, Y.G., Karashanova, D., Scaramuzza, N.. Studies on conductivity and dielectric properties of peo/pvp nanocomposite electrolytes for energy storage device applications. Bulgarian Chemical Communications, 53, 1, 2021, ISSN:08619808, DOI:10.34049/bcc.53.1.4429, 5-9. SJR (Scopus):0.18, JCR-IF (Web of Science):0.24 **Q4** (Scopus)

22. Ivanov, G.R., Avramov, I.D., Strijkova, V.J., Marinov, Y.G., Vlakhov, T.E., Bogdanova, E., Hadjichristov, G.B.. Mass sensitivity of Langmuir-Blodgett monolayer film coated surface acoustic wave resonators to volatile organic solvents. Journal of Physics: Conference Series, 1762, 2021, ISSN:17426588, DOI:10.1088/1742-6596/1762/1/012002, 012002. SJR (Scopus):0.21 **Q4** (Scopus)

23. Ivanova, N, Genova, J, Chamati, H. Physical properties of SOPC lipid membranes containing cholesterol by molecular dynamics simulation. Advances in Biomembranes and Lipid Self-Assembly, Academic Press, 2021, ISBN:9780323914994, 1. SJR (Scopus):0.28 **Q4** (Scopus)

24. Vlakhov, T. E., Yordan G. Marinov, Georgi B. Hadjichristov, George R. Ivanov. Electrical Impedance Spectroscopy-Based Detection and Quantification of Methanol Vapors by Use of Phospholipid Langmuir-Blodgett Film. XXX International Scientific Conference Electronics (ET-2021), IEEE, 2021, DOI:10.1109/ET52713.2021.9579527, SJR (Scopus):0.11

25. Vlakhov, T. E., Ginka K. Exner, Yordan G. Marinov, Georgi B. Hadjichristov. Glassy-State Discotic Liquid Crystals and Their Nanocomposites with Single-Walled Carbon Nanotubes: DSC and Optical Absorption. XXX International Scientific Conference Electronics (ET-2021), IEEE, 2021, DOI:10.1109/ET52713.2021.9580152, SJR (Scopus):0.11

ONGOING RESEARCH PROJECTS:

1. Research Project “Liquid crystal nanocomposites for applications in photonics, sensorics and biomedicine”, National Science Fund (NSF) of Bulgaria contract № KP-06-N58/6 from 19.11.2021 granted under "Competition for financing fundamental scientific research - 2021". ISSP-coordinator Prof. DSc Y. Marinov
2. Research Project “New effects in nano-thin ordered organic films (Langmuir and Langmuir-Blodgett) and their use for conceptual development of a new generation of biosensors for working in a fluid environment at ambient conditions and real-time monitoring of hard-to-find water pollutants (anti-terrorism) or early diagnosis by tumor markers (acronym NanoBioSensors)” (contract № KP-06-OPR 03/9) by the Ministry of Education and Science, through the National Science Fund of Bulgaria (2019 – 2021), ISSP-coordinator Prof. Y. Marinov.
3. Research Project “Advanced Nanocomposite Polymer Membranes for Na-, Mg-ions conductive electrolytes, Proton-Exchange, and Chromogenic Applications”, under National Scientific Program “Petar Beron i NIE” (P. Beron), BNSF project ANAPOM (2020-2022), contract № KP-06-DB-1/16.12.2019, Dr. Koduru, ISSP-coordinator Prof. Y. Marinov.

4. Research Project “Obtaining and study of nanostructured materials by optical methods and impedance spectroscopy (2018-2021), Bulgarian Ministry of Education and Science under the National, Research Programme “Young scientists and postdoctoral students” approved by DCM #577 / 17.08.2018, coordinator Assist. Prof. T. Vlakhov
5. Research Project “A mechanistic approach to revealing the molecular mechanism of how oxidized lipids alter the 2D and 3D lipid organization in model membranes” National Science Fund, Bulgaria – Grant DN18-15/15.12.2017), Coordinator, principal investigator: Prof. G. Staneva, IBPBME-BAS; ISSP-BAS /partner organization/ Coordinator: Prof. V. Vitkova
6. 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. V. Doltchinkova, Sofia University “St. Kliment Ohridski”; Coordinator from ISSP-BAS /partner organization/: Prof. V. Vitkova
7. Bilateral Research Project /ISSP-BAS and Tallinn University of Technology, Estonian Academy of Science (Estonian projects TAR16016 and IUT-T4 / Preparation of composite materials with multifunctional properties: structural studies and application) Coordinator: Assoc. Prof. Dr Angelina Stoyanova-Ivanova

INTERNATIONAL COLLABORATION:

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

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

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

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

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

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

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

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

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

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

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

TEACHING ACTIVITIES:

PhD Student Todor Vlakhov (ISSP-BAS); Supervisors: Prof. DSc. Yordan G. Marinov and Prof. Georgi Hadjichristov

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

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

MSc Thesis, University of Chemical Technology and Metallurgy – Sofia,
Christine Asparuhova Angelova, "Elasticity of model biomimetics membranes in the presence of the antimicrobial peptide KLAKLAK-NH2: Analysis of thermal fluctuations in the shape of lipid vesicles ", November 2021; Scientific adviser from ISSP-BAS: Assoc. Prof. Dr. Angelina Stoyanova-Ivanova

Internship Thesis, Christine Asparuhova Angelova (MSc. student, UCTM, Sofia), in French
Defended on 14/09/2021 with grade A;
Supervisors: Prof. Victoria Vitkova and Assoc. Prof. Angelina Stoyanova-Ivanova

DEPARTMENT PHYSICAL OPTICS AND OPTICAL METHODS

LABORATORY

OPTICS AND SPECTROSCOPY

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

TOTAL STAFF: **13**
RESEARCH SCIENTISTS: **9**
ASSOC. MEMBERS: ***7***

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

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

RESEARCH ACTIVITIES:

I. Spectroscopy of solid ion-conducting polymer nanocomposite electrolytes with added nanoparticles

It was elucidated the role of graphene oxide (GO) nanoparticles for the increase of the ionic electrical conductivity of electrolyte system composed of polymers poly (ethylene oxide) (PEO) and poly (vinylpyrrolidone) (PVP), as well as $NaIO_4$ salt as an ion donor. The GO nanoadditives were at concentration of 0.2; 0.4; 0.6 and 0.9 % by weight (wt%). The ion-polymer system PEO/PVP/$NaIO_4$/GO that conducts sodium ions, is new and specific, and is of practical interest as a multifunctional material for applications in organic electronics and sensors. The effect of GO nanoparticles was determined by complex electrical impedance spectroscopy and complex dielectric spectroscopy in the frequency range 1 Hz – 1 MHz. The role of GO nanoparticles was explained in terms of dipole reorganization in the ion-conducting nanocomposite complex (and solid polymer electrolyte) PEO/PVP/$NaIO_4$/GO, when an external alternating electric field is applied to this dielectric material. The ion conductivity of the studied electrolyte was measured depending on the concentration of GO nanoparticles. The results obtained from this study are important for the production of nanocomposite polymer electrolytes with improved ionic conductivity.

