Dear Colleagues,

2011 marked an emerging from the crisis situation of the previous years. We all hope it would be a sustainable tendency in the functioning of ISSP. All the efforts of the staff and administration aiming at a finance stabilization of the Institute have to be admired.

The 2011 productivity of ISSP in total is 232 publications, printed and in press. 113 of them have been published in high impact factor or impact rank journals. The total number of citations in 2011 is 878. Two books by foreign publishers were edited by O. Ivanov and by L. Pramatarova. One book on the history of physics was published in Bulgaria, with the co-authorship of M. Kuneva.

In 2011 the Internal Project Competition of the Institute has been resumed. Five scientific projects, three of them lead by young researchers, were supported by modest levels of funding, which nevertheless permits a more extended scientific activity and attracts much attention among the scientists.

Notably, four scientific projects of young team leaders were well funded by the National Science Fund. Successful leaders provide a very good perspective for their teams in the next few years.

The European Optical Society Prize 2011 was awarded to a paper published by Assoc. Prof. S. Tonchev et al. Prof N.Vuchkov was included in the Golden Book of Bulgarian Inventors as an Inventor of the year 2011. S. Terzieva received the Ivan Geshov prize of BAS for young researcher.

Academician N. Sabotinov and Assoc. Professor K. Kolentsov were elected Honorary Members of the Institute. Assoc. Professors M. Mitov, M. Grozeva, L. Pramatarova and D. Dimitrov were awarded the Georgi Nadjakov Sign of Honour 1st degree. Assoc. Professor P.Simeonova was awarded the Georgi Nadjakov Sign of Honour 2nd degree. Awards for the best scientific achievements of the year 2011 in ISSP were presented to the teams lead by Assoc. Professor E. Vlahov and Assist. Professor J. Genova. Medals and diplomas brought pride and satisfaction not only to their winners, but to the Institute as a whole.

The 17th edition of our broadly recognized International School of Condensed Matter Physics will take place in September 2012. The School will be devoted to 40th anniversary of ISSP. This and other jubilee activities will be the main focus of the starting year.

Alexander G. Petrov
The Georgi Nadjakov Institute of Solid State Physics (ISSP) is specialized in fundamental and applied research in the field of condensed matter physics, microelectronics, optics, spectroscopy, and laser physics.

The main scientific and applied achievements of the Institute are in the field of condensed matter theory, critical phenomena and phase transitions, superconductivity and superconducting materials, low temperature physics, liquid crystal physics, soft and living matter physics, structure and properties of crystals and amorphous materials, nanophysics, atom and plasma physics, integrated optics, optical fibres, acoustooelectric and microelectronic sensors, metal vapour lasers.

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 its disposal 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, 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 videomicroscopy and micromanipulation of lipid membranes;
- Lasers of various systems - metal vapour, hollow cathode, picosecond lasers for plasma physics and laser analysis of materials with possible application in ecology;
- High-tech experimental sets for laser cooling of atoms (~ 0.0001K) and application of lasers to archaeology;
- Equipment (Physical Properties Measurement System produced by Quantum Design, USA) for studies of electrical, magnetic and thermal properties of materials, surfaces and structures.

HISTORICAL REFERENCE: ISSP at BAS is created by a Decree No 362 / October 16, 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 is 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.
ORGANIZATION OF THE INSTITUTE OF SOLID STATE PHYSICS

DIRECTORATE

Director: Academician A.G. Petrov, D.Sc.
Deputy Director: Prof. K. Blagoev, D.Sc.
Scientific Secretary: Assoc. Prof. M. Primatarowa, Ph.D.
Secretaries: Mrs. L. Dedinska, Dipl. Eng.
Assist. Prof. E. Vlaikova (FP7 of EU)

ADMINISTRATIVE STAFF

Administrative Director: Mr. Chr. Popov, Dipl. Eng.
Administration’s office: Head: Mrs. I. Velkova, Dipl. Eng.
Accountant’s office: Head: Mrs. E. Popova

DIVISIONS

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Material Physics Head: Prof. M. Gospodinov, D.Sc.
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Center for Investigation of the Physical Properties of Materials, Surfaces and Structures: Head: Assoc. Prof. V. Lovchinov, Ph.D.

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Secretary: Assoc. Prof. M. Grozeva, Ph.D.

2. Acad. N. Sabotinov, D.Sc.
3. Prof. V. Kovachev, D.Sc.
4. Prof. M. Petrov, D.Sc.
5. Prof. M. Gospodinov, D.Sc.
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7. Prof. K. Blagoev, D.Sc.
8. Prof. I. Bivas, D.Sc.
11. Assoc. Prof. M. Mitov, Ph.D.
12. Assoc. Prof. M. Primatarowa, Ph.D.
13. Assoc. Prof. D. Dimitrov, Ph.D.
14. Assoc. Prof. S. Tonchev, Ph.D.
15. Assoc. Prof. T. Milenov, Ph.D.
RESEARCH ACTIVITIES:

The quantum critical behavior of the 2+1 dimensional Gross-Neveu model in the vicinity of its zero temperature critical point is considered. This model is widely used in condensed matter theory and high energy physics. We have used the concept of finite-size scaling to extract information about the leading temperature behavior of the free energy and the mass term, defined by the fermionic condensate and determined the crossover lines in the coupling \( g \) - temperature \( T \) plane. These are given by \( T \sim |g - g_c| \), where \( g_c \) denotes the critical coupling at zero temperature. According to our analysis no spontaneous symmetry breaking survives at finite temperature in contrast to previous studies. The scaling function of the singular part of the free energy is found to exhibit a maximum corresponding to the crossover line \( T = g - g_c \). Its universal value at the quantum critical point was found to be negative. Interpreted in terms of the thermodynamic Casimir effect, this result implies an attractive Casimir “force”.

We present an interatomic potential for nickel within the second moment approximation of tight-binding theory. The potential is an improved version of a previously developed potential for nickel and its stable alloys with aluminum. The present model is fitted to experimental values of the lattice parameter and the cohesive energy of Ni. The potential is
found to reproduce fairly well a variety of the physical properties of the element under study. Most of the properties computed with the aid of the new potential were not used in the fitting procedure, which demonstrates its ability to predict other properties. Advantages and weaknesses of the new potential are discussed in detail.

The molecular wheel Fe\textsubscript{18}(pdH)\textsubscript{12}(O\textsubscript{2}C Et)\textsubscript{6}(NO\textsubscript{3})\textsubscript{6} (shortly, Fe\textsubscript{18}) is the largest molecular wheel synthesized so far. We have made a comprehensive study of the magnetic properties of this system bases on inelastic neutron scattering (INS) and SQUID magnetometer experiments supplemented by semiclassical, DMRG, and Quantum Monte Carlo calculations. As a result, we show that the adequate magnetic model describing the system is the S=5/2 quantum Heisenberg chain composed of alternating J\textsubscript{1}=J\textsubscript{2}=2.88 meV, J\textsubscript{3}=1.02 meV exchange bonds supplemented by very weak single-ion magnetic anisotropy term.

We analyze the quantum phase diagram of the mixed-spin Heisenberg chain containing general isotropic three-spin exchange interaction term. The study is based on the numerical DMRG method as well as on a number of exact analytical results concerning the phase boundaries. The analysis demonstrates, in particular, that the considered quantum spin system possesses a number of quantum dimerized phases characterized by multiferroic properties.

We study the ferromagnetic spin chain with both first- and second-neighbor interactions. We obtained the condition for the appearance and stability of bright and dark solitons for arbitrary wave number inside the Brillouin zone. The influence of the second-neighbor interaction and the anisotropy on the soliton properties is considered. The scattering of dark solitons from point defects in the discrete spin chain is investigated numerically.

We employ a concept popular in physics the Zipf rank approach in order to estimate the number of years that EU members would need in order to achieve "convergence" of their per capita incomes. Assuming that trends in the past twenty years continue to hold in the future, we find that after t=30 years both developing and developed EU countries indexed by i will have comparable values of their per capita gross domestic product $G_{i,t}$. Besides the traditional Zipf rank approach we also propose a weighted Zipf rank method. In contrast to the EU block, on the world level the Zipf rank approach shows that, between 1960 and 2009, cross-country income differences increased over time. For a brief period during the 2007–2008 global economic crisis, at world level the $G_{i,t}$ of richer countries declined more rapidly than the $G_{i,t}$ of poorer countries, in contrast to EU where the $G_{i,t}$ of developing EU countries declined faster than the $G_{i,t}$ of developed EU countries, indicating that the recession interrupted the convergence between EU members. We propose a simple model of GDP evolution that accounts for the scaling we observe in the data.

**PUBLICATIONS:**

1. H. Chamati and N. S. Tonchev, Quantum critical scaling and the Gross-Neveu model in 2+1 dimensions, EPL (Europhysics Letters) \textbf{95} (2011) 40005, 6 pages. ISSN 0295-5075
3. J. Shao, P. Ch. Ivanov, B. Urosevic; H.E. Stanley, B. Podobnik, Zipf rank approach and cross-country convergence of incomes, EPL (Europhysics Letters), \textbf{94} (2011), 48001. ISSN 1286-4854
Trimerized quantum Heisenberg model for the magnetic molecular wheel system Fe$_{18}$(pdH)$_{12}$(O$_2$CEt)$_6$(NO$_3$)$_6$ (submitted to Phys. Rev. B).

6. J. Ummelthum, N.B. Ivanov, and J. Schnack, Quantum phase diagram of the mixed-spin Heisenberg chain (S, s)=(1, 1/2) with three-spin exchange interaction (in preparation for publication)


ONGOING RESEARCH PROJECTS:

Quantum effects in spin systems with strong competing interactions (National Science Fund, Project DO02-264)
RESEARCH

Some important features of the $P-T$ (pressure-temperature) phase diagram of unconventional ferromagnetic superconductors with spin-triplet Cooper pairing of electrons have been investigated by the means of the modern theory of phase transitions. The results have been compared with the experimental data for the intermetallic compound UGe$_2$. In our previous publications (2005-2009), the basic features of this phase diagram have been explained in a remarkable agreement with the experimental results but some problems related to the meta-magnetic phase transition and to the order of the paramagnetic-to-ferromagnetic phase transition at relatively high pressure have not been elucidated. In order to resolve these problems we extend our theory by an additional term of sixth order in the magnetisation. In this way, under certain circumstances, the theory may describe the first order paramagnetic-ferromagnetic phase transition at relatively high pressures (up to the quantum phase transition at $T = 0$ and $P = P_C$ – critical pressure; for UGe$_2$, $P_C = 1.6$ kbar) and the change of the order of the same phase transition (at a tri-critical point $P_t$) to a second order phase transition at relatively lower pressures (for UGe$_2$, $P_t \sim 1$ kbar and the second order phase transition extends up to the ambient pressure). This picture, in a total agreement with the experiments for UGe$_2$, is described by the theory, provided the coefficient of the fourth order term in the expansion of the free energy in powers of the magnetisation linearly depends on the pressure and changes sigh at the tri-critical pressure $P_t$.

For the same class ferromagnetic superconductors, the diamagnetic susceptibility above the superconducting phase has been investigated. The most interesting cases of three dimensional (3D), quasi-2D (thin films) and 2D (single atomic layer) ferromagnetic superconductors have been described in details. A part of the results are submitted for a publication; other results are still in course of preparation for a publication.
A model for studying the properties of electron gas in crystal structures was created. The relation of the electron gas equilibrium density to pressure and external magnetic field has been studied. A system of non-linear equations was composed to describe the dependence of the equilibrium density, pressure, external magnetic field and chemical potential of crystal lattice, consisting of isotopes with certain nuclear charge and mass number. A numerical procedure was developed to allow solving systems of equations with extreme accuracy. The minimum of the Gibbs energy has been investigated.

Coherent excitation of quantum systems with ultrashort laser pulses is essential for a variety of fields such as spectroscopy, quantum information and control of molecular dynamics. Recently, the proposed method of piecewise adiabatic passage (PAP) appears to be a promising technique for executing complete and robust population transfer between quantum states using a series of femtosecond laser pulses with constant (but varying from pulse to pulse) phases. Exploiting the periodicity of the femtosecond pulses combined with the pulse to pulse slowly varying peak amplitudes and phases, we analyze this piecewise problem with the adiabatic Floquet theory. Then, with the use of Kolmogorov-Arnold-Moser type perturbation theory we obtain an effective smooth (nonpiecewise) Hamiltonian, and analyze the conditions for adiabatic transfer. Due to its effectively adiabatic nature the method of PAP is robust to a variation of intensities, durations and shapes of the pulses.