Nanocomposite flexible electrolyte membranes from poly (ethylene oxide) (PEO) and nanocrystals of starch (SNCs) with the addition of magnesium bromide ($MgBr_2$) were thoroughly investigated upon variation of the concentration of $MgBr_2$ in PEO/SNCs was varied (5, 10, 15, 20 and 25 wt%). The microstructure and thermal stability of the nanocomposite membranes are characterized by scanning electron microscopy, X-ray diffraction, Fourier-transform infrared spectroscopy, and differential scanning calorimetry. Studies of these membranes were also performed by complex electrical impedance spectroscopy and complex dielectric spectroscopy in the frequency range 0.1 Hz – 1 MHz with temperature variation in the range 30 – 70 °C. It was measured that in comparison with undoped PEO/SNCs (10 wt%),

the room-temperature conductivity of the electrolyte membranes with composition PEO/SNCs (10 wt%)/$MgBr_2$ (25 wt%) shows an increase of more than three orders of magnitude. The diffusion coefficient (*D*) and the total concentration of ions (*n*) in the studied nanocomposite electrolyte membranes were determined by dielectric spectroscopy. It was found that the values of these parameters increase in proportion to the concentration of the $MgBr_2$ salt, and at 25 wt% $MgBr_2$ their values are suitable and attractive for storing electricity.

II. Optics and optoelectronics of composites and nanocomposites based on liquid crystals

Complex electrical impedance and dielectric spectroscopy were applied to study dielectric relaxations and their thermal behavior in ion-conducting composites/complexes of polymer poly (ethylene oxide) (PEO) and E8 nematic liquid crystals (LCs), at a composition ratio PEO:E8 = 70:30 wt%. Flexible thin films PEO/E8 with a thickness of 150 μm were examined, as well as such films of Na^+ ion-conducting electrolyte PEO/E8/$NaIO_4$ with the same PEO:E8 composition ratio, but additionally containing 10 wt% of the salt sodium metaperiodate ($NaIO_4$) as a source of Na^+ ions. Molecular dynamics, namely the dielectric relaxation of PEO/E8 and PEO/E8/$NaIO_4$, were characterized by analyzes of complex impedance and dielectric spectra measured in the frequency range of 1 Hz – 1 MHz, upon temperature change around the glass transition temperature of these composites. The relaxation and polarization of the dipole formations in PEO/E8 and PEO/E8/$NaIO_4$ were established and compared, both in terms of their electrical impedance and their dielectric response depending on temperature. The results obtained for molecular organization, dynamics of molecular relaxation and electrical polarization in the studied ion-conducting polymer-LC composites/complexes are useful for optimizing their structure and functionality, and are attractive for applications in flexible organic electronics and energy storage devices.

New nanocomposites synthesized from discotic liquid crystals (DLCs) from the star-shaped tris(ketohydrozone) compound LTTH6 were studied, to which single-walled carbon nanotubes (SWCNTs) were added at a concentration of 1 wt%. SWCNTs/LTTH6 nanocomposites were formed as thin films with a thickness of 3 μm. They were characterized by differential scanning calorimetry and optical absorption spectroscopy in the near UV, visible and near IR spectral ranges. The research was focused on the determination of the structural and mesomorphic properties of thin films of these DLC nanocomposites, which can find applications as functional opto- and electrically-active materials. Regarding the mesomorphism and liquid-crystal behavior of SWCNTs/LTTH6 nanocomposites, it was found that at room temperature the columnar liquid-crystalline phase of DLC LTTH6 in them can be in the glassy state. The photo-induced thermal effect observed in such films was also studied, as well as their photoelectric response at room temperature, in view of their possible applications for sensors and other devices. The electronic properties of this type of nanostructured DLC material and the electrical characteristics of thin films thereof are interesting from a practical point of view, e.g., for applications in organic electronics (OLEDs, displays and organic field-effect transistors) and sensors.

III. Impedance spectroscopy of phospholipid Langmuir-Blodget molecular monolayers

The electro-impedance response of Langmuir-Blodget (LB) nano-thin (~ 3–6 nm) molecular monolayers (planar films) of phospholipid dipalmitoyl-phosphatidyl-ethanolamine (DPPE) was studied when such LB films were exposed to harmful volatile organic compounds (methanol, acetone, chloroform, ethanol, hexane, carbon tetrachloride). The suitability of DPPE LB films for practical applications for the detection of such vapors was tested by complex electrical impedance spectroscopy in the frequency range 0.1 Hz – 1 MHz. It was found that as a result of sorption of vapors on the film, the impedance response of DPPE LB films changes significantly, which is suitable for detecting the presence of tested volatile

compounds in gas phase. It was shown that the change of the frequency spectra of the complex electrical impedance of the films can serve to obtain information about the concentration of the detected vapors, within certain limits. This makes the studied phospholipid structures interesting as nano-thin layers for biosensor applications, and the idea is to use them in a sensor element with interdigital microelectrodes. This allows the proposed experimental scheme to be a platform for the construction of micro-sensor devices for the detection of vapors and other hazardous volatile organic compounds.

The electro-impedance response of DPPE LB films was also studied in order to detect low concentrations of Cd^{2+} ions in water (1 μg/L, which is 5 times lower than the permissible norm in drinking water). The detection and transmission of the signal was performed through an electrolyte interface – a droplet of liquid electrolyte. The main findings of the study were that the presence of Cd^{2+} leads to a change in the complex electrical impedance and electrical conductivity of DPPE LB films, due to electrostatic interactions between Cd^{2+} ions and DPPE LB monolayers. The results obtained in this work show that phospholipid DPPE LB monolayers together with the applied detection technique are sufficiently sensitive to detect the presence of heavy metal ions (especially Cd ions) in water at concentrations lower or comparable with permissible limits for drinking water and can be used to quantify the concentration of ions. Thus, phospholipid DPPE LB films can be a suitable molecular matrix for biodetection in active layers of possible micro-biosensors.

Graphene films were grown by chemical vapour deposition (CVD) on Cu foil. We investigated single-layer graphene-coated Cu foils with respect to the Cu-graphene coupling and Cu oxidation to Cu_2O as a way for its relaxation. Correlating results were obtained from Raman and XPS characterization, ellipsometry and the EBSD technique. We find strong Cu-graphene coupling on the nonoxidized Cu grains and gradual release of this coupling along the "strain" line without significant doping effects. Our ellipsometric results provide an estimate for the typical oxide layer thickness beneath the graphene after 6 months of sample aging, which varies from fractional parts of a nanometer to 6–7 nm. We confirm that in the case of polycrystalline foil oxidation to Cu_2O of graphene-coated copper is grain-selective, with (001)-oriented grains being most resilient and (011)-oriented ones most susceptible to oxidation. Correspondingly, the strong Cu-graphene coupling and the strain in the graphene lattice is released very nonuniformly and over different time scales. From a visualization of graphene grains by means of coating by liquid crystal, it is found that graphene grown on electropolished Cu foil exhibits larger grains with lower defect density. It is found that the Cu-graphene coupling alters the frequency and the intensity ratio of the G and 2D band, and a determination of the number of graphene layers from Raman spectral parameters should preferably be made after transfer on isolating substrate.

The work on determining the optimal regimes of the technological process for the realization of films with the prescribed characteristics (refractive index, density, strength, adhesion, etc.) with new optical materials with the vacuum deposition system Symphony 9 of Tecport Optics, purchased under Operational Program "Development of the Competitiveness of the Bulgarian Economy" was carried out. Multilayer coatings for the near and far UV range - anti-reflective and mirror by using refractory oxides - Al_2O_3 and SiO_2. Narrowband mirrors (minus filters) with more than 40 layers for wavelengths of 520 and 1040 nm with high transmission in a wide spectral range (270-900 nm) have been realized.