Multiphase proton-exchanged waveguide layers in X, Y and Z-cut LiNbO₃ have been studied. The phase composition of proton-exchanged waveguides was studied by mode spectroscopy, IR absorption spectroscopy and mechanical stress measurements. An attempt to indicate stress correlation to the relative quota of the different phases in the proton exchanged layer adds to the physical knowledge on this matter. It is found that: i) a correlation exists between mechanical stress and the phase composition; ii) highly protonated phases and deep waveguides with very low mechanical stress could be obtained in Y-cut LiNbO₃ at specific technological conditions; iii) an optimal thickness of the three-layer structure at which the stress of the layer as a whole is minimal exists; iv) the substitution-interstitial proton ratio could be estimated from the sign and the magnitude of the stress; v) stress measurements confirm the paraelectric state of highly protonated phases since such layers had lost their anisotropy.

A book dedicated to quality control entitled “Applications and Experiences of Quality Control”, ed. by Ognyan Ivanov, was issued by the publisher INTECH. Various aspects of quality control have been presented in it. In the creation of the book were involved 98...
scientists. The publication will be of assistance to professionals working in different fields but having an interest in quality control. One of the chapters is dedicated to original research conducted in ISSP. It deals with two cases of electromagnetic field-matter interactions: when the field is excited by acoustic waves propagating along the surface of a piezoelectric material and when there is an unspecified field source. Specific developments with practical applications have also been presented.

PUBLICATIONS:

Monographs:
1. O. Ivanov, M. Kuneva, Quality control methods based on electromagnetic field-matter interactions. In Application and Experience of Quality Control, Ed. O. Ivanov, INTECH, Vienna, 509-536 (2011)

Papers:
4. I. Boradjiev and S. Guerin. „Piece wise passage revealed by Floquet thoery”, Young European physicists, 18.06.2011-22.06.2011, Toulouse (France) – oral presentation
5. I. Boradjiev and S. Guerin “Piece wise passage revealed by Floquet thoery”, Control of Quantum Dynamics of Atoms, Molecules and Ensembles by Light, Nessebar (Bulgaia), 03.07.2011- 09.07.2011 – oral presentation

ONGOING RESEARCH PROJECTS:
- Electronic properties of solid state systems (BAS)
- Coherent control of quantum systems (NSF)
- Quantum computers and quantum information (NSF)
RESEARCH ACTIVITIES:

In the framework of the research activity of the Laboratory following crystals were synthesized: La$_2$CoMnO$_6$ (LCMO) in pure state and doped with Pb and (Pb+Pt); La$_2$NiMnO$_6$ (LNMO); LaMnO$_3$ (LPMO) in pure state and doped with Pb; RMnO$_3$ (R=Ho, Er, Yb, Tm, Lu); Bi$_2$NiMnO$_6$ (BNMO); Bi$_2$Fe$_4$O$_9$; Bi$_2$Mn$_4$O$_{10}$; Pb$_3$Ni$_{1.4}$Mn$_{5.6}$O$_{15}$ (PNMO); YMnO$_3$; YCrO$_3$; NiFe$_2$O$_4$; NiZnFe$_2$O$_4$; MnWO$_4$; LiFe$_3$O$_8$ (LFO); (PbZn$_{1/3}$Nb$_{2/3}$O$_3$)$_{0.9}$–(PbTiO$_3$)$_{0.1}$; PbSc$_{0.5}$Ta$_{0.5}$O$_3$ and Pb$_{0.78}$Ba$_{0.22}$Sc$_{0.5}$Ta$_{0.5}$O$_3$ as well as thin films of LCMO, LNMO, BNMO and structures consisting of thin films permalloy on an antiferromagnetic substrate (LuMnO$_3$). The obtained crystals were structurally characterized with single-crystal X-ray diffractometry, and in some cases (e.g. Bi$_2$Fe$_4$O$_9$) with neutron scattering measurements, as well as with measurements of their magnetic properties. The magnetic and electric behavior of the obtained crystals and thin films was investigated. A series of Raman and Infrared spectroscopic investigations were carried out to clarify the interplay of lattice deformations, phonon mixing, spin-phonon coupling and the type of magnetic ordering in the obtained multiferroic and magnetoolectric crystals. Their normal vibrations of various symmetries were theoretically analyzed and the pertinent frequencies were experimentally determined.

Crystals of Bi$_2$SiO$_{20}$ doped with Se were grown and it was established that doping with Se was accompanied with preferential absorption of Fe from the melt by means of the substitution of 3Si$^{4+}$ by (Se$^{6+}$+ 2 Fe$^{3+}$) ions. The measured absorption spectrum in UV-VIS region, polarized Raman spectra and an IR transmission spectrum indicated local lowering of the symmetry of the Fe-occupied tetrahedral positions. The compound Bi$_{36}$MgP$_2$O$_{60}$–δ was synthesized and its structure was refined as cubic (sillenite type) - I$23$ with lattice parameter of $a_o = 10.15704(12)$ Å. Its fundamental vibrations were characterized by Raman and IR transmission spectroscopy.

It is established that small quantities of single-walled carbon nanotubes (SWNTs) enhance the flexoelectric response in some liquid crystals (LC). The asymmetric anchoring of the LC molecules induces a dipole moment in the SWNT which leads for the LC E7 to a three-times increase of its flexoelectric coefficients.

With a recently developed method a large class of exact solutions of the running-wave type are obtained for the b-equation and the generalized equation of de-Gasperis processes which facilitates the assessment of the behavior of various systems.
PUBLICATIONS:


3. Dulk'in, E., Mihailova, B., Gospodinov, M., Roth, M., *Electric field dependence of characteristic temperatures in PbSc(0.5)Ta(0.5)O(3) and Pb(0.78)Ba(0.22)Sc(0.5)Ta(0.5)O(3) relaxors studied via acoustic emission*, EPL Volume: 94 Issue: 5 (2011) Article Number: 57002.


10. B.J.Maier, N.Waeselmann, B.Mihailova, R.J.Angel, C.Ederer, C.Paulmann, M.Gospodinov, A.Friedrich,and U.Bismayer, *Structural state of relaxor ferroelectric PbSc0.5Ta0.5O3 and PbSc0.5Nb0.5O3 at high pressuresup to30Gpa*, Phys. Rev. (B) 84 (2011) 174104.


**ONGOING RESEARCH PROJECTS:**

Financed by the Bulgarian National Scientific Research Foundation at the Bulgarian Ministry of Education and Science:

1) TKX-1712/2007: “Growth, characterization and investigation of the physical properties of new crystals in the systems Bi-Co(Ni)- Mn(Ru)-O and La-Co(Ni)-Mn(Ru)-O with magneto-electric/ multiferroic behaviour” – April 2012.

**COLLABORATION:**

1. Synthesis and study of multifunctional materials based on the complex oxides of bismuth and allotropic forms of carbon- Institute of Common and Inorganic Chemistry, Russian Academy of Sciences, Moscow, Russia

2. Growth and characterization of oxide crystals for optical applications - Research Institute of Solid State Physics and Optics, Budapest, Hungary
RESEARCH ACTIVITIES:
The research activities of the Laboratory for Biocompatible Materials (BCM) in 2011 were:

1. Theme: “Biocompatible materials: Modification and functionalisation the surface of materials”
   1.1 Hydroxyapatite/nanodiamond (HA/DND) coatings are obtained and studied using the method of soaking in simulated body fluid (SBF);
   1.2 Hydroxyapatite/nanodiamond (HA/DND) coatings are obtained and studied using the method of laser-liquid-solid interaction (LLSI) and are obtained materials with organized micro- and nanometer scaled surface;
   1.3 The behaviour of different cell cultures on these materials is studied;
   1.4 Different DND powders and suspensions are obtained and studied;
   1.5 The obtained samples are studied with: SEM/EDX, XRD, AFM, FTIR and Raman spectroscopy, Nanoscaning, Coherent microscopy, Contact angle (wettability).
   1.6 A project on this theme was started with the Bulgarian Ministry of Education and Science, TK-X1708/07, which is successfully finished on 05.04.2011.

2. Theme: “Improving the method – white light interferometry for studying thick and rough coating of HA and HA/DND composite layers”
   2.2 New Z-scan techniques have been developed for analysis of thick transparent layers and making localised measurements of layer thickness and refractive index. Our software for the control, the measurement and the analysis by Z-scan has been improved greatly through this project.
   2.3 Several series of different samples were prepared at the ISSP for studying HA during the project, using DND nano-particles, bioceramics (CaP), polymers and fibronectine.
   2.4 A project on this theme was started with French partner from InESS, CNRS, Strasbourg, France, PICS project 4848, which was successfully finished on 10.12.2011

3. Theme: “Biocompatible materials: Obtaining of composite layers on solid substrates”
3.1. A microdesign is prepared for projecting on solid substrates using laser system and scanning head.

3.2. The combination of laser system and the growing layer system allows the obtaining of nanostructural composite layers of HA/DND.

3.3. The method includes using of DND, as collagen (the organic part of bone tissue). It is known that DND provides architectural plan for HA mineralization, inorganic part of bone tissue, such as collagen, which is a new perspective in medicine.

3.4. DND changes the mechanic parameters of composite layers and can strengthen the bone tissue, which is the main requirement for obtaining better artificial bones.

3.5. A project on this theme was started with National Innovation Found, NIF 02-54/28.12.07, which was successfully finished in the beginning of 2011.

4. 3D calcium phosphate (CaP) matrices were prepared from natural resources found in big amounts in nature (powdered egg-shells micex with phosphoric acid). Such 3D matrices characterized by high degree of porosity are used as bone scaffolds and thus they play an important role in tissue engineering. In the current experimental direction, the matrices are additionally functionalized through the immersion in several functional fluids (through bilateral project with the Hungarian Academy of Sciences).

5. Aiming at surface modification of various biomaterial surfaces, deposition of the natural polymer cellulose acetate has been carried out by applying the method of electrospinning. Polymer fiber network suitable for the incorporation of HA or DND particles has been obtained (through bilateral project with the Hungarian Academy of Sciences).

PUBLICATIONS:


FUTURE RESEARCH PLANS OF THE LABORATORY INCLUDE:

1. Control of the process of plasma polymerization of hexamethyldisiloxane on the surfaces of stainless steel, titanium, titanium alloys and glass. Growth of HA and HA-DND composite layers on the modified by plasma polymerization surfaces.
2. Preparation of titanium alloys with biomedical applications and DND incorporation and study of their bioactivity through the deposition of HA.

3. Cell culture experiments with various cell lines for biocompatibility investigation of the prepared samples and layers. Investigation of the protein adsorption and reorganization on the modified surfaces for improving their biocompatibility with living cells.

4. Study of the process of laser-liquid-solid interaction for stimulated HA growth by using different wavelengths, laser power, pulse repetition, time duration, etc.

5. Measurements by classical and novel techniques for complementary characterization of the surfaces.

6. Preparation of CaP scaffolds with additional functionalization for cell culture experiments.

7. Characterization of cellulose acetate polymer fiber network.

8. Preparation of CaP scaffolds with incorporated DND nanoparticles for bone scaffolds with improved properties.
DIVISION NANOPHYSICS

LABORATORY

PHOTOELECTRICAL AND OPTICAL PHENOMENA IN WIDE BAND GAP SEMICONDUCTORS

HEAD: Prof. Diana Nesheva, D.Sc.
tel: 979 5686; e-mail: nesheva@issp.bas.bg

TOTAL STAFF: 11
RESEARCH SCIENTISTS: 10
ASSOC. MEMBERS: 2

Assoc.Prof. D. Arsova, Ph.D.; Assoc.Prof. Z. Ivanova, Ph.D.; Assoc.Prof. V. Pamukchieva, Ph.D.; Assoc.Prof. Z. Aneva, Ph.D.; Assoc.Prof. Z. Levi, Ph.D.; Assoc.Prof. K. Kolentsov; Assoc.Prof. S. Balabanov; Assist.Prof. I. Bineva, Ph.D.; Assist.Prof. M. Mineva, Ph.D.; E. Zaharincheva, technologist

RESEARCH ACTIVITIES:

1. NANOSTRUCTURED THIN FILMS

   Studies were carried out and an application for Bulgarian patent has been submitted concerning Al/c-Si/ SiO₂/Si-SiO₂/Al metal-insulator-silicon (MIS) structures with Si-SiO₂ layer containing crystalline Si nanoparticles. It has been shown that these structures could be applied in dosimetry as an alternative of the presently used radiation sensors based on MIS structures having a SiO₂ dielectric layer. Essential characteristic of these structures is the high sensitivity at low doses of registered radiation which is important for their application in medicine, in dosimetric control for the nuclear industry and in cosmic research.