A large number of spectrophotometric studies have been performed in different spectral areas for colleagues from the ISSP, institutes at the Bulgarian Academy of Sciences and external users. ISSP has signed framework agreements for cooperation and joint activities with

companies in the industry engaged in the development or use of optical coatings - Optics AD, Kimcoop Holding Ltd., Milkotronic Ltd., Opteco and Partners Ltd.

We report the existence of stable dissipative light bullets in Kerr cavities. These three-dimensional (3D) localized structures consist of either an isolated light bullet (LB), bound together, or could occur in clusters forming well-defined 3D patterns. They can be seen as stationary states in the reference frame moving with the group velocity of light within the cavity. The number of LBs and their distribution in 3D settings are determined by the initial conditions, while their maximum peak power remains constant for a fixed value of the system parameters. Their bifurcation diagram allows us to explain this phenomenon as a manifestation of homoclinic snaking for dissipative light bullets. However, when the strength of the injected beam is increased, LBs lose their stability and the cavity field exhibits giant, short-living 3D pulses. The statistical characterization of pulse amplitude reveals a long tail probability distribution, indicating the occurrence of extreme events, often called rogue waves.

Stable light bullets and clusters of them are presented in the monostable regime using the mean-field Lugiato–Lefever equation [Gopalakrishnan, Panajotov, Taki, and Tlidi, Phys. Rev. Lett. 126, 153902 (2021)]. It is shown that three-dimensional (3D) dissipative structures occur in a strongly nonlinear regime where modulational instability is subcritical. We provide a detailed analysis on the formation of optical 3D crystals in both the super- and sub-critical modulational instability regimes, and we highlight their link to the formation of light bullets in diffractive and dispersive Kerr resonators. We construct bifurcation diagrams associated with the formation of optical crystals in both monostable and bistable regimes. An analytical study has predicted the predominance of body-centered-cubic (bcc) crystals in the intracavity field over a large variety of other 3D solutions with less symmetry. These results have been obtained using a weakly nonlinear analysis but have never been checked numerically. We show numerically that indeed the most robust structures over other self-organized crystals are the bcc crystals. Finally, we show that light-bullets and clusters of them can occur also in a bistable regime.

We consider arrays of coupled nonlinear optical cavities subject to coherent optical injection. These devices are described by the discrete generalized Lugiato–Lefever equation. We predict that stable three-dimensional localized structures, often called discrete light bullets, and clusters of them may form in the output of the coupled optical resonators. We consider both anomalous and normal dispersion and show that it results in the generation of, respectively, bright and dark discrete light bullets.

We investigate the formation of dark vector dissipative solitons in the presence of nonlinear polarization mode coupling in optical resonators subject to a coherent optical injection in the normal dispersion regime. This simple device is described by coupled Lugiato-Lefever equations. The stabilization of dark dissipative solitons is attributed to a front locking mechanism in the bistable regime as shown in a recent communication [B. Kostet et al., OSA Continuum 4, 1564 (2021)]. Here, we focus on a tristable homogeneous steady state regime. We show that two branches of dark dissipative solitons can coexist for a fixed value of the system parameters. These coexisting solutions possess different polarization states and different peak powers in the microresonator. We characterize their formation by drawing their bifurcation diagrams in regimes far from any modulational instability. It is shown that both branches of localized structures exhibit a heteroclinic collapsed snaking type of behavior. The coexistence of two vectorial branches of dark localized states is not possible without taking into account polarization degrees of freedom.

We investigate experimentally the nonlinear polarization dynamics of a VCSEL subject to optical injection of a frequency comb. By tuning the polarization of the injected comb to be orthogonal to that of the VCSEL, we demonstrate the generation of either a single polarization

or a dual polarization frequency comb. The injection parameters (injected power and detuning frequency) are then used either to generate harmonics of the initial comb spacing or to increase the number of total output frequency lines up to 15 times the number of injected comb lines. Optimisation of the injection parameters yields a comb extending over 60 GHz for a comb spacing of 2 GHz with a carrier to noise ratio (CNR) of up to 60 dB. Our technique allows us to separately control the comb spacing, comb bandwidth, CNR and polarization. Our finding can be used for spectroscopy measurement and also for polarization division multiplexing in optical data communications.

Application of laser technology for studying painting materials – media, pigments, varnish – has been widely researched in the last few decades due to its certain advantage of offering well-controlled working tools for fast, non-destructive *in situ* analysis with high accuracy. A detailed overview with emphasize on the main spectroscopic methods with laser-adopting equipment is done. The capabilities of complete characterization of the physical and chemical structure of paintings are illustrated with some impressive cases of practically solved problems.

High electro-optical coefficients, excellent optical properties and the possibility to change the refractive index by modifying their composition in regions where waveguide has to be formed, make $LiNbO_3$ (LN) and $LiTaO_3$ (LT) key materials for photonics. Being one of the main contemporary technologies for obtaining optical waveguides in LN and LT, proton exchange (PE) allows fabrication of high-quality waveguides for modulators, switches, multiplexers and Y-splitters.

The importance of phase composition for the quality of proton-exchanged waveguide layers in LN and LT has stimulated its detailed study. It requires an adequate nondestructive approach allowing fast and easy determination of phases, as could be provided by IR spectroscopy. A deconvolution of IR spectra is used to attribute the spectra components to definite phases in multiphase PE waveguides. This method also allows an estimation of the thickness of the phase sublayers of which modified layers are to be made.

The phase composition of $Li_{1-x}H_xNbO_3$ and $Li_{1-x}H_xTaO_3$ waveguide layers produced at different modifications of the proton exchange (PE) technology and having complex phase composition with different quota of the phases present is analyzed based on their mode and IR spectra. The intrinsic stress caused by crystal lattice deformations at a relatively high level of hydrogen doping in the PE layers is estimated by the optical integral method. An attempt to explain the level of stress is made based on the phase composition of the studied samples. The results contribute to a better understanding of the properties and characteristics of such waveguides.

A research on short-term and long-term DC-drifts in electro-optical modulators based on annealed proton exchange waveguides in $LiNbO_3$ crystals after wafer pre-annealing was performed. The relaxation time of the DC-drift of the operating point for a short-term drift was measured in minutes, and for long-term drift it was measured in hours. DC-drift was measured by applying bias voltage and changing crystal temperature. The obtained results show significant impact on the stability of operating point in EO-modulators after treatment of defective structure of the near-surface layer of a $LiNbO_3$ crystal results in the simultaneous reduction in short-term DC-drift and increase in operation stability of electro-optical modulators during long-term measurement of temperature by activation energy calculation.

Using chemical etching it was shown that the density of dislocation in lithium niobate (LN) single crystal wafers is higher near the surface in depth about 20 μm than in the depth of crystal. It caused to change of diffusion coefficient during the waveguide formation with proton exchange (PE) method and can increase DC-drift of intensity optical modulators based on PE-waveguides.

PUBLICATIONS:

1. Diana Nesheva, Zsolt Fogarassy, Margit Fabian, Temenuga Hristova-Vasileva, Attila Sulyok, Irina Bineva, Evgenia Valcheva, Krassimira Antonova, Peter Petrik. Influence of fast neutron irradiation on the phase composition and optical properties of homogeneous SiOx and composite Si–SiOx thin films.. Journal of Materials Science, 56, Springer Nature, 2021, ISSN:1573-4803, DOI:https://doi.org/10.1007/s10853-020-05338-3, 3197-3209.
2. G. B. Hadjichristov, T. E. Vlakhov, Y. G. Marinov, N. Scaramuzza. Ion-conducting fexible thin films of composites from poly(ethylene oxide) and nematic liquid crystals E8—characterization by impedance and dielectric relaxation spectroscopy. Polymers, 13, 24, MDPI, 2021, ISSN:2073-4360, DOI:10.3390/polym13244465, 4465-1-4465-27.
3. Hadjichristov, G. B., Marinov, Y. G., Vlakhov, T.E., Scaramuzza, N. Phospholipid Langmuir-Blodgett nano-thin monolayers: electrical response to Cadmium ions and harmful volatile organic compounds. Advances in Biomembranes and Lipid Self-Assembly, 34, Chapter 5, 2021, DOI:10.1016/bs.abl.2021.11.005, 129-172.
4. Hadjichristov, G.B., Exner, G.K., Marinov, Y.G., Vlakhov, T.E. Photo-electrical response of nanocomposites of single-walled carbon nanotubes incorporated in tris(keto-hydrozone) discotic mesogen. Journal of Physics: Conference Series, 1762, 2021, ISSN:17426588, DOI:10.1088/1742-6596/1762/1/012011, 012011.
5. Kuneva, M. K., Tonchev, S. H., Antonova, K. T. Phase composition analysis of proton exchanged LiNbO3 and LiTaO3 by IR spectra deconvolution. Advances in Materials Science Research, 47, Nova Publishers, 2021, ISBN:Print: 9781685073121; 1685073123 eBook: 9781685073283; 168507328X, DOI:https://doi.org/10.52305/MNQH8929, 31.
6. Kuneva, M. K., Tonchev, S. H., Christova, K. Phase composition and stress in proton exchanged waveguides in LiNbO3 and LiTaO3. Newest Updates in Physical Science Research, 5, BPInternational, 2021, ISBN-13(15): 978-93-90888-34-4 (Print); 978-93-90888-41-2 (eBook), DOI: https://doi.org/10.9734/bpi/nupsr/v5/2074F, 12, 140-151.
7. Panajotov, K., Tlidi, M., Song, Y., Zhang, H. Discrete light bullets in coupled optical resonators. Optics Letters, 46, 16, OSA, 2021, DOI:10.1364/OL.433629, 4072-4075.
8. Victoria Vitkova, Vesela Yordanova, Galya Staneva, Ognyan Petkov, Angelina Stoyanova-Ivanova, Krassimira Antonova, Georgi Popkirov. Dielectric properties of phosphatidylcholine membranes and the effect of sugars. Membranes, 11, 2021, 847-869.
9. Vlakhov, T. E., Yordan G. Marinov, Georgi B. Hadjichristov, George R. Ivanov. Electrical Impedance Spectroscopy-Based Detection and Quantification of Methanol Vapors by Use of Phospholipid Langmuir-Blodgett Film. XXX International Scientific Conference Electronics (ET-2021), IEEE, 2021, DOI:10.1109/ET52713.2021.9579527.
10. Vlakhov, T. E., Ginka K. Exner, Yordan G. Marinov, Georgi B. Hadjichristov. Glassy-State Discotic Liquid Crystals and Their Nanocomposites with Single-Walled Carbon Nanotubes: DSC and Optical Absorption. XXX International Scientific Conference Electronics (ET-2021), IEEE, 2021, DOI:10.1109/ET52713.2021.9580152.
11. Vlakhov, T.E., Hadjichristov, G.B., Marinov, Y.G. Photo-thermal effect by discotic liquid crystals doped with single-walled carbon nanotubes. Comptes Rendus de L'Academie Bulgare des Sciences, 74, 9, 2021, ISSN:13101331, DOI:10.7546/CRABS.2021.09.03, 1289-1295.
12. Vlakhov, T.E., Marinov, Y.G., Hadjichristov, G.B., Scaramuzza, N. Complex electrical impedance and dielectric spectroscopy of Na+-conducting PEO/PVP/NaIO4 solid polymer electrolyte with incorporated nano-sized Graphene Oxide. Journal of Physics: Conference Series, 1762, 2021, ISSN:17426588, DOI:10.1088/1742-6596/1762/1/012010, 012010.

13. Vlakhov, T.E., Ivanov, G.R., Marinov, Y.G., Hadjichristov, G.B. Phospholipid langmuir-blodgett films and impedance spectroscopy for detection of acetone and methanol vapours. Compt. Rend. Acad. Bulg. Sci., 74, 6, 2021, ISSN:13101331, DOI:10.7546/CRABS.2021.06.04, 828-834.
14. Кънева, М. К. Ex situ опазване на консервационно значими видове от род Centaurea в България (книгопис). сп. "Наука", 3, 4, СУБ, 2021, ISSN:08613362 (печатно); 2603-3623 (електронно), 79-79
15. Кънева, М. К. Лазерни методи при реставрация и консервация на кавалетна живопис. първо, Фараго, 2021, ISBN:978-619-206-201-9, 136
16. Цонев Л. В. Провадийската Омуртагова колона - опит за анализ. Булга медиа, 2021, ISBN:978-954-9670-55-4, 114
17. Цонев, Любомир, Маркишки, Пенчо, Кръстев, Иван. Археоастрономия: три етюда за обекти в България. първо, Булга медиа София, 2021, ISBN:978-954-9670-56-1, 298 Друго
18. Borisova, D., Goranova, M. Infrared Spectral Measurements of Quartz, Malachite and Hematite in Interpretation of Remote Sensing Data. Conference Proceedings, 11th Congress of the Balkan Geophysical Society, 2021, European Association of Geoscientists & Engineers. 2021, DOI:10.3997/2214-4609.202149BGS52, 52-1-52-5
19. Doumbia Y., Wolfersberger D., Panajotov K., Sciamanna M. Optical Injection Dynamics of VCSEL Frequency Combs. Optics InfoBase Conference Papers, IPR 2021 - Part of OSA Advanced Photonics Congress 2021, IEEE, 2021, DOI:https://ieeexplore.ieee.org/document/9541561
20. Doumbia, Y., Wolfersberger, D., Panajotov, K., Sciamanna, M. Tailoring frequency combs through VCSEL polarization dynamics. Optics Express, 2021, 29(21), pp. 33976–33991, 29, 21, OSA, 2021, DOI:10.1364/OE.432281, 33976-33991.
21. Gopalakrishnan S.S., Panajotov, K., Taki M., Tlidi M. Dissipative Light Bullets in Kerr Cavities: Multistability, Clustering, and Rogue Waves. Phys. Rev. Lett., 126, AIP, 2021, DOI:10.1103/PhysRevLett.126.153902, 153902.
22. Ivanov, G.R., Avramov, I.D., Strijkova, V.J., Marinov, Y.G., Vlakhov, T.E., Bogdanova, E., Hadjichristov, G.B. Mass sensitivity of Langmuir-Blodgett monolayer film coated surface acoustic wave resonators to volatile organic solvents. Journal of Physics: Conference Series, 1762, 2021, ISSN:17426588, DOI:10.1088/1742-6596/1762/1/012002, 012002.
23. Koduru, H.K., Marinov, Y.G., Kaleemulla, S., Rafailov, P.M., Hadjichristov, G.B., Scaramuzza, N. Fabrication and characterization of magnesium—ion-conducting flexible polymer electrolyte membranes based on a nanocomposite of poly(ethylene oxide) and potato starch nanocrystals. Journal of Solid State Electrochemistry, 25, 8, 2021, ISSN:14328488, DOI:10.1007/s10008-021-05018-5, 2409-2428.
24. Kostet B., Gopalakrishnan S.S., Averlant E., Soupart Y., Panajotov K., Tlidi M. Vectorial dark dissipative solitons in Kerr resonators. OSA Continuum, 4, OSA, 2021, DOI:10.1364/OSAC.418653, 1564.
25. Kostet B., Soupart Y., Panajotov K., Tlidi M. Coexistence of dark vector soliton Kerr combs in normal dispersion resonators. Phys. Rev. A, 104, APS, 2021, DOI:10.1103/PhysRevA.104.053530, 053530.
26. Li X., Song Z., Zhang H., Song Y., Panajotov, K. Editorial: Ultrafast Photonics of Low-Dimensional Materials. Front. Phys., 8, 2021 DOI:10.3389/fphy.2020.632406, 632406.
27. Martinov, B.L., Staneva, A.D., Vlakhov, T.E., Slavov, S., Dimitrov, D., Marinov, Y.G., Hadjichristov, G.B. Synthesis and characterization of nanosized ZnTiO3doped with reduced graphene oxide (RGO). Journal of Physics: Conference Series, 1762, 2021, ISSN:17426588, DOI:10.1088/1742-6596/1762/1/012031, 012031.