   Crystal structure and microstructure of single layers of ZnₓCd₁₋ₓSe (0.39 ≤ x ≤ 1), prepared by thermal vacuum evaporation, have been investigated by means of X-ray diffraction and Raman scattering. It has been shown that both binary and ternary films have cubic structure. Pure CdSe and ZnSe phases have not been observed in the ternary films. Combined photoelectrical and Raman measurements were carried out to get information about spectral photosensitivity of the films. On the basis of the obtained results existence of Cd-enriched nanosized regions was assumed. A linear increase of the optical band gap with increasing Zn content has been observed.

2. DISORDERED MATERIALS - CHALCOGENIDE GLASSES AND THIN FILMS

   It has been experimentally confirmed that the new “light annealing effect” recently reported by us is due to the duel action of light. The illumination of preliminary annealed thin Ge-As-S films causes changes of the Tauc parameter, characterizing the structural disorder, that are in correlation with the changes of the optical band gap energy. It has been observed that both values decreased after photodarkening, but after a long-term illumination the values began to increase. Thus the photobleaching (PB) overcomes the photodarkening (PD) without any thermal treating. The photobleaching occurred earlier in thinner films and in nanosized films only PB is observed. Changes of the both parameters of disorder i.e. the
Tauc slope and the Urbach energy, have been observed but no correlation between them has been found. This result is a proof for the different origin of the disordered parameters. The idea of the dual action of light gives new possibilities for explaining the peculiarities of the photoinduced phenomena in amorphous chalcogenide semiconductors.

Low-temperature photoluminescence of heavily Er-doped Ga$_2$S$_3$-GeS$_2$ glasses with a ratio of [GeS$_2$/Ga$_2$S$_3$] = 4, 3, 2 and 1.8 - 2.4 mol % Er$_2$S$_3$ has been studied. The typical 4f–4f emission bands of Er$^{3+}$ ions at 830, 1000 and 1550 nm have been observed in the whole investigated temperature range 10-300 K, while new PL bands with higher intensity centred at 670, 870, 1120, 1260 and 1350 nm have been observed for [GeS$_2$/Ga$_2$S$_3$] = 3. Thus a considerable influence of the host on the efficiency of 4f–4f transitions of embedded Er$^{3+}$ ions is documented with the outcome that the (GeS$_2$)$_{75}$(Ga$_2$S$_3$)$_{25}$ composition appears near optimal for the emission of Er$^{3+}$ ions. With decreasing temperature the PL efficiency is enhanced considerably with pronounced narrowing of all bands. In the case of the strongest PL band at ~1550 nm, the narrowing at low temperature is further accompanied by the resolution of well pronounced fine structure due to “crystal field” splitting of corresponding electronic terms. The influence of Er-doping and thermal annealing at 100 and 200 °C on basic optical parameters of thin amorphous films with the optimal composition has been specified.

New alkali-antimonite (Sb$_2$O$_3$)$_{70}$(Na$_2$O)$_{20}$(ZnO)$_{10}$ glasses doped with 0.25, 0.5 and 1.0 mol% Er$_2$O$_3$ have been investigated by using UV-V-NIR absorption, infrared emission and fluorescence decay techniques. The role of Er-doping level on the evolution of the observed absorption bands at 1533, 977, 800, 652, 546, 521 and 489 nm has been established. The Judd–Ofelt theory has been applied to calculate the basic radiative parameters. With a view to possible applications, details of the Er$^{3+}$ emission at ~1530 nm and spectroscopic characteristics such as the stimulated emission cross-section ($\sigma_s$), the parameter of ($\sigma_s\times$ FWHM) and the quantum efficiency ($\eta=\tau_R/\tau_{\text{meas}}$) have been summarized. The obtained results indicate that the glasses studied could be used as a laser medium and for optical amplification in the 1.5 µm region.

The optical properties and surface morphology of Ge$_3$Sb$_{40-x}$S$_{50}$Te$_{10}$ (x=10, 20 and 27) thin films evaporated from powdered glassy materials were studied by spectroscopic ellipsometry performed in the UV-VIS-NIR range and by AFM imaging. For both kinds of quaternary systems, the optical constants (n and k) decreased with increasing Ge content with their values being smaller for the Ge$_3$As$_{40-x}$S$_{50}$Te$_{10}$ compositions. AMF images has revealed cracks-free film surface which is fully covered with uniformly distributed grains whose size and distribution depend on the film composition. For all films, the average roughness did not exceed 5 nm, giving evidence for sufficiently high smoothness. The vibrational properties of impurities in the powdered glasses and corresponding films were studied by FTIR spectroscopy. Vibrational modes attributed to O-H hydroxyl groups, molecular H$_2$O and carbon impurity atoms have been detected in the IR spectra of the powdered glasses but they have not been observed in the IR spectra of the thin films. Vibrational modes of oxygen atoms bonded to basic elements, such as Ge-O and Te-O bonds have been detected in the IR spectra of both kinds of samples.

The dependence of second harmonic generation on the thickness of Ge$_{35}$Sb$_5$S$_6$ chalcogenide glass films has been experimentally and theoretically investigated. It has been shown that there are two components in the quadratic optical susceptibility, a component which is dependent on the film thickness and a second one independent of the thickness. The relation of these contributions allows one to estimate the role of the bulk electric dipole mechanism, which increases with decreasing film thickness.

Chalcogenide thin films from the system GeSe$_2$-GeTe-PbTe with 10 different compositions were studied. It has been shown that the film dark conductivity varies within 5-6 orders of magnitude. It has also been found that the dark current activation energy...
increases with both decreasing Pb content and increasing Ge content. A good sensitivity to ammonia has been demonstrated by Ge$_{32}$Se$_{55}$Te$_{13}$ films which made this composition suitable for ammonia sensors operating in damp air. The Ge$_{31}$Se$_{66}$Te$_{3}$ and Ge$_{32}$Se$_{64}$Te$_{4}$ films have shown good sensitivity and fast response to water/alcohol and water/acetone vapour, respectively and could be used for sensors operating in dry air.

**PUBLICATIONS:**


**ONGOING RESEARCH PROJECTS:**

**Financed by the Bulgarian Academy of Sciences:**

1. Semiconductor nanoparticles in amorphous thin film matrix: formation, structure and properties.
Financed by the Bulgarian Ministry of Education, Youth and Sciences:

2. New amorphous and glassy materials based on Ge suitable for sensor applications, Contract D002-123.

COLLABORATION:

1. Preparation and investigation of optical properties of semiconducting glasses for photonic applications, Institute of Photonics and Electronics, Prague, Czech Republic.
2. Optical and photoelectrical characterization of thin films and nanostructured layers based on ZnSe, Institute of Physics, Belgrade, Serbia.
4. Investigation of optical and electrical properties of nanostructures chalcogenide semiconductors suitable for memory applications, Physico Thechnical Institute, Sankt Peterburg, Russia.
RESEARCH ACTIVITIES:

In 2011 the research activities of the Laboratory were focused on the study of structure, optical and electrical properties of Si-based semiconductor heterostructures with nano-sized dielectric layers (such as SiO\(_x\)N\(_y\) and SiO\(_2\)) and with nanostructured semiconductor films (such as AlN, AlN:Cr and AlN:Si) prepared by applying contemporary technological methods (such as plasma immersion implantation of low-energy N\(^+\) and H\(^+\) ions and pulsed laser ablation), revealing potential possibility for preparation of multifunctional Si-based structures and their usage for nano- and optoelectronics purposes.

1. STUDY OF PULSED LASER DEPOSITED NANOSTRUCTURED AlN FILMS

The study of the structure and properties of thin AlN films synthesized by pulsed laser deposition (PLD) at different technological conditions continued in 2011. The analysis of the results from the XRD, HRTEM and AFM measurements has shown that AlN films deposited in nitrogen ambient and at high laser incident fluence (> 5 J/cm\(^2\)) are predominantly amorphous with smooth film surface morphology. SEM micrographs have visualized the columnar film structure. By increasing the nitrogen pressure from 0.1 to 10 Pa, in the amorphous films small crystallites are formed, the phase and size of which are dependent on the dynamic N\(_2\) pressure.

It has been established that doping of AlN films with Cr atoms (AlN:Cr) does not change the AlN:Cr films structure, while doping of AlN films with Si atoms (AlN:Si) facilitate the growth of nanosized crystallites in metastable cubic phase. The analysis of the I-V characteristics of MIS structures with the AlN:Cr and AlN:Si films has revealed that the electrical current though these films is carried out by electrons via deep levels in the AlN energy bandgap and it is limited by the space charge of electrons trapped in deep levels.

2. PREPARATION AND STUDY OF NANOSIZED SiO\(_x\)N\(_y\) LAYERS IN SILICON

Formation of nanosized SiO\(_x\)N\(_y\) layer through high-temperature annealing (1050°C) in oxidizing ambient of Si substrates modified by low-energy (4 keV) plasma immersion implantation of nitrogen with fluences of 10\(^{16}\) - 10\(^{18}\) cm\(^{-2}\) is studied. The implanted profiles of the atomic (N\(^+\)) and molecular nitrogen (N\(_2\)\(^+\)) are modeled for different annealing durations taking into account the diffusion process. From the analysis of the FTIR and
ellipsometric spectra presence of Si-O and Si-N bonds is established in the synthesized layers with low refractive index (varying from 1.47 to 1.59 at $\lambda=633$ nm). These results have shown that the applied technological processes offer a potential possibility to synthesize nanosized (~10-40 nm) SiO$_x$N$_y$ layers with low concentration of nitrogen.

3. THEORETICAL STUDY OF PROCESSES AT PHASE BOUNDARIES

The processes at phase boundaries are theoretically studied for liquid-phase epitaxy, considering smooth inter-phase boundaries. In the frame of the given assumptions the distribution of the components near phase boundaries is determined. The width of phase boundary is estimated at concrete values of the growth rate (39 and 15 Å/sec), experimentally established for liquid-phase epitaxy of GaAs. On the basis of the experimental results, the linear dependence of the growth rate on the temperature drop rate is checked and confirmed.

4. FORMATION OF Si NANOCRYSTALLITES BY HIGH-ENERGY ELECTRON IRRADIATION OF ION-IMPLANTED Si-SiO$_2$ STRUCTURES

The influence of high-energy electron (20 MeV) irradiation on the surface morphology of Si-SiO$_2$ structures implanted with Si$^{+}$ (15 keV) or O$^+$ (10 keV) and on the formation of nanosized Si particles in the oxides is studied by atomic-force microscopy (AFM). Bombarding the SiO$_2$ surface with 20 MeV electrons generates radiation defects, which facilitates the out-diffusion of oxygen from the SiO$_2$ network and, as a consequence, the formation of nc-Si particles. This effect is more pronounced in Si-SiO$_2$ structures implanted with O$^+$ ions.