28. Sosunov, A. V., Ponomarev, R. S., Zhuravlev, A. A., Mushinsky, S. S., Kuneva, M. K. Reduction of DC-drift in LiNbO3-based electro-optical modulator. Preprints, 2021, 11, MDPI, 2021, DOI:https://doi.org/10.20944/preprints202111.0262.v1
29. Sosunov, A., Ponomarev, R., Zhuravlev, A., Mushinsky, S., Kuneva, M. Reduction of drift of operating point in lithium niobate-based integrated-optical circuit. Bulletin of Perm University. Physics, 2, 2021, ISSN:ISSN (Print): 1994-3598, DOI:https://doi.org/10.17072/1994-3598-2021-2-05-13, 5-13
30. Tlidi M., Gopalakrishnan S.S., Taki M., Panajotov K. Optical crystals and light-bullets in Kerr resonators. Chaos, Solitons and Fractals, 152, Elsevier, 2021, DOI:10.1016/j.chaos.2021.111364, 111364.

CITATIONS FOR 2021: 163

ONGOING RESEARCH PROJECTS:

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

" Optics, electro-optics and spectroscopy of new materials and systems", 2021/2023, budjet subsidy from the Bulgarian Academy of Sciences (BAS)

Financed by the Bulgarian Ministry of Education and Science:

Research project No КП-06 ПН57/5 (from 19.11.2021):
"Development and application of spectrophotometric methods for determination of thin films optical constants"
funded by the Ministry of Education and Science of Bulgaria, through the National Science Fund of Bulgaria

Research project No КП-06-Н58/2 (from 19.11.2021):
"Study of the possibilities for deposition of two- or multi- layered structures of type: graphene bufer layer- single crystalline Si substrate"
funded by the Ministry of Education and Science of Bulgaria, through the National Science Fund of Bulgaria

Research project No. КП-06-N58/6/2021 (from 19.11.2021):
"Liquid crystal nanocomposites for applications in photonics, sensorics and biomedicine",
funded by the Ministry of Education and Science of Bulgaria, through the National Science Fund of Bulgaria

Research project No. КП-06-Russia/8 (from 11.12.2020) in the frame of Bilateral Cooperation Program 'Bulgaria – Russia':
"Investigation of the deposition of Langmuir-Blodget nano biofilms and their interaction with various types of acoustic waves in piezoelectric structures",
funded by the Ministry of Education and Science – the National Science Fund of Bulgaria

Research project No. КП-06-OPR 03/9 (from 5 Sep 2018):
"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)",

funded by the Ministry of Education and Science, through the National Science Fund of Bulgaria

“Improvement of ion exchange methods for obtaining optical waveguides for highly stable integrated optical systems”, Contract with Ministry of Education and Sciences of Perm region - № C-26/848 and with Russian Federation research Funf and Perm region, Project № 20-42-596001. Term: 2021-2023

INTERNATIONAL COLLABORATION:

1. Department of Applied Physics and Photonics (TW-TONA), Vrije Universiteit Brussel, B-1050 Brussels, Belgium
2. Faculté des Sciences, Université Libre de Bruxelles, Campus Plaine, C.P. 231, Brussels B-1050, Belgium
3. Departamento de Fisica and Millennium Institute for Research in Optics, FCFM, Universidad de Chile, Casilla 487-3, Santiago, Chile
4. Shenzhen Engineering Laboratory of Phosphorene and Optoelectronics, Collaborative Innovation Center for Optoelectronic Science and Technology, Institute of Microscale Optoelectronics, Shenzhen University, Shenzhen 518060, China
5. KTH Royal Institute of Technology, 164-40 Kista, Sweden
6. Weierstrass Institute, Mohrenstrasse 39, 10117 Berlin, Germany
7. Chaire Photonique, LMOPS, CentraleSupélec, 2 Rue Edouard Belin 57070 Metz, France
8. Université de Lorraine, LMOPS, 2 Rue Edouard Belin 57070 Metz, France
9. Institute of Physics, Technical University of Lodz, 90-924 Lodz, Poland
10. University of Perm, Russia
11. Research group of Prof. Dr. Nicola Scaramuzza, Dipartimento di Fisica, Università della Calabria, Rende (CS), ITALY; CNR-IPCF UoS di Cosenza, Licryl Laboratory, and Centro di Eccellenza CEMIF.CAL, Cosenza, ITALY
12. Research group of Prof. Dr. S. K. Prasad, Centre for Nano and Soft Matter Sciences, P.O.Box 1329, Jalahalli, Bangalore 560013, India

TEACHING ACTIVITIES:

Assoc. Prof. M. Kuneva, Ph.D

- 120 hours Introductory course of physics for students on English, University of Architecture, Civil Engineering and Geodesy, Sofia, 2021
- 60 hours laboratory exercises in physics, bachelor program, Technical University, Sofia, 2021
- A series of 10 invited lectures for the Perm State Research University on the topic: "Optical waveguide layers obtained by proton exchange in lithium niobate and lithium tantalum: technology and research methods", 23. 11 - 17.12. 2021

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:**5**
RESEARCH SCIENTISTS: **5**

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

RESEARCH ACTIVITIES:

Laboratory of Atomic Spectroscopy works in the field of quantum optics, quantum optical analogies and analytical atomic spectroscopy.

In the field of quantum optics, a comparative analysis of the most popular quantum control techniques was made, evaluating their performance in the presence of various sources of error. Consideration techniques include resonant excitation, adiabatic transitions, composite adiabatic transitions, universal composite pulses, and shaped pulses. Possible sources of error include intensity distribution, interaction time variation, inhomogeneous broadening, Doppler broadening, unwanted draw, pulse shape errors, and errors in the use of the rotating wave approximation. For different types of errors, different techniques appear to be superior to the others, but the overall assessment shows that universal composite pulses are the most error-resistant. A new method for estimating the temperature vibration of a cooled ion has been developed. The technique uses narrow-spectrum composite pulses to "scan" the populations of different vibrational states. Unlike traditional methods, this approach does not involve a thermal distribution of phonon populations and is also applicable outside the Lamb-Dicke regime. A new method for controlling "transmon" superconducting qubits has been developed. The method is based on composite pulses and allows reducing the main types of errors that occur in this type of qubits: coherent errors from the calibration of the qubits, "leakage" of population outside the computational subspace of the qubits, and errors due to decoherence. A new method for laser cooling of ions in traps has been developed, which aims to improve the speed and accuracy of standard sideband cooling. The method relies on composite pulses to apply an effective pi-pulse to a large set of vibrational transitions with different Rabi frequencies.

In the field of quantum optical analogies, a construction was realized, representing a new design of an optical insulator, the action of which does not depend on the polarization of light. The device is based on a Sanyak interferometer and contains two compositions of Faraday rotator and half-wave plate, which act as a non-reciprocal rotator, ie. rotator in one direction and compensator in the opposite direction. Isolator tests showed an isolation level between 43 dB and 50 dB for all input polarizations (linear, circular or elliptical). A new retarder design has been developed - an optical device that slows down one component of polarization relative to the other (orthogonal to it). The system is based on a combination of reciprocating polarizing rotator, Faraday rotator and two quarter-wave plates as the phase shift in both directions

depends on the combined angle of rotation of the rotators and can be adjusted by one of the half-wave plates in the reciprocating rotator. The design was experimentally tested at wavelengths of 650 nm and 632.8 nm, for which the effect of a half-wave plate in the forward direction and a quarter wave plate in the opposite direction was achieved. Another demonstrated useful functionality of the design is the action of the system in one direction as a neutral element (zero retarder), which leaves the polarization unchanged, and in the opposite direction acts as a common retarder. In the specific case demonstrated for a wavelength of 632.8 nm and appropriately selected angles, in the opposite direction the action is on the eighth wave plate. The proposed design is applicable wherever it is necessary to control the polarization in the two opposite directions - polarization analysis, new designs of insulators or circulators and the implementation of quantum gates.

The work in the field of analytical atomic spectroscopy was related to the completion of the archeometric study of ceramics from the Neolithic settlement of Chavdar, located in the Pirdop-Zlatitsa field and dating to the Early Neolithic (VII - VI millennium BC). The laser-induced plasma spectroscopy (LIBS) identified the elements contained in the volume of the ceramic, the engobe and the white painted decoration applied on it. The mineral composition was determined by FT-IR (Fourier-Transform Infrared Spectroscopy). LIBS analysis of the engobe and white decoration showed the presence of the elements Si, Ca, Fe, Al, Ti, Mn, Mg, Na, K, Li, Sr and Ba as well as traces of In. and Cu. In white decoration the main element is Ca, while in engobe are Si and Fe. The mineral components in the ceramic body (aluminosilicates, various clay minerals, feldspars and oxides) were identified by FT-IR analyzes. Based on the results obtained from LIBS and FT-IR analyzes, it can be concluded that the determining factor for the reddish-brown color of the engobe is the mineral hematite (Fe_2O_3), while the main mineral in white decoration is calcite ($CaCO_3$). The results also showed incomplete dehydroxylation of the clay, which shows that the studied ceramics were fired at a temperature of 500 ÷ 650ºC.

AWARDS:

Research team: O. Ivanov, **V. Mihailov**, S. Karatodorov, J. Perez Diaz won first place in a competition for the best scientific achievement of the ISSP-BAS - *"Method for laser ablation threshold determination of solid materials"*

PUBLICATIONS:

1. Al-Mahmoud, M., Dimova, E., **Hristova, H**., Coda, V., Rangelov, A. A., Montemezzani, G., "Polarization-independent optical isolator in a Sagnac-type configuration", ***Applied Optics,*** 60, 14, Optical Society of America, 2021, ISSN:1559-128X, DOI:10.1364/AO.423730, 4230-4234. SJR (Scopus):0.668, JCR- IF (Web of Science):**1.98 Q1**, (Web of Science)

2. Al-Mahmoud, M., **Hristova, H**., Coda, V., Rangelov, A. A., Vitanov, N. V., Montemezzani, G., "Non-reciprocal wave retarder based on optical rotators combination", ***OSA Continuum***, 4, 10, Optical Society of America, 2021, ISSN:2578-7519, DOI:10.1364/OSAC.439325, 2695-2702. SJR (Scopus):0.592 **Q2** (Scopus)

3. Boyan T. Torosov, Bruce W. Shore, Nikolay V. Vitanov. Coherent control techniques for two-state quantum systems: A comparative study. ***Physical Review A,*** 103, 033110, American Physical Society, 2021,DOI:https://doi.org/10.1103/Phys.RevA.103.033110, JCR-IF (Web of Science): **3.14** (Scopus) **Q1**

4. **V. Atanassova**, L. Ghervase, I. M. Cortea, **V. Mihailov**, **V. Tankova**, V. Nikolov, "Multi-analytical approach for characterization of archaeological pottery excavated in the Early-Neolithic settlement of Chavdar, Bulgaria", ***Spectroscopy Letters*, 54(7)**, pp. 549–559, 2021 **IF=1.179**, DOI:https://www.tandfonline.com/doi/full/10.1080/00387010.2021.1957940.

5. Gegova-Dzhurkova, R.**,** Nesheva, D.**,** Dzhurkov, V.**,** Scepanovic, M., Grujić-Brojčin, M., Bineva, I., **Mihailov, V**., Levi, Z., Manolov, E., Popovic, Z.V.. Modification of surface morphology and lattice order in nanocrystalline ZnO thin films prepared by spin-coating sol–gel method. ***Journal of Sol-Gel Science and Technology***, 100, 1, Springer, 2021, ISSN:0928-0707, DOI:https://doi.org/10.1007/s10971-021-05635-6, 55-67. **IF =2.326** (Web of Science): **Q2** в Scopus

6. Georgieva, Mirela; Stoyanova-Ivanova, Angelina; Cherneva, Sabina; Petrov, Valeri; Petrova, Violeta; Andreeva, Laura; **Mihailov, Valentin**; Petkov, Alexander; Mikli, Valdek Characterization and comparison of as received and clinically retrieved Bio-active™ orthodontic archwires 2021, ***Biotechnology & Biotechnological Equipment*** 35(1):1301-1311, **IF=1.179; Q3** в Scopus DOI: 10.1080/13102818.2021.1964381

7. Gegova-Dzhurkova, R., Nesheva, D., **Mihailov**, V., Dzhurkov, V., Terziyska, P., Manolov, E.. Effect of infrared laser irradiation on electrical conductivity and ethanol sensitivity of sol gel ZnO thin films. ***Journal of Physics: Conference Series,*** 1762, Institute of Physics Publishing, 2021, ISSN:1742-6588, **Q4** в **Scopus** DOI:doi:10.1088/1742-6596/1762/1/012037, 012037. SJR (Scopus):0.21

8. **V Tankova**, **V Mihailov**, G Malcheva, P Penkova, L Leshtakov. Quantitative determination of antimony in archaeological bronze artefacts by laser-induced breakdown spectroscopy. ***Journal of Physics: Conference Series***, 1859, 1, IOP Publishing, 2021, ISSN:17426588, **Q4** в **Scopus**, DOI:10.1088/1742-6596/1859/1/012026, 1-6. SJR (Scopus):0.21

9. Hristo Kisov, Kiril Blagoev, **Vani Tankova,** Biliana Georgieva, Velichka Strijkova, Petia Petrova, Georgi Dyankov, "Organic random laser generation by stimulated cascaded four-wave mixing", ***Optics & Laser Technology***, (accepted)

PATENTS:

"Method for laser ablation threshold determination of solid materials"
O. Ivanov, **V. Mihailov**, S. Karatodorov, J. Perez Diaz №: 67278 B1 (2021)

ONGOING RESEARCH PROJECTS:

- Atomic and Plasma Physics (funded by the budget subsidy of BAS),
- Applications of laser ablation for the study of traditional materials in cultural heritage (under the Academy's bilateral agreements with National Institute for the Development of Optoelectronics - INOE 2000, Bucharest, Romania).