MONOGRAPH:

PUBLICATIONS:


ONGOING RESEARCH PROJECTS:

“Structure and properties of semiconductor heterostructures with nano-sized and nanostructured dielectric and semiconductor films” Financed by the Bulgarian Academy of Sciences

INTERNATIONAL COLLABORATION:

1. “Structure and properties of new materials and thin films for nano-technologies in optoelectronics”, with the Eotvos L. University, Budapest, Hungary

2. “Multifunctional structures based on silicon prepared by physical and chemical methods for application in electronics and optoelectronics”, with the Institute of Physical Chemistry, RA, Bucharest, Romania

3. “Silicon oxide films with embedded silicon nanoinclusions for advanced opto- and nanoelectronics applicatios”, with the Institute of Semiconductor Physics, NASU, Kyiv, Ukraine

4. “Characterization of diluted magnetic semiconductor nanostructured thin films” with the National Institute for Lasers, Plasma and Radiation Physics, Bucharest, Romania

5. “Enhancement of radiation hardness of semiconductor heterostructures by cyclic annealing” with the Joint Institute for Nuclear Research, Dubna, Russia
RESEARCH ACTIVITIES:

The scope of the research activities of the Laboratory is addressed the nanoelectronics as follows:

- investigation of thin and ultra-thin dielectric, semiconductor and metal layers important for the production of large-scale integrated microelectronic structures (nanoscale) and for development of solid state sensors based on the silicon and the thin-film microelectronics (incl. high-\(k\) dielectrics for dynamic memories; gas-sensitive layers for sensor devices; mono- and polycrystal silicon, anisotropic and hard ferromagnetic layers).
- development and optimization of the technology for deposition of the layers investigated.
- development of new microelectronic structures and devices (incl. memory and sensor structures).

A strong dependence of the dominant conduction mechanism in high-\(k\) Ta\(_2\)O\(_5\) layers (5-10 nm) on the presence and on the concentration of Hf and Al as dopants is established. Hf and Al passivate the deep traps in Ta\(_2\)O\(_5\) due to oxygen vacancies and create new shallow traps. Tunneling processes through these shallow traps constitute both the mechanism of conductivity and the long-term reliability after electrical stress. Based on those results, storage capacitors for dynamic memories in nanoelectronics, with stable electrical parameters at high temperature working conditions (up to 100° C) are developed. Active dielectric is 6 nm Hf- or Al-doped Ta\(_2\)O\(_5\). By this way is shown, that the introduction of small amount of Al and Hf into the matrix of Ta\(_2\)O\(_5\) can extent the potential of pure Ta\(_2\)O\(_5\) as a high-\(k\) material. The results are essential for fabrication of memory capacitors with predefined properties and electrical behavior, at various working temperatures (20-100° C).

Charge-trapping processes in MIS capacitors based on pure and Hf-doped Ta\(_2\)O\(_5\) (∼10 nm) as a function of type of the gate (Pt, Al, W, TiN, Ru, RuO\(_2\)) and of the chemical composition of the interface region at Si are investigated. The traps responsible for the charge trapping, and their effect on the long-term reliability of the stacks are identified.

Measurements giving information on the nanomechanical properties (elastic modulus and nanohardness) of pure and Hf- and Al-doped Ta\(_2\)O\(_5\) films are realized. Both techniques Atomic Force Microscopy and Nano Indentation are used. The results for the...
nanomechanical parameters of high-k $\mathrm{Ta}_2\mathrm{O}_5$-based films are prioritized ones and they concern the implementation of ultrathin high-k dielectrics in Micro Electro Mechanical Systems (MEMS) for the needs of nanoelectronics.

The influence of oxidation time on the electrical properties of MIM structures with $\mathrm{ZrO}_2$-based, ($\mathrm{ZrAlO}$, $\mathrm{ZrSiO}$) high-k dielectrics deposited by atomic layer deposition (ALD) is investigated. It is found that incorporation in $\mathrm{ZrO}_2$ of Al and Si in small amounts substantially decreases the leakage currents without compromising permittivity and Al is more effective to do this. The oxidation time has to be carefully optimized in order to obtain favorable electrical behavior – the optimal oxidation time is found to be 5-10 s. Layers obtained by shorter oxidation times have high concentration of oxygen vacancies, hence higher leakage currents. Longer oxidation times result in less dense films. By using the optimized oxidation process, $\mathrm{ZrAlO}$ and $\mathrm{ZrSiO}$ layers with equivalent oxide thickness less than 1 nm and leakage currents satisfying the requirements for the next generation MIM-based DRAMs, have been obtained.

One-dimensional analytical model suitable for large scale cells under illumination has been developed. The model is based on two main assumptions. The first one is that in the case of wide gap semiconductors the concentration of the free dark carriers related to the non-equilibrium (generated) carriers can be neglected. This assumption simplifies the transport equations. In the second one, we accept electro-neutrality of the each $dx$ region of the $i$-layer. This assumption is supported by the fact that the concentration of the non-equilibrium carriers is much smaller then the state density independently of their energy position in the forbidden gap. The model is successfully applied for a-$\mathrm{Si}$:H, a-$\mathrm{Si}$:Ge:H based cells. This model allows us to simulate the I-V characteristics using finite number of fundamental parameters (electron and hole diffusion lengths, light absorption coefficient and its intensity). By fitting of the simulated characteristics to the experimental ones the above parameters are determined.

$\mathrm{SiO}_x$ ($x = 1.3$) films with thicknesses of 50 and 100 nm deposited on c-Si by thermal evaporation of $\mathrm{SiO}$ in vacuum were subjected to $\mathrm{N}_2$ or two-step $\mathrm{N}_2$, 90%$\mathrm{N}_2$+10%$\mathrm{O}_2$ annealing at 1000 °C for 60 min. The time of the second annealing step (oxidation) was varied in order to alter the depth to which the $\mathrm{SiO}_x$ films were intentionally oxidized. The I-V and XTEM results obtained confirm that the suggested two-step annealing leads to a formation of two-layer $\mathrm{SiO}_2$-Si nanocrystals/$\mathrm{SiO}_2$ gate dielectric, which contains Si nanocrystals. The nanocrystals are with a diameter of ~ 4-5 nm and are embedded in a stoichiometric $\mathrm{SiO}_2$ matrix. The I-V measurement showed that the current through the two-layer gate dielectric is limited by the $\mathrm{SiO}_2$ region, close to the top surface, formed during the second annealing step. MOS structures subjected to a two-step annealing show larger retention times when charged with electrons/holes in comparison with the control or annealed only in $\mathrm{N}_2$ structures. This makes them suitable for application in non-volatile memory devices with high density, high switching speed and low energy consumption. MOS structures containing silicon nanocrystals in the gate dielectric have been tested as dosimeters for ionizing radiation. Before irradiation the nanocrystals have been charged with electrons by applying a pulse to the gate electrode. $\gamma$-irradiation with doses in the range 0-100 Gy causes approximately linear variation of the flatband voltage, resulting in sensitivities of ~ 2.5 mV/Gy. At higher doses the sensitivity decreases because of decrease of the oxide electric field.
PUBLICATIONS:


ONGOING RESEARCH PROJECTS:

Physics and technology of thin and ultra thin films for application in micro- and nanoelectronics. (supported by Bulgarian Academy of Sciences).

28
Trapping phenomena and their implication on long-term reliability of nano-scale metal gate/high-k dielectric-based devices (supported by National Science Fund).

COLLABORATION:
1. Fraunhofer Inst. of Integrated Systems and Device Technology, Erlangen, Germany
3. Institute of Semiconductor Physics, Kiev, Ukraine
4. Institute of Physics, University of Skopje, Macedonia
5. University of Nish, Serbia
RESEARCH ACTIVITIES:

In 2011 the scientific and applied research of Acoustoelectronics laboratory was focused on creation of new materials, technologies and elements in accordance with the Academy’s basic strategic goal - delivery of the society based on knowledge and active partner in the European scientific area.

The scientific investigations in the laboratory are being carried out mainly in the following directions:

- Piezoelectric temperature microsensors – acoustic characteristics and metrological parameters.
- Mass sensitive quartz gas sensors on the base of BAW - preparation, investigation and application.
- Plasma polymers and composites – synthesis, structure, properties and application.
- Resonant structures using surface transverse waves (STW), Rayleigh surface acoustic waves (RSAW) and bulk acoustic waves (BAW) and their applications.

- PIEZOELECTRIC TEMPERATURE MICROSENSORS

The influence of the temperature on the motional resistance of quartz temperature sensors developed and realized in “Acoustoelectronics” laboratory is investigated. The results show that the resonators keep its working capacity with temperature up to +250°C. This fact gave the reason for measuring of the acoustic characteristics and metrological parameters of quartz temperature sensors at temperatures between 150 to 250°C in order to widen their working temperature interval of 100°C /4.2 to 520 K/.

A multi-channel generator (4 - 40 MHz) with acoustic resistance up to 120 Ohm was developed for the purpose of piezoelectric microsensors for cryogenic temperatures. The generator successfully passed the experimental test at the Acoustoelectronics laboratory. The result can be improved by development and implementation of software for management of functional modules.

- MASS – SENSITIVE QUARTZ RESONATORS

The sensitivity of silicon thin films obtained by E-beam evaporation to NO₂ was studied. The NO₂ sensitivity of the films was estimated by Quartz Crystal Microbalance (QCM)
method. The obtained results showed that the layers are amorphous and thin SiO\textsubscript{x} films exist on their surface. The layers possess high sensitivity in the interval 1000 ppm-2500 ppm NO\textsubscript{2}. The process of sorption is physical and response times are short. The investigated Si-QCM structure could be used as sensor element for NO\textsubscript{2} detection.

Thin films from different oxides (Al\textsubscript{2}O\textsubscript{3}, ZrO\textsubscript{2} magnetron sputtered and Ta\textsubscript{2}O\textsubscript{5} e-beam evaporated with different roughness parameters – 20, 200 and 400 nm were used in the research of stem cells (MSCs) adhesive potential, morphology, phenotypical characteristics in vitro tests and separation of different factors influenced on cell/biomaterial interaction such as nano topography, surface chemistry and surface free energy. The best results were obtained in the case of magnetron sputtered oxide coatings with minimum parameters of roughness, intermediate values of surface free energy and the greater part of SFE polar components and fractional polarity. The changes at molecular-genetic apparatus MSCs (IDO gene expression degree) and MSCs marker number increasing on the oxide nanostructural surface were observed. The results show the effect of surface parameters modification on the regularities of nanomaterials interaction with mesenchymal stem cells and open the perspective for a direct control of such parameters as adhesion, proliferation, differentiation of MSCs during their culturing.

- SYNTHESES AND STUDY OF PLASMA POLYMERS AND COMPOSITES

Composite films from a mixture of hexamethyldisiloxane (HMDSO) and detonation nanodiamond particles (DNDs) are synthesized. The chemical structure of the composite consists of DNDs, distributed in the polymer matrix. The effect of DNDs on the humidity and ammonia sorptive properties of the polymers obtained is studied by measuring the mass changes as a result of gas sorption. For this purpose a QCM is used. The results show that with respect to obtain sensing element for measuring humidity, ammonia or other gases it is possible to maximize the sensor sensitivity to certain gas by using an appropriate concentration of DNDs in HMDSO. Thus a high degree of sensor sensitivity together with short response time and minimum hysteresis could be achieved. In this way composite of plasma polymerized HMDSO with DNDs could to be used as a gas sensitive layer for the development of quartz resonator sensors.

After optimization deposition parameters for obtaining plasma polymers from HMDSO on film plate acoustic resonators (FPAR) using Lamb waves, analysis of the results with respect to sensor’s application was done.

- RESONANT STRUCTURES USING RAYLEIGH SURFACE ACOUSTIC WAVES (RSAW), SURFACE TRANSVERSE WAVES (STW) AND BULK ACOUSTIC WAVES (BAW) AND THEIR APPLICATIONS IN LOW-NOISE MICROWAVE OSCILATORS, COMMUNICATIONS AND SENSOR SYSTEMS

The mass loading sensitivity of the S0 mode of a Lamb wave propagating in a thin aluminum nitride (AlN) membrane on silicon (Si) has been studied theoretically and experimentally. The theoretical predictions have been confirmed experimentally with practical two-port 890 MHz film plate acoustic resonators (FPAR) operating on that mode. The resonators have been fabricated on the surface of a Si wafer coated with a thin AlN film using conventional photolithography. The AlN membrane type waveguide has been obtained by etching the Si underneath the AlN layer in a dry plasma etching process. The mass sensitivity of the FPAR devices has been tested by a controlled deposition of hexamethyldisiloxane (HMDS) on top of the FPAR structure and subsequent measurement of the resonance frequency shift and device insertion loss as a function of the HMDS thickness. The results have been compared with surface transverse wave (STW) two-port resonators, coated with HMDSO films the thickness of which has been optimized for
maximum gas sensitivity as used in a variety of gas sensing applications. It has been shown that the Lamb wave mode features up to 5 times higher mass loading sensitivity of the resonant frequency compared to its well studied STW counterpart. In addition to that, the Lamb wave mode demonstrates an insignificant loss increase with mass loading which is very important from the application oriented point of view. These results imply the great potential of the S0 Lamb wave mode for gas sensing applications.