INTERNATIONAL COLLABORATION:

- National Institute for Research and Development of Optoelectronics (INOE 2000), Magurele, Romania
- French National Research Center CNRS, Institute of Physics.

- Faculty of Physics, Jagiellonian University, Krakow, Poland
- Faculty of Physics, University of Belgrade, Serbia.

DEPARTMENT - LASER, ATOMIC, MOLECULAR AND PLASMA PHYSICS

LABORATORY

METAL VAPOUR LASERS

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

TOTAL STAFF: **20**
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. Lyubomir Stoychev, PhD; Assist. Prof. Stefka Slaveeva, PhD; Assist. Prof. Georgi Yankov, PhD; Assist. Prof. Stefan Karatodorov, PhD; Assist. Prof. Danka Yordanova, PhD; Assist. Prof. Ognian Sabotinov, PhD; Physicist Viktoria Atanassova, PhD; Physicist Klaoyan Zlatanov, PhD; Assist. Ivan Kostadinov; Assist. Krassimir Dimitrov; Assist. Yulian Fedchenko; Physicist Blagovela Blagoeva; Sc. Eq. Worker Lyubomir Kandov

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

RESEARCH ACTIVITIES:

Copper Bromide (CuBr) vapor laser with an active volume of the discharge zone 10 liters (diameter 8 cm and length 200 cm) and oscillating on the atomic copper self-terminating transitions ($\lambda\lambda$510.6 nm и $\lambda\lambda$578.2 nm) was investigated. A record-high average output power of 140 W for the atomic CuBr vapor lasers was obtained. The average laser power of 131 W achieved with commutation of just 10 kV is also superior for the atomic CuBr vapor lasers. At the excitation of the same laser tube with the patented bipolar powerful high-voltage power supply an average output power of 151 W was also obtained. A 20-W compact and mobile CuBr laser excited with an all-solid-state bipolar power supply, in which the hydrogen thyratron was replaced with an IGBT (insulated-gate bipolar transistor), was also developed.

A power fluence of 0.85 TW.cm^{-2} was obtained at the atomic copper lines ($\lambda\lambda$510.6 nm and $\lambda\lambda$578.2 nm) with a new near-diffraction-limited (M^2 = 1.2) laser system, which comprised of three sealed-off laser tubes, as follows: oscillator, double-pas amplifier and power amplifier. Precise microprocessing of various materials, namely stainless steel, silicon and optical grade fused quartz, was also accomplished. Laser-matter interaction is also theoretically studied using analytical solution of the nonstationary heat conduction equation for the cases of aluminum, copper, silicon, and stainless steel.

Diffraction-limited laser radiation at the 6.45-μm line with an average output power of 2.3 W was produced by a new sealed-off master oscillator – power amplifier (MO–PA) strontium vapor system, which was developed and investigated. The MO–PA system had the following essential improvements: a small-bore laser tube (8 mm) placed in a stable flat-flat resonator instead of unstable cavity was used as a MO; a lens telescope is utilized instead of

the mirror telescope that eliminates the angular incidence of the laser radiation and minimizes the absorption losses. Precise microwelding and microcutting of optical grade silica were also realized to demonstrate the capabilities of the new MO–PA system and to assess the laser beam divergence.

A study on interaction of femtosecond laser radiation on various synthesized biopolymer materials (2D and 3D constructions) was carried out. Laser parameters (wavelength, laser pulse energy, irradiated area, number of the applied pulses, scan speed) were varied in wide range to optimize them for surface modification of each synthesized cell matrix.

Using ATR-FTIR method, spectral investigation in the infrared spectral region (4000–400 cm^{-1}) was made with FTIR spectrometer with resolution 4 cm^{-1} and equipped with ATR crystal for determination of mineralogical composition of the pigments used for decoration of ceramic dishes from the early Neolithic – late Chalcolithic era and found on the territory of Bulgaria.

AWARDS:

Academician Nikola Vassilev Sabotinov was awarded by the President of Republic of Bulgaria with the order necklace "Sts Cyril and Methodius" (Decree № 260 on the 4th of October 2021 published in the State Gazette № 84 on the 08th of October 2021) for particularly significant merits in the field of science.

PUBLICATIONS:

1. N. Stankova, A. Nikolov, **E. Iordanova**, **G. Yankov**, N. Nedyalkov, P. Atanasov, D. Tatchev, E. Valova, K. Kolev, S. Armyanov, D. Karashanova, N. Fukata, "New Approach toward Laser-Assisted Modification of Biocompatible Polymers Relevant to Neural Interfacing Technologies", *Polymers*, **13(17)**, art. No. 3004, 2021 **IF = 4.329** & **Q1** in **Web of Science** and in **Scopus**, https://doi.org/10.3390/polym13173004.
2. S. Y. Buhmann, S. M. Giesen, M. Diekmann, R. Berger, S. Aull, **P. Zahariev**, M. Debatin, K. Singer, "Quantum sensing protocol for motionally chiral Rydberg atoms", *New Journal of Physics*, **23(8)**, art. No. 083040, 2021 **IF = 3.732** & **Q2** in **Web of Science** and **Q1** in **Scopus**, https://doi.org/10.3390/polym13173004.
3. **K. Zlatanov**, N. Vitanov, "Multilevel laser induced continuum structure", *Entropy*, **23(7)**, art. No. 891, 2021 **IF = 3.012** & **Q2** in **Scopus**, https://www.mdpi.com/1099-4300/23/7/891.
4. K. D. Esmeryan, **Yu. I. Fedchenko**, **G. P. Yankov**, **K. A. Temelkov**, "Laser Irradiation of Super-Nonwettable Carbon Soot Coatings–Physicochemical Implications", Coatings, **11**, art. No. 58, 2021 **IF = 2.881** & **Q2** in **Web of Science** and in **Scopus**, https://www.mdpi.com/2079-6412/11/1/58.
5. **I. K. Kostadinov**, **K. A. Temelkov**, **S. I. Slaveeva**, B. L. Ivanov, **N. V. Sabotinov**, "High-power single-tube Sr vapor laser oscillating in the Mid-IR spectral range", *IEEE J. Quantum Electronics*, **57(5)**, art. No. 1500206, 2021 **IF = 2.318** & **Q3** in **Web of Science** and **Q1** in **Scopus**, https://doi.org/10.1109/JQE.2021.3102819.
6. **I. K. Kostadinov**, **K. A. Temelkov**, **D. N. Astadjov**, **S. I. Slaveeva**, **G. P. Yankov**, **N. V. Sabotinov**, "High-power copper bromide vapor laser", *Optics Communications*, **501**, art. No. 127363, 2021 **IF = 2.310** & **Q3** in **Web of Science** and **Q2** in **Scopus**, https://doi.org/10.1016/j.optcom.2021.127363.
7. C. Pizzolotto, A. Sbrizzi, A. Adamczak, D. Bakalov, G. Baldazzi, M. Baruzzo, R. Benocci, R. Bertoni, M. Bonesini, H. Cabrera, D. Cirrincione, M. Clemenza, L. Colace, M.

Danailov, P. Danev, A. de Bari, C. De Vecchi, M. De Vincenzi, E. Fasci, F. Fuschino, K. S. Gadedjisso-Tossou, L. Gianfrani, K. Ishida, C. Labanti, V. Maggi, R. Mazza, A. Menegolli, E. Mocchiutti, S. Monzani, L. Moretti, G. Morgante, J. Niemela, A. Pullia, R. Ramponi, L. P. Rignanese, M. Rossella, M. Stoilov, **L. Stoychev**, J. J. Suárez-Vargas, L. Tortora, E. Vallazza, A. Vacchi, "Measurement of the muon transfer rate from muonic hydrogen to oxygen in the range 70-336 K", *Physics Letters, Section A: General, Atomic and Solid State Physics*, **403**, art. No. 127401, 2021 **IF = 2.85** & **Q2** in **Scopus**, https://www.sciencedirect.com/science/article/pii/S0375960121002656?via%3Dihub.

8. **V. Atanassova**, L. Ghervase, I. M. Cortea, V. Mihailov, V. Tankova, V. Nikolov, "Multi-analytical approach for characterization of archaeological pottery excavated in the Early-Neolithic settlement of Chavdar, Bulgaria", *Spectroscopy Letters*, **54(7)**, pp. 549–559, 2021 **IF = 1.179** & **Q3** in **Web of Science** and **Q4** in **Scopus**, https://www.tandfonline.com/doi/full/10.1080/00387010.2021.1957940.

9. **I. K. Kostadinov**, **G. P. Yankov**, L. T. Popova, **S. I. Slaveeva**, **Yu. I. Fedchenko**, **K. A. Temelkov**, "High-power high-beam-quality sealed-off master oscillator – power amplifier system oscillating in the middle infrared spectral range on strontium atomic transitions", *Journal of Physics: Conference Series*, **1859(1)**, art. No. 012054, 2021 **Q4** in **Scopus** (SJR: 0.210), https://iopscience.iop.org/article/10.1088/1742-6596/1859/1/012054.

10. **K. Kostadinov**, **D. N. Astadjov**, **G. P. Yankov**, L. T. Popova, **S. I. Slaveeva**, **Yu. I. Fedchenko**, **K. A. Temelkov**, "High-beam-quality sealed-off master oscillator–power amplifier system oscillating in visible spectral range on copper atomic transitions for micromachining in science and technology", *Journal of Physics: Conference Series*, **1859(1)**, art. No. 012056, 2021 **Q4** in **Scopus** (SJR: 0.210), https://iopscience.iop.org/article/10.1088/1742-6596/1859/1/012056.

11. I. Balchev, T. Nurgaliev, **I. Kostadinov**, L. Lakov, M. Aleksandrova, G. Avdeev, E. Valcheva, S. Russev, K. Genkov, T. Milenov, "RF magnetron sputtering of $Bi_{12}TiO_{20}$ thin films on various substrates", *Journal of Physics: Conference Series*, **1859(1)**, art. No. 012060, 2021 **Q4** in Scopus (SJR 0.210), https://iopscience.iop.org/article/10.1088/1742-6596/1859/1/012060.

12. T. Milenov, D. Dimov, A. Nikolov, N. Stankova, I. Avramova, G. Avdeev, S. Russev, D. Karashanova, B. Georgieva, **I. Kostadinov**, "Nd:YAG laser ablation of micro-crystalline graphite in a water suspension", *Journal of Physics: Conference Series*, **1859(1)**, art. No. 012006, 2021 **Q4** in **Scopus** (SJR 0.210), https://iopscience.iop.org/article/10.1088/1742-6596/1859/1/012006.

13. **D. Yordanova**, **K. Temelkov**, D. Mihailova, J. Van Dijk, "Modelling of multiple-hollow-cathode-discharge laser", *Journal of Physics: Conference Series*, 2021 **1762(1)**, 012017 **Q4** in **Scopus** (SJR 0.210), https://iopscience.iop.org/article/10.1088/1742-6596/1762/1/012017.

14. **E. Iordanova**, **G. Yankov**, A. Daskalova, A. Dikovska, L. Angelova, D. Aceti, E. Filipov, G. Stanev, B. Calin, M. Zamfirescu, "Ultra-short laser modification of chitosan/silver nanoparticles (AgNPs) thin films for potential antimicrobial applications", *IOP Material Science and Engineering*, **1056**, art. No. 012002, 2021 (SJR 0.198), https://iopscience.iop.org/article/10.1088/1757899X/1056/1/012002/pdf.

15. **N. Sabotinov**, "Bulgarian scientific contribution to the development of metal vapor lasers", *Academia Letters*, art. No. 2194, 2021, https://www.academia.edu/50171296.

PATENTS:

Maintained patents:

1. Method for determination of laser ablation threshold of solid state materials, No. 67278 from 11.03.2021	O. Ivanov, V. Mihailov, **S. Karatodorov**, José Luis Pérez-Díaz
2. Method of atmospheric electricity extraction, No. 67018 from 27.01.2020	**D. N. Astadjov**, I. Angelov, M. Gospodinov
3. Laser tube for infrared strontium laser with strontium halide vapour, No. 66683 from 28.05.2018	N. K. Vuchkov and **K. A. Temelkov**
4. Laser tube for infrared strontium laser with strontium halide vapour, No. 66247 from 31.08.2012	N. K. Vuchkov, **K. A. Temelkov**, **N. V. Sabotinov**
5. Three-component glassy matrices processing variable nonlinear optical properties, No. 66129, 30.06.2011	**T. S. Petrov**, B. Shivachev and H. Yoneda
6. Gas discharge tube for sputtered hollow cathode laser, No. 65813, 31.12.2009	**M. G. Grozeva**, D. Mihailova, **N. V. Sabotinov**
7. Laser tube for ultraviolet copper laser, No. 64880, 31.07.2006	N. K. Vuchkov, **K. A. Temelkov**, **P. V. Zahariev**, **N. V. Sabotinov**

Patents in procedure:

1. Gas-discharge laser, reg. No. 113173 from 23.06.2020	**I. K. Kostadinov**, **D. N. Astadjov**, **K. A. Temelkov**, **G. P. Yankov**

ONGOING RESEARCH PROJECTS:

- Dynamics and formation of plasma induced by infrared femtosecond laser pulses in transparent medium (funded by BNSF under grant KP-06-PH58/11 2021).
- ELI ERIC BG for research infrastructure (funded by contract D01-401 18.12.2020).
- Basic research and development of high-beam-quality high-power laser system oscillating in visible spectral range (funded by BNSF under grant KP-06-H37/2 06.12.2019).
- Functionalization of 3D printed fibrous matrixes by femtosecond laser modelling (funded by BNSF under grant 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 BNSF under grant 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 BNSF under grant DN 18/07 2017).
- Laboratory “Laser Technologies” at Centre of Excellence “Mechatronics and Clean Technologies”.

- Lasers, laser technologies and applications (funded by the budget subsidy of BAS).
- Femtosecond laser applications in material microprocessing (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.

Prof. Dr. K. Temelkov organized the traditional 24th Winter Seminar of PhD Students and Young Scientists in Physics (Webinar), 07 December, 2021.

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

Prof. Dr. K. Temelkov and Assist. I. Kostadinov gave an invited lecture "HIGH-POWER DIFFRACTION-LIMITED LASER SYSTEM OSCILLATING IN MIDDLE AND VISIBLE SPECTRAL RANGE ON STRONTIUM AND COPPER ATOMIC SELF-TERMINATING TRANSITIONS" at the 14th Spring Seminar of PhD Students and Young Scientists in Chemistry (Webinar), 22-24 June, 2021.