The investigations on low-noise microwave oscillators stabilized with Lamb wave FPAR devices have continued in 2011. Phase noise data from practical FPAR based feedback loop oscillators in the 900 MHz range have been evaluated and used to calculate the flicker noise constant of the FPAR device. Its value of $2.1 \times 10^{-36} / \text{Hz}$ is lower or comparable with the best acoustic wave resonators built to date.

**PUBLICATIONS:**


5. L. Arapan, I.D. Avramov and V. Yantchev “Thin film plate acoustic resonators for integrated microwave power oscillator applications”, ELECTRONICS LETTERS 2011 Vol. 47 No. 7


8. Юрукова Л.С. Калецков К.М. Радева Е.И., Электролуминесцентные индикаторные элементы с улучшенными параметрами, Журнал Известия высших учебных заведений. Физика, Издательство ООО "Издательство научно-технической литературы" ISSN 0021-3411, Том 54 Цит. в РИНЦ 0, Номер 2 Цит. в WOSR, Страницы 306-310 Цит. в ScopusR, 2011.

Symposium and the European Frequency and Time Forum, May 1-5, San Francisco, USA

ONGOING RESEARCH PROJECTS:

1. Project financed by Bulgarian Academy of Sciences
   1.1 Mass-, gas- and thermosensitivity of sensor systems and devices using different acoustic wave modes Bulk, Lamb, Rayleigh and Transverse surface acoustic waves.

2. Projects financed by National Foundation of Scientific Research at the Ministry of Science and Education
   2.1. New nanobiocomposite materials for bone implants.

3. Projects in frames of Inter-academic and Inter-institute collaboration
   3.1 Development of new sensitive layers (coatings) based on nano-sized semi-conductive structures for analytical application using mass-sensitive piezoresonance sensors.
   3.2 Investigation of impurities in helium gases on the base of quartz crystal microbalance.
   3.3 Development of a leaky surface acoustic wave (LSAW) sensor on lithium tantalate for liquid analysis.

COLLABORATION:

2. “Development of new sensitive layers (coatings) based on nano-sized semi-conductive structures for analytical application using mass-sensitive piezoresonance sensors”- Russian Academy of Science, Russia.
3. “Development of a leaky surface acoustic wave (LSAW) sensor on lithium tantalate for liquid analysis” - Research Center Karlsruhe, Germany.
RESEARCH ACTIVITIES:

The Low temperature physics laboratory studies different problems in the field of condensed matter physics related to the phenomena of magnetism and superconductivity. The theoretical investigations of phase transitions (classical and quantum) and critical phenomena in various physical systems were carried out. The experimental work is connected with obtaining and investigation of new magnetic, superconducting and composite materials and improvement of their characteristics aiming the applications.

THEORETICAL STUDIES

Infinite sets of thermodynamic inequalities which generalize the well known inequalities of Brooks Harris, Bogoliubov (Jr.) and Jiljibre are derived. They provide upper bounds on the difference between the quadratic fluctuations of intensive observables of a N-particle system and the corresponding Bogoliubov - Duhamel inner product. The novel feature is that, under sufficiently mild conditions, the upper bounds have the same form and order of magnitude with respect to N for all the quantities derived by a finite number of commutations of an original intensive observable with the Hamiltonian. The results are illustrated on two types of exactly solvable model systems: one with bounded separable attraction used in the theory of magnetism and the other containing interaction of a boson field with matter.

MAGNETISM AND MAGNETIC MATERIALS

Magnetic and transport properties of NdBaCo$_2$O$_{5+\delta}$ system are studied in less investigated hole doped region (0.52<\(\delta\)<0.72) and in pulsed magnetic fields up to 47 T. The conductance in zero magnetic field and \(T<130\) K is described by a two-gap expression completed by the term of variable range hopping (VRH). The thermoelectric power \(S(T)\) measurements confirm magnetic phase diagram found by magnetic and electric transport investigations. VRH mode gives good approximation at zero and high magnetic field 47 T. The isothermal magneto-conductance \((G)\) of hole doped polycrystalline NdBaCo$_2$O$_{5.72}$ is well fitted by \(G(H, T)/G(0) = G_0 \exp(H/H_0)\) dependence at 55 K<\(T<138\) K (the region where FM state appears) instead of simple linear dependence found for manganites La$_{0.7}$Sr$_{0.3}$MnO$_3$. The parameter \(H_0\) is considered as the magnetic field of full spin sublattices’ reorientation.
and MR saturation. The magnetoconductance is possibly realized through the \( a \)-oriented grains due to the strong decrease of resistivity \( \Delta \rho / \rho_c \) in magnetic field along \( a \)-axis.

**SUPERCONDUCTIVITY AND SUPERCONDUCTING MATERIALS**

Investigation of intra- and inter-granular effects in overdoped polycrystalline \( R_{1-x}Ca_xBa_2Cu_3O_{y-\delta} (R=Y, \text{Eu, Gd, Er and } x=0, 0.025, 0.05, 0.10, 0.20, 0.30) \) samples was carried out by using different experimental techniques. It was established that low level overdoping leads to the improvement of intragranular critical current, flux pinning and irreversibility field of samples at 77 K making their values higher than for non substituted, fully oxygenated YBCO samples. Temperature dependence of intergranular critical current implies that it is governed by the S-I-S type joints between the grains. For highly overdoped samples the suppression of intragranular critical current and flux pinning has been observed. The intergranular critical current is characterized by S-N-S type. Indirect evidences suggest that this is a result of carriers’ phase separation supporting the idea that the quality of superconducting condensate is strongly influenced by overdoping. The field dependence of activation energy for TAFF shows that 2D pancake vortices are typical for underdoped samples, while 3D vortex system exists in overdoped ones. Vortex dynamics and irreversibility line are also influenced by the doping effect. The existence of vortex glass-vortex liquid phase transition was established by transport and third harmonic AC susceptibility measurements. The scaling behavior of E-J data in Ca substituted samples is similar to the other polycrystalline YBCO samples. Previously established morphology dependence of dynamic exponent (\( z \)) was confirmed. However, \( z \) values are smaller than the usually reported for non-substituted YBCO. Static exponent (\( \nu \)) shows a tendency for field dependence. These observations have been explained with the peculiarities of Ca substituted samples.

The pinning and transport properties of samples MoSn\(_x\)Sr\(_2\)YCu\(_2\)O\(_{8-\delta}\) (\( x=0 \) and 0.03) as a function of temperature and magnetic field have been investigated. It was established that Mo-1212 is a highly anisotropic superconductor with the formation of 2D vortices. The Sn doping increases the anisotropy and modifies the intergrain superconductivity of Mo-1212. The temperature dependences of resistivity of undoped and Sn-doped Mo-1212 were described by the relation \( \rho(T) = (\rho_0/T) \exp(-U/k_B T) \). The fit to this relation indicates the temperature range of application of the flux-creep approximation. The penetration depth \( \lambda \), the coherence length \( \xi \) and the attempt frequency \( \nu_0 \) were determined for Mo-1212. The field dependences of the parameters \( \rho_0 \) and \( U \) denote the presence of a crossover field, \( H_{cross} \). Some interpretations of the \( H_{cross} \), as well as the nonlinear electric field vs. current density characteristics were discussed.

The multifilamentary modification of coated conductors in Roebel meander shaped strands was successfully performed by employing a picosecond-infrared laser system. The measured magnetization losses of the 125 mm wide striated single strand were five times lower than that of the non-striated one. In the case of the cable sample the loss were reduced by a factor of three at high field amplitudes. The additional ac loss reduction in the Roebel cable with filamentary modification of the coated conductor strands was confirmed in case of 12 mm wide cables. Self-field measurements under current flow were successfully employed to single striated Roebel strands by moveable Hall-sensor. It was found a different behavior for currents penetrating from the edges and currents penetrating from the top and bottom surfaces. In order to investigate the critical current of a stacked Roebel cable, the influence of flux creep on the cable’s properties was analyzed. Using the material’s properties derived from measurements on a single conductor as input for our calculations, we were able to predict the critical current of the cable in two limiting situations: good current sharing and complete electrical insulation among the strands. Our calculations are in agreement with the
measured critical current of three 4 mm wide Roebel cable samples. A non-homogeneous distribution of the magnetic field in the cable cross-section causes a variation of the critical current along the length of each strand. The critical current of the cable is the lowest when the strands are completely insulated and increases with reducing the resistance between the strands.

The oxygen non-stoichiometry content, \( \delta \), was determined in GdBa\(_2\)Cu\(_3\)O\(_y\) and ErBa\(_2\)Cu\(_3\)O\(_y\) (\( y=6.5+\delta \)) by measuring the absorption of the blue colored \( \text{I}_3 \)-starch compound. The unit cell lattice parameters were determined from XRD patterns. A correlation, between the unit cell parameter, \( c \), and oxygen coefficient, \( y \), was established. The derived new relation can be used for the rapid semi-quantitative analysis of the oxygen content in the mentioned compounds.

Bulk superconducting (SC) ceramics containing Bi\(_{1.6}\)Pb\(_{0.4}\)Sr\(_2\)Ca\(_2\)Cu\(_3\)O\(_z\) and La\(_{0.6}\)Pb\(_{0.4}\)MnO\(_3\) in weight ratio 90/10 have been produced from the initial components prepared by a low-temperature Pechini method. The obtained composites were analyzed by scanning electron microscopy (SEM) with energy-dispersive X-ray spectroscopy. They contain several phases. It was established that the SC 2212 phase predominates in the composite. The phase La\(_{0.6}\)Pb\(_{0.4}\)MnO\(_3\) transforms in solid solution with preliminary composition La\(_{0.5}\)(Sr+Ca)\(_{0.5}\)Mn\(_{1-z}\)Cu\(_z\)O\(_3\), which after full replacement of the La and Mn ions leads to the appearance of phases with nominal composition Sr\(_{1-x}\)Ca\(_x\)CuO\(_y\). AC and DC magnetization measurements were used to study the SC and magnetic properties of the samples. Both samples are SC with critical temperatures 75 and 77 K, respectively. It was concluded that the SC and magnetic phases stably coexist in the composite.

**PUBLICATIONS:**


9. A. Stoyanova-Ivanova, St. Georgieva, T. Nedeltcheva, L. Dimova, B. Shivachev, "*Variation of the unit cell parameters of the REBa$_2$Cu$_3$O$_y$ (RE = Gd, Er) ceramics in function of the oxygen content*", Bulgarian Chemical Communications, V.43, № 2, 2011, pp.320-324


**TEACHING ACTIVITIES:**

Ph.D. Student K. Buchkov, supervisor Assoc. Prof. E. Nazarova

**AWARDS:**

- S. Terzieva wins The “I. Geshov” award of the Bulgarian Academy of Sciences for the prosperous young scientist in Physics;
- The scientific team leading by E. Vlakhov (E. S. Vlakhov, N. Kozlova, L. S. Lobanovskii, R. Wawryk, and K. A. Nenkov, High magnetic field study of magnetic and transport properties of hole doped cobaltite NdBaCo$_2$O$_{5+δ}$, Phys. Rev. B 84, 184440 (2011)) wined the First place in the ISSP BAS competition for the Most important ISSP BAS scientific achievement in 2011.

**ONGOING RESEARCH PROJECTS:**

I. Projects financed by Bulgarian Academy of Sciences:
1. New materials and multifunctional magnetic materials.

II. Projects financed by contracts with EU, NATO and other international sources:
1. Overdoping of 1-2-3 HTS materials and its influence on the ac losses, critical current, flux pinning, activation energy **EURATOM-FU07-CT-2007-00059**

**INTERNATIONAL COLLABORATION:**

1. Obtaining and investigation of thin film structures of magnetic oxides (manganites and cobaltites), Institute of Physics, Polish Academy of Sciences, Warshaw, Poland;
2. Synthesis and structure investigation of multifunctional materials, Center for Materials Research, Tallin Technical University, Tallin, Estonia;
3. International Laboratory for High Magnetic Fields and Low Temperatures – Wroclaw, Poland.
DIVISION LOW TEMPERATURE PHYSICS

LABORATORY

ENVIRONMENTAL PHYSICS

HEAD: Assoc. Prof. Vasil Lovchinov, PhD
Tel: 9746265; e-mail: lovcinov@issp.bas.bg

TOTAL STAF: 5
RESEARCH SCIENTIST: 4
Assoc. Prof. P. Simeonova, PhD; Assist. Prof. I. Radulov, PhD; Dimitar Petrov, PhD student; Petja Papazova, PhD student; Technician P. Zashev

RESEARCH ACTIVITIES:

In 2011 the Laboratory of Environmental Physics continued its activities in completing the tasks and goals of the project “Improvement of the life quality by the use of sustainable management of surface waters – application to the catchments of the rivers Struma and Mesta” (DO-02-352) granted by the National Science Fund. The results obtained could be summarized as follows:

• The multivariate statistical (environmetric) strategy was further improved and applied for assessment of the river water quality with introduction of original models of the risk assessment and pollution sources ranking along the flows of the rivers Struma and Mesta.
• New original integral indices for pollution and for climate impact were created. Special attention was paid for introduction of indices for assessment of risk events (floods, draughts) in the river catchments of Struma and Mesta.
• Analysis of monitoring data from River Tundja has started;
• A dataset from monitoring results from Maritsa River was completed to perform environmetric analysis.

The research scientists of the Laboratory worked also on the project “Environmental Physics” sponsored by Bulgarian Academy of Sciences. The summarized results are as follows:

• Systematic investigation of the application of environmetric strategies for modeling and interpretation of air-borne particles monitoring data;
• Statistical method for calibration of analytes model solutions;
• Classification and modelling of clinical data for patients suffering from alcohol abuse.

The studies on the magnetic and surface properties of nano-structured lantanoide monoaluminates were completed and included in the PhD thesis of Dimiter Petrov.

In 2011 the postdoc specialization of Assist. Prof. Dr. Ilia Radulov (Marie-Curie program) in Creta, Greece was finished. His activity was concentrated on studies of magnetic, transport and thermodynamic properties of high temperature superconductors. As a results of these studies by AFM observation of the magnetic properties of powder samples of CaFe$_2$As$_2$ evidences have been found for the presence of partial superconductivity in the domain walls.

• Another aspect of the postdoc specialization of Assist. Prof. Dr. Ilia Radulov is the investigation of the spin – charge interaction in high temperature superconductors and more specifically in slightly doted monocrystals of La$_2$CuO$_{4+x}$ (x<0.1). By the use of unique instrumentation and samples for the first time clear experimental evidence is obtained for launching of FE arrangement in monocrystal phase of La$_2$CuO$_{4+x}$ at temperature of nearly 4.5 K. An attempt was made to offer a theoretical background
(using the phenomenological theory of Landau type) of the effect observed. A publication
for Physical Review Letters is submitted for consideration.

- The Laboratory was presented during the International Symposium on «Dissipation and
development of the physical and mathematical knowledge on the Balkans” in Sofia,
October 17-18, 2011. A special session was dedicated to the 100 anniversary of the
superconductivity where Doc. Dr. V. Lovchinov presented a plenary lecture entitled
“Low temperatures and superconductivity”. The world tendencies in the joint
development of these two phenomena as well as their development in Bulgaria were
discussed. The presentation will be published in a special issue.
- The successful activity of Doc. Dr. V. Lovchinov for the creation and functioning of the
Centre for investigation of the physical properties of the materials, surfaces and structures
(associated with the Institute of Solid State Physics) has to be mentioned. In 2011 with
the active participation of the PhD student Krastyu Buchkov (Laboratory of low-
temperature physics) and Assist. Prof. Irina Bineva (Laboratory of photoelectric and optic
phenomena in broad zone semiconductors) a series of measurements for both local and
external users were performed using the unique apparatus PPMS and AFM.
- In 2011 the researchers from the Laboratory of Environmental Physics took part in
reviewing of 3 scientific manuscripts for international scientific journals. Additionally,
Doc. Dr. P. Simeonova was reviewer of the dissertation of Ishtiak Ahmed Najar, Faculty
of Ecology, Pondicharry University, Kashmere, India on invitation of the University
Rector Office.
- Doc. Dr. V. Lovchinov was member of scientific juries appointed for obtaining the
educational and scientific degree “Doctor” at Faculty of Chemistry, University of Sofia
and Institute of Solid State Physics.

TEACHING ACTIVITIES:
Ph.D. Student D. Petrov, supervisor Doc. Dr. V. Lovchinov;
Ph.D. Student P. Papazova, supervisor Doc. Dr. P. Simeonova.

PUBLICATIONS:
1. Stefan Tsakovski, Pavlina Simeonova, Vasil Simeonov, Sediment Pollution Assessment
2. Stefan Tsakovski, Pavlina Simeonova, Vasil Simeonov. Classification and Modeling of
   Different Fractions of Aerosol Monitoring Data, *Journal of Environmental Science and
3. D. Petrov, B. Angelov, V. Lovchinov Magnetic susceptibility and surface properties of
4. D. Petrov, B. Angelov, V. Lovchinov. Metamagnetic DyAlO₃ nanoparticles with very low
   magnetic moment, *J. of Sol-gel Science and Technology*, vol. 58 no.3 (2011), pp. 636-
   641.
5. D. Petrov, Nanocrystalline GdAlO₃: XPS, EPR and magnetic susceptibility Studies,
7. D. Simeonov, L. Spasov, P. Simeonova. Statistical Calibration of Model Solutions of
   Kanev. Statistical Interpretation of Medical Data of Patients with Alcohol Abuse. *Centr.

**ONGOING RESEARCH PROJECTS:**

2. “Environmental Physics” funded by Bulgarian Academy of Sciences.

**INTERNATIONAL COLABORATION:**

1. Universite de Liege, Belgium - L’Universite de Liege, Depart. Physique, Group SUPRA.TECS.
2. International Laboratory for High Magnetic Fields and Low Temperatures – Wroclaw, Poland.

**FUTURE RESEARCH PLANS OF THE LABORATORY INCLUDE:**

1. The work on Project DO-02-352 (Environmetric assessment of the quality of surface waters along the streams of the Struma River and Mesta River) will be continued. Monitoring data will be interpreted by the use of multivariate statistical methods (cluster analysis, principal components analysis, neuron nets).
2. Development of environmetric long-term strategy for assessment of the quality of the Tundja River and Maritsa River using data from monitoring. The results will be used in the PhD thesis of the PhD student Petia Papazova.
3. Statistical interpretation of marine organisms monitoring data (heavy metal content) from the Black Sea to identify pollution sources.
4. Participation in a scientific team (along with scientists from the Military hospital) for establishing alcohol abuse effects using statistical interpretation of medical parameters.
5. Start of the project “Structural and physical investigations of nano-structured thin layer and bulk materials based on ordered porous dielectric matrices” with the Russian Academy of Sciences.
6. Continuation of the cooperation with Universite de Liege, Belgium - L’Universite de Liege, Depart. Physique, Group SUPRA.TECS with the new project entitled "Electrical and magnetic properties of perovskite magnetic materials".
RESEARCH ACTIVITIES:

The studies on the electroconvection in nematic liquid crystals with short range smectic C order, and a dimer molecule as a structural unit were aimed at taking into account the effect of the angle of smectic tilt in the supramolecular complexes (clusters) on the relaxation processes initiated by low and high frequency electric fields. The first studies have been carried out on the growing of a smectic C liquid crystal with temperature independent tilt angle, in a liquid crystal cell, oriented by single walled carbon nanotubes (SWCNTs). It was demonstrated that the most effective alignment of the layers is achieved on SiOx/ITO treated surfaces. Well aligned and sufficiently large for experimental studies local smectic C monocrystals have been fabricated.

Using laser polarization micro-Raman spectroscopy, organic material has been studied, that was obtained through implantation of polymethylmethacrylate (PMMA) with Si ions accelerated to 50 keV at 10^{14} to 10^{17} ions/cm^2. The depolarization ratio has been measured at different wavelengths of the exciting laser light, the size of the carbon clusters produced in the ion implanted polymer has been estimated experimentally and their special orientation has been determined. Using impedance measurements, the photoelectrical response of donor-acceptor molecular systems (two-component molecular complexes), including carbonyl groups has been studied. The photo-flexoelectrical properties have been investigated of thin homeotropic layers of liquid crystal mixtures of the type guest-host, where the host is a nematic liquid crystal.

We have developed a technology for reducing the VICCEL thickness down to 20 microns, and their packing into a flexible carrier of 75 microns thickness, capable of bending with a radius of 2 mm. The optical, electrical, mechanical and thermal properties of the lasers have been characterized. This new packing approach has been demonstrated for such applications as optical sensors and optical communications. The VICCELs in combination with liquid crystals have been studied theoretically, for three configurations of the liquid crystal cell. We have predicted the possibility for choosing the orientation of the linear polarization of the generated light by varying the cell length; by electro-optical switching and control; by electro
optical tuning of the light wavelength. The electrical properties of VICCELs with two resonators have been investigated. The theoretical studies on the effect of the parameters of the optical crystal structure on the operation mode of VICCELs with a photonic crystal have been carried on. The spatial distribution of the light polarization upon focusing with a metal-dielectric multilayer has been studied theoretically. It was shown, that linear and circular polarizations are not preserved and a matrix form for the optical resolution was derived. The influence of the optical feedback on the behavior of solitons in wide aperture VICCELs was studied theoretically and the presence of bifurcation of light waves, leading to spontaneous motion with constant velocity was demonstrated.

The mechanical strains in protonated waveguide layers have been measured, obtained at various technological regimes in lithium niobate crystals from all three orientations. The contractability coefficient was calculated for a multiphase protonated lithium niobate with various thicknesses of the phase sublayers.

A review has been made of the spectroscopic methods, used for investigation of proton-exchange waveguides. A review was written on the methods for dotation of Li Niobate with ions of rare earth elements. In a book chapter have been described the applications of the transverse acousto-electrical effect and the surface photocharge effect for quality control of a number of production parameters in a wide range of technological branches, as well as the original development of methods and sensors, based on these two effects. A reference bibliography has been composed with quantitative exploration of the publications of Bulgarian authors in the field of physics for the period 1889-1960.

A new approach was demonstrated for dynamical recording of long diffraction gratings, that can also be used as phase masks for preparation of large area diffraction gratings. The recording of a diffraction grating with a period of 500 nm and length above 300 nm was experimentally demonstrated. The conditions have been investigated for the formation of a “self-organized” relief on a metal surface upon exposure by ultrafast laser pulses by stimulated excitation of a surface plasmon-polariton (SPPs) by means of a diffraction grating. The connection of femtosecond laser pulses with a surface electromagnetic wave has been systematically studied by varying the period of the grating couple in broad limits (440 - 800 nm). A method for has been developed for fabrication of diffraction grating with an exact number of lines, on the wall of a cylinder, oriented along its axis. The method was demonstrated for a grating with $15$ lines. An external resonator polarization transformator was developed, that converts effectively the polarization of a laser beam from radial into axial. The element was prepared on the basis of a resonance structure of hydrogenated amorphous silicon.

A functional method has been developed for contactless characterization of resonance chemical- and bio- sensors. Besides for testing of bio-sensors, the method can be used for characterization and testing of all kinds of optical devices or modules, working on the basis of optical resonance. Studies have been performed on microstructured optical fibers with “hanged core”, used as sensor elements for biochemical measurements. Experiments were carried out on the application of these fibers as refractometric biosensors – spectral response of the Bragg grating as function of the refraction index, as well as problems with the microcapillary filling and cleaning of the optical fibers.

Calculation have been carried out on the propagation of electrical and magnetic fields in photonic crystal fiber, consisting of a waveguide optical medium containing 6 air cylinders, placed at the edges of an uniform hexagon. The calculated results are analyzed in order to
obtain the value of the longitudinal constant for propagation of the waveguide mode of photonic crystal fiber with the highest accuracy.

The aging dynamics of interfacial processes in the anchoring of liquid crystals on polymer surfaces has been studied. A specific interface of the nematic liquid crystal 4-n-pentyl-4’-cyanobiphenyl (5CB) and a polymer surface of poly(vinyl-4 fluorocinnamate) (PVCN-F) was explored, obtaining a 10 fold reduction of the relaxation time of the easy axis. Electrooptical studies were performed on suspensions of lipid vesicles with the aim of establishing whether the induced structural anisotropy of the vesicles under the effect of external electric field can lead to optical anisotropy of the entire suspension. In a suspension of giant vesicles with a radius of 10 µm (incident light is λ=0.5 µm) as in our case, the possible very weak anisotropy of the shape or phase as a whole, is being screened by the strong scattering.

In 2011 interdisciplinary research of megalithic and quasi-megalithic objects in Bulgaria was continued. In recent years, all studies are carried out in one of the general research directions in BAS, namely "Cultural heritage and national identity." This activity is also part of the mission of the ISSP, as far as proposing new approaches in interdisciplinary contact areas between physics and archeology, as well as transferring results to the cultural development of Bulgaria. A systematic search was conducted, strict localization and archaeo-astronomical interpretation of these monuments. Objectives include: a) cataloging and monitoring; b) analysis of the global picture of the Balkan megalithic region in comparison to Western European and Caucasian areas; c) monitoring of structural development from the viewpoint of building static; d) establishing a relationship with rock sanctuaries; e) selection of suitable sites for possible dating by photo-luminescence in future; f) establishing suitable sites for laser scanning for extracting and storing of complete and detailed three-dimensional information about them.

We have studied the effect of the rotational structure on the vibrational relaxation and electronic radiationless desactivation in molecules. Calculations have been performed on the characteristics of phosphorescence from the first excited triplet state of the thiophosgene molecule. Our variational method has been elaborated, designed for exploring the vibrational structure and IVR of a polyatomic molecule at very high levels of vibrational excitation, using the exact expression for the molecular kinetic energy. Theoretical investigations have been carried out on the vibrational structure and IVR characteristics of the formaldehyde molecule, up to very high vibrational excitation energies (~17000 cm⁻¹).

We have carried out studies aimed at clarifying the effect of hydrogen on the mechanical properties of hydrated amorphous silicon (a-Si:H). It is well known that hydrogen is an important factor for improving the electronic properties of a-Si:H. In a comparative study of the mechanical properties of hydrated and not hydrated amorphous silicon it has been established, that the presence of hydrogen in the silicon matrix does not change the elasticity module, but it enhances the material hardness. The nanohardness of a-Si:H was in the range 12.2–12.7 GPa, comparable to that of crystalline silicon. We have shown, that by treatment of amorphous silicon in hydrogen plasma, the material hardness in the surfacial area can be significantly enhanced. This result is of interest for purposes of applications, since it presents a technological method for restoring the mechanical hardness of silicon surfaces, if it has been reduced as a result of some kind of treatment (e.g. ion implantation).
Simulations have been carried out on the transmission of neutrons through materials like Be, Fe and W, that are eventual candidates for building material for the walls of the Thermonuclear reactor ITER, France.

Work has been done on the measurement of induced optical birefringence and scattering in a suspension, containing electrodeformable vesicles. Three layer structures ZnS/Ag/ZnS have been formed on diffraction gratings. A good polarization dependent transmission has been achieved through metal layer.

Various schemes of a high dispersion spectrograph of echelle type have been explored with the aim of building an echelle spectrograph designed for the 2-meter telescope in Rozhen observatory.

PUBLICATIONS

PUBLISHED PAPERS


40. Л. Цонев, Д. Колев, Я. Динчев, „Долмените в Сакар планина”, доклад в пълен текст (15 стр) в Материалите от Конференцията „Човекът и Вселената”, организирана от Съюза на учените в България, клон Смолян, 6-8.10.2011, Смолян.
41. Л. Цонев, Д. Колев, Я. Динчев „Долмените в Сакар”, сп. Обекти, брой 10 (2011).

MONOGRAPHS


INTERNATIONAL COLLABORATION:

1. Free University of Brussels, Departmet of Photonics, Belgium
2. Forschungszentrum Rossendorf, Institut fuer Ionenstralphysik und Materialforschung, Germany
3. Pluridisciplinary Laboratory Joliot Curie at the Ecole Normale Supérieure, Lyon (CNRS UMR 5161) France, The Institute Albert Bonniot, UJF & INSERM U309, and CEA, Grenoble, France and funded by Ministry of Education and Science BG (K 1402/ 2004), and 6th FP ECC MCRTN “CLUSTOXDNA”
4. Ecole Normale Supérieure de Lyon, Laboratoire Pluridisciplinaire Joliot-Curie, (CNRS USR 3010) France; UJF, Institute Albert Bonniot, INSERM U309 and CEA-CENG, Grenoble, France
5. Research Institute of Solid State and Optics, Budapest, HAS, Hungary
6. Institute of Ion Beam Physics and Materials Research, AIM – Center, POB 510119 01314 Dresden Germany
RESEARCH ACTIVITIES:

Studies of the optical absorption, thermo-optical and dielectric properties of photosensitive liquid crystal mixtures of the type quest –host were performed. In all three mixtures a strong response on UV light was detected due to isomerization of the photoactive additives. The temperature shift of clarification due to changes in the cis isomer population and in the length of azo-molecules under UV lightening was analyzed. A dependency of the dielectric constant on the nature of photoactive additive was shown. For the first time a reduction of the bending elastic constant at photoisomerization is observed. This result was explained via formation of reversed cis isomers.

The electro-optical properties of monolayer PDLC with gradient in liquid crystal droplets size were studied in order to use such a devise as a light modulator. Applying weak low frequency voltages a high contrast of the modulated light was achieved due to the significant phase shift in the passing coherent light. The spatial profile of the phase shift along the PDLC layer can be applicable in devises for modulation and active control of laser light.

The study of the influence of single-walled carbon nanotubes on nematic mixture E7, activated with DC voltage, which results in gradient flexoelectric and surface induced domains formation in cell with very thin (hundreds of nanometers) lipid layer was continued. The observed differences in the electro optic behavior were a result of the reduction of the nonhomogeneity of the electric field in presence of the carbon nanotubes as well as their concentration in the vicinity of the electrodes.

The bending elastic modulus of vesicles with long tubular protrusions, connected to their membranes was obtained via thermally induced shape fluctuation method as a weighted mean over 10 vesicles. The obtained value was compared to the bending elastic constant of quasishperical vesicle with the same lipid content without tubular protrusion, connected to their membrane. It was shown that the obtained values are identical.

The effect of the pH reduction of the water phase (4 < pH < 5,5) on the bending elasticity of pure phosphatidylcholine membranes was studied experimentally. It was shown that at higher acidity of the aqueous solution the value of the bending elastic modulus decreased. A significant influence of the bactericidal agent imidazole on the mechanical properties of lipid membranes was proven experimentally. The addition of millimolar concentration of imidazole in the aqueous solution led to considerable (of about 40%) increase of the bending elastic modulus of lipid membranes.
A computer program, performing the analysis of the time correlation of the shape of quasispherical lipid vesicle was developed. Preliminary data for the value of the friction coefficient between the monolayers, comprising the lipid bilayer was obtained using the new software.

A review on dynamics of lipid vesicles was prepared at the invitation of the prestigious serious Advances in Planar Lipid Bilayers and Liposomes, ELSEVIER. The opportunities that the dynamical study of membrane fluctuations offers as an experimental method for the study of material properties of lipid membrane were presented and discussed. An example was shown in details to illustrate how by means of analysis of thermally induced shape fluctuations of quasishperical lipid vesicle important material constants of the lipid bilayer (bending elastic modules of free and blocked exchange of molecules between the monolayers, comprising the lipid bilayer and friction coefficient between these monolayers) can be obtained. The second part of the review was focused on dynamics of free lipid vesicles in linear hydrodynamic flows. A special attention was given to the dependency of the rheological properties of vesicle suspension on the individual dynamics of vesicles in the flow.

PUBLICATIONS

Optical absorption, thermo-optical and dielectric studies have been performed on three guest–host nematic mixtures featuring photo-sensitized flexoelectric polarization. As host material the liquid crystal 4-butylcyclohexane carboxylic acid 4-pentyloxy-phenyl ester, a room temperature nematic with a negative dielectric anisotropy was taken. The different azo-dye compounds, also exhibiting liquid crystallinity were employed as the low-concentration guest component in the mixtures. In each case illumination of the sample with actinic (UV) light leads to strong photoisomerization driven effects. We have analyzed correlations among the shift of the isotropic–nematic phase transition temperature, population of the cis isomers, and the change in the length of the azo-dyes upon UV illumination. The UV induced changes demonstrate strong dependency in the dielectric constant values on the nature of the photoactive dopant. It was described the first observation of the lowering of the bend elastic constant upon photoisomerization, a feature ascribed to the formation of the bent-shaped cis isomers. The relationship between the photo-driven shift of the clearing temperature and the molecular conformation (cis and trans forms) may be helpful in the design of functional molecular systems and soft materials for molecular electronics and optoelectronics which make use of photosensitivity of azo-dye doped nematics.

A linear-gradient single-layered microscale PDLC film containing large nematic droplets is examined for tunable low-voltage modulation of a passed laser beam with a reduced light scattering. By such planar films with bipolar configuration of the droplets one can achieve a high-contrast amplitude modulation as well as an efficient electrically commanded phase modulation, both efficiently controllable through LC droplet-size gradient. These properties may be useful for tunable PDLC-based light filters and modulators, configurable phase masks, adaptive-optic and other practical devices and sensors, as well as systems of optical data processing, operating at video rates (30–80 Hz).

PUBLICATIONS:

1. New Photoactive Guest-Host Nematics Showing Photoflexoelectricity
2. Observation of Flexoelectricity in a Mixture of Carbon Single Walled Nanotubes with a Nematic Liquid Crystal

3. Gradient polymer-disposed liquid crystal single layer of large nematic droplets for modulation of laser light
Georgi B. Hadjichristov, Yordan G. Marinov, and Alexander G. Petrov,


5. Behaviour of photosensitive soft materials: Thermo-optical, dielectric and elastic constant studies on azo-dye doped nematic liquid crystals
S. Sridevi, Uma S. Hiremath, C.V. Yelamaggad, S. Krishna Prasad, Y.G. Marinov, G.B. Hadjichristov, A.G. Petrov
Materials Chemistry and Physics 130, 1329–1335 (2011), ISSN: 0254-0584

6. Study of the water systems quality by the energy spectra method
S. Todorov, L. Todorova

ONGOING RESEARCH PROJECTS:

Projects, additionally financed by contracts with Ministry of Education and Science:
1. “Flexoelectric properties of liquid crystals”, Indo-Bulgarian intergovernmental program, contract Bin-5/07, NSF.

Projects funded under the Academy’s bilateral agreements:
2. Nanostructured and bioactive liquid crystals, CNR Universita della Calabria, Italy

TEACHING ACTIVITIES:

Academician Alexander G. Petrov - lecture courses on Bioelectronics for Chemistry Dept. of St.Kliment Ohridski University of Sofia.
Assoc. Prof. Y. Marinov - one month student training: on research of lyototropic liquid crystalline nanostructures. One student from Biomedical engineering Department, Johns Hopkins University, Baltimore, USA.
RESEARCH ACTIVITIES:
Atomic structure and properties

The first experimental results have been obtained by new laboratory equipment, based on Laser Induced Break Down Spectroscopy method. The equipment consists of Q switched Nd:YAG laser, optical elements and their mountings and registration by multichannel spectrometer and corresponding electronic components. A number of bronze artifacts from “Baley” settlement were investigated. The artifacts were separated on several groups, depends on the different quantities of Pb and Sn, which are important elements for determination of technology (Fig. 1). “White” ceramic artifacts from Preslav were investigated. The artifacts were divided on two main groups, which have different quantities of Ca and Ti. The Li, K, Na, Rb elements from IA group were detected.

Figure 1. Bronze sample from late bronze age (2000BC) from “Balay” settlement- Bulgaria and its LIBS spectrum.
Quantum optics

The experiments on the new designed experimental set-up – magneto-optical trap were started. The base characteristics of the magneto-optical trap were determined. These are: number of the Rb atoms in the trap; relative size of the cooled atoms cloud; temperature of the atoms in the trap and time of trap filling. Saturation spectroscopy of “cooling” and “repump” lasers was done for stabilization on the isotope structure of $^{87}$Rb. Systems for frequency stabilization of the lasers as well as for turn on/off were designed.

A technique for creation of arbitrary flat profile of excitation pulses was proposed. The method is based on composite pulses, which are formed by applying the sequences of pulses, having determined phases. In this way, the excitation profile can be influenced and the analog of $\pi$ – pulses with flat profile could be created. If the composite phases are chosen in an appropriate way, the nonadiabatic losses can be canceled to the high degree.

The method for creation of high entangled states of atoms in an optical trap was proposed. The technique is similar to the method of laser cooling.

Plasma physics

Collision Electron Spectroscopy was proposed for determination of partial concentration of different components in the gas mixture. The base of the method is detection and treatment of the electron spectra. The electron spectra arise due to the Penning ionization of gas mixtures by He metastable atoms. If the concentration of electrons at a given energy is determined the concentration of mixed atoms, taking part in the Penning process could be obtained. In CES the electrons diffuse, with out collisions in the equipotential space and the characteristic for Penning ionization maxima will appeared on the electron distribution function. The method was verified in the mixture of He and Ar, Kr, N$_2$ and air (Fig. 2). The detector for this method was designed. These investigations lead to the conclusion that this detector could be used for monitoring of contaminations in different conditions.

The profile of the He I 492.2 spectral line was investigated in the space of the hollow cathode discharge. The observed deviation in the spectral line maximum and changing in the Lorenz spectral line halfwide depend on gas pressure and on the place in the hollow cathode discharge, from where the spectral line is emitted. This effect can be explained by penetration of the electric field in the negative glow of the discharge. Using the profile of the H$\beta$ spectral line, the distribution of intensity of electric field in Grim lamp was determined. The electric field distribution was obtained employing improved polarization – spectroscopy technique from the Stark widening of the Hydrogen spectral line. The obtained data allow creating theoretical model for spectral line profile forming in the spectral lamp conditions, as well as for determination of the dark cathode space parameters.

Deconvolution of experimental dynamic opto-galvanic signals in the glow plasma of hollow cathode discharge of Ar atomic transitions in the spectral range 451 nm – 462 nm was done. The obtained signals were fitted with theoretical determined function and the decay lifetimes of the states, taking part in the processes, which were responsible for the signal creation at different discharge currents.

The dynamic opto-galvanic signals of Fe positive ions were compared with nonresonances optogalvanic signals in Ar/Fe and Kr/Fe discharges in hollow cathode discharge. The differences of rising time and amplitude of these two types of signals were observed, which depends on discharge current and power of the illumination laser beam.
7 Torr He + 0.1 Torr air
I_{\text{disch}} = 1.5 mA
4 mm anode-cathode gap

Second derivative, au

Sensor voltage, V

He

\( N_2 \)

\( O \)

Figure 2. Collisional Electron Spectrum of mixture of He and air.

PUBLICATIONS


INTERNATIONAL COLLABORATION
1. State Key Laboratory of Quantum Optics and Quantum Optics Devices, College of Physics and Electronics Engineering, Shanxi University contract № DO02-1/2008 with NSF
2. Institute of Physics Beograd, Serbia
3. Institute of Physics Yagelonia University Krakow Poland

EDUCATION
One student for bachelor degree (supervisor Dr. E. Dimova) and one for master degree (supervisor Dr. G. Malcheva) prepared their diploma work in the Laboratory.
One student for PhD was finished thesis – supervisor Prof. D. Zhechev.

ONGOING PROJECTS
1. Laser Diagnostics in archaeology DO 02-274/2008 with NSF
2. Physics of atoms, molecules and plasma – project in the framework of Bulgarian Academy of Sciences.
3. EURATOM – “Transport of W atoms and ions near the wall”
4. New techniques for quantum control and their application – NSF
5. Quantum computers and quantum information - NSF

FUTURE INVESTIGATIONS
1. Investigations of artefact from ceramic and metal, employing single and double pulse excitation. The LIBS method will be also applied to industry samples.
2. The manipulation of ensembles of cooled atoms will be carried out by external electromagnetic fields. Theoretical investigation will clarify the manipulation of quantum ensembles by composite pulses, having arbitrary pulse shape.
3. The Collision Electron Spectroscopy will be applied for investigation of plasma parameters and detection of admixture, including from solid samples. The computer compatible system for these analyses will be design.
4. Dynamic optogalvanic signals will be employed for plasma diagnostics.
RESEARCH ACTIVITIES:

RESEARCH AND DEVELOPMENT of new laser sources; optimization of the excitation, laser efficiency and beam quality; processes in the gas discharge plasma:

- In order to increase the output laser parameters for application in laser surgery, a new laser tube design of He-Ne-SrBr$_2$ laser with considerably enhanced active volume is developed with in two versions: without (T1) and with (T2) incompact fill of ZrO$_2$ insulation in the discharge free zone.

- A 2D model (r, z) to determine numerically the gas temperature distribution in the T1 nanosecond pulsed longitudinal discharge at different binary He-Ne mixture is developed. The radial gas temperature distribution in T2 nanosecond pulsed longitudinal He discharge is analytically determined. By measurement of the relative time-resolved intensities of some He and Ne spectral lines the time-resolved electron temperature is determined in the discharge afterglow for different He, Ne и He-Ne mixtures.

- A kinetic Monte-Carlo model is developed describing the electron behaviour in a hollow cathode discharge (HCD) by following closely the electrons while they travell and collide in the discharge.in terms of kinetic quantities like electron energy distribution function, mean electron energy. Results of the electron energy distribution function, the mean electron energy and the distribution of the ionization events in the discharge volume under typical discharge conditions, are obtained. Analysis of the output data is done with special attention to the influence of the so-called pendulum electrons. The Monte-Carlo simulations of all the electrons in HCD show that there is a high concentration of highly energetic electrons in the whole discharge volume; the concentration is highest in the cathode fall region; showing that the inelastic processes - excitation and ionization are very probable.

- The results from the kinetic model demonstrate that due to the high concentration of energetic electrons in the whole discharge volume, the HCD is very appropriate medium for excitation and ionization of laser ablated material for elemental analysis. As the inelastic collisions have a maximum at the axis, the probability of ionization and excitation of the ablated atoms is higher at the axis, hence, the axis of the HCD is the most suitable place for the registration of the light signal, used for the spectroscopic determination of the elemental
composition. Based on the results of modeling, a discharge tube for combination of laser ablation and emission analysis in a hollow cathode discharge was designed.

LASER APPLICATIONS:

- A master oscillator-power amplifier (MOPA) system, based on the atomic CuBr vapour laser with divergence close to the diffraction limit (100 µrad), is used for high-precision micromachining of nickel and tool steel samples in order to improve their mechanical characteristics for application in automobile industry. Laser micromachining consists in drilling of microholes in highly polished square plates with 10-mm size of the corresponding material. New software is developed to control the MOPA system and the XY table, on which the samples are placed, for drilling of the microholes by special patterning, i.e. in the apex of equilateral triangle and microhole depth is equal to the hole radius. The microhole diameter and the distance between their centres (the side of the equilateral triangles) are varied for each sample. A minimal diameter of the hole 4-6 µm and heat affected zone of 0.3 µm are achieved.

- The nonlinear properties and the refraction coefficients of several synthesized multicomponent glasses were measured. Quasi-oscillation of second harmonics is observed as a result of defects in the glass causing changes in the matrix symmetry.

- Laboratory set-ups for laser cleaning, based on nanosecond Nd:YAG and CuBr lasers, were built. Optical systems for guiding the laser beam and laser parameters control were designed. The cleaning parameters for different stone, marble, metal and leather samples were determined. Preliminary tests of laser cleaning of real marble and metal archaeological artifacts were done.

PUBLICATIONS:

Journal articles:


Conference reports:

1. N. K. Vuchkov, K. A. Temelkov, Lasers Oscillating at deep Ultraviolet Cu\(^+\) and middle infrared Sr lines, International Conference Atomic and Molecular Pulsed Lasers, Tomsk Russia, September 12-16, 2011.


15. G. Yankov, H. Yoneda, I. Stefanov, B. L. Shivachev, T. Petrov, ALT’11 Advanced laser technologies, 03-08 September 2011, Golden Sands, Bulgaria, Nonlinear refractive index measurement of new multicomponent glassy matrix possessing variable nonlinear susceptibility by using z-scan method.

PATENTS: 5

ONGOING RESEARCH PROJECTS:
- Metal vapour lasers: processes in the gas discharge plasma and interaction between laser emission and materials (funded by the budget subsidy of BAS).
- Novel multi-component glass-like telluride matrixes having variable nonlinear optical properties (funded by NSF DO 02-305/2008)
- Laser methods for diagnostics in archaeology (funded by NSF DO 02-274/2008)
- Standardization of laser techniques for investigation and restoration of cultural heritage (Bulgarian-Romanian bilateral agreement: funded by NSF HTC 02-21/2010)
- Plasma technologies and their applications (under the Academy’s bilateral agreements – IFFM, Gdansk, PAN, Poland)
APPLIED RESEARCH UNIT

MOLECULAR BEAM EPITAXY

HEAD: Assoc.Prof. Gencho M. Minchev, Ph.D.
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TOTAL STAFF: 3
RESEARCH SCIENTISTS: 2
Assist. Prof. T. Mincheva, Ph.D.

APPLIED RESEARCH RESULTS:

Patent pending method and instrument for measuring, with ultimate precision, the ratios of frequencies for a number of equal periodic processes have been developed. The method is applicable for a broad range of technical or fundamental measuring tasks exploiting periodic processes or frequency sensors – i.e. for medical diagnostics, field bio-control, precise instrumentation, (nano)technological control, etc. Its resolution is limited only by the unavoidable natural inherent phase noise of the used periodic processes or frequency sensors, so in this narrow sense no other solution could achieve better results. The advantages are clear: precision always closely to the natural limits; principal elimination of all internal sources of errors, imperfections and drifts; universal and “final” solution.

ONGOING RESEARCH PROJECTS:

Budget Project: “Identifying, registration and analysis of three-dimensional structure of biomacromolecules and cellular organelles based on bonding to sensors of a novel measuring equipment by conformal reaction”.
RESEARCH ACTIVITIES:

Documentary research in the Museum fund of Prof. E. Leyarovski presents history of the Laboratory on low temperature physics at the Bulgarian Academy of Sciences. We examine organization history, equipments, biography of some physicists and scientific results in the area of low temperature and superconductivity in Bulgaria. Three stages in the history of superconductivity in Bulgaria are determined. The new scientific results are due of integration. The local integration has between physicists, chemists and engineers in the Laboratory. National integration has between Sofia University and Bulgarian Academy of Sciences in the United Centre of Physics. The Laboratory for High Magnetic Field and Low Temperatures in Wroclaw provides international integration [1].

The reportage for Symposium “Dissemination and development of physics and mathematics on the Balkans” examines organization, thematic variations of the reports and the significant interest of the participants to this scientific event [2].

Memoirs of the Union of the Physicists in Bulgaria carry on tradition, started since 1973, in electronic version. The names and the photographs of Presidents are collected [3].

Reports of the National seminar “From Rutherford to collider”, held in Yambol (24-25 March 2011) are shown in 11 short documentary films. The history of university physics in Bulgaria presents professors of the Sofia University who laid the foundation and obtained important scientific results in theoretical physics during the first half of 20th century [4-5].

PUBLICATIONS:

1 G. Kamisheva, Historical remarks for the Superconductivity in Bulgaria, Dissemination and Development of Physics and Mathematics on the Balkans, 2011 (in print)
2 Г. Камишева, Разпространение и развитие на физико-математическите знания на Балканите, Светът на физиката, 2011 (in print)
4 G. Kamisheva, Roots of the Theoretical Physics in Bulgaria, Dissemination and Development of Physics and Mathematics on the Balkans, 2011 (in print)
5 Г. Камишева, Корените на теоретичната физика в България, От Ръдърфорд до колайдера, Сборник с резюмета, Национален семинар, Ямбол, 2011, (НАОП, Ямбол, 2011) 13 – 14