БЪЛГАРСКА АКАДЕМИЯ НА НАУКИТЕ ИНСТИТУТ ПО ЕЛЕКТРОНИКА "АКАДЕМИК ЕМИЛ ДЖАКОВ"

BULGARIAN ACADEMY OF SCIENCES INSTITUTE OF ELECTRONICS "ACADEMICIAN EMIL DJAKOV"

EMIL DJAKOV INSTITUTE OF ELECTRONICS

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ABOUT THE ACADEMICIAN EMIL DJAKOV INSTITUTE OF ELECTRONICS

The Institute of Electronics at the Bulgarian Academy of Sciences was established in 1963 as a non-profit state organization conducting research, education and dissemination of scientific knowledge in the fields of Physical Electronics, Photonics and Quantum Electronics and Radio Sciences. Soon, the Institute of Electronics evolved as a leading scientific institution in these areas of applied physics and engineering within the Bulgarian Academy of Sciences and in Bulgaria.

Throughout the several decades of its history, the activities of the Institute were expanded toward fast developing fields of applied physics and engineering, such as high technology material fabrication, treatment and analysis, nanosciences and nanotechnologies, nanoelectronics, photonics, optoelectronics, quantum optics, environmental monitoring, biomedical photonics and applications.

Key research areas:

- The investigations in physical electronics are focused on the generation and control of electron and ion beams and their interaction with matter. Novel techniques, theoretical modeling, experimental and industrial equipment are developed for surface modification, thin film deposition and characterization, welding and melting of metals by intense electron beams in vacuum. The physical basis is studied of technologies for fabrication of nano-dimensional structures using electron and ion beams. Computer simulation and experimental investigations are carried out on electron and ion lithography of submicron and nanoelectronic structures. The possibilities are explored of creating nanomaterials and nanoelectronic elements utilizing superconducting carbon and polymer films and experimental devices on that basis. Another area of research concerns fundamental properties of gases and plasma of rare gases and metal vapors; restoring electron-molecule cross-sections; modeling of binary interactions in molecular gases for industry, ecology and spectroscopy needs. Arc plasmas and arc plasma torches are studied in view of diagnostics and applications, such as plasma-assisted formation of thin films and coatings, and realization of plasma-chemical processes. Langmuir probe measurements are employed for diagnostics of chemically active plasma discharges.
- The research in photonics and quantum electronics includes: experimental and theoretical studies of the interaction of pulsed and ultrashort-pulsed laser radiation with matter; new technologies based on near-field optics, plasmonics and nanostructuring; laser deposition and processing of active and passive optical and magnetic films; electromagnetically induced transparency and absorption in alkali atoms with metrological applications; investigations and development of complex laser systems for modification and analysis of semiconducting and HTSC materials; theoretical and experimental studies of nonlinear optical phenomena; bio-medical photonics.
- The research in radio sciences is concentrated on studying the interaction of optical and microwave electromagnetic radiation with the atmosphere and Earth surface, namely, laser radar remote sounding and monitoring of the atmosphere, microwave radiometric sensing of the soil moisture; detection, amplification and signal processing techniques for extraction and interpretation of information; design of microwave devices for radar and communication system applications; nonlinear processes in optical communication media.

Scientists from the Institute are actively involved as experts in the work of a number of governmental and international organizations, such as the National Scientific Fund, scientific boards at other institutes within the Bulgarian Academy of Sciences, academic boards of universities, editorial boards of Bulgarian and international scientific journals, expert boards of the European Commission, program committees of national and international scientific events.

Scientists from the Institute are delivering 35 academic courses in ten universities in Bulgaria and have been invited to lecture at universities in the European Union, Japan, etc. At present, seven doctoral students are preparing their theses in the Institute.

The Academician Emil Djakov Institute of Electronics was where the first Bulgarian laser, lidar, plasma torch, ultrahigh vacuum pump, micro-channel electron-optical converter, parametric microwave amplifier, Josephson junctions and SQUID, portable microwave moisture meter, magnetometer, installations for electron lithography, electron beam melting, refining, and welding were built, followed by the development of several advanced e-beam technologies, novel types of optical gas sensors, pioneering achievements in nanostructuring and nanoparticle formation, laser and plasma high technologies.

The Academician Emil Djakov Institute of Electronics aims to sustain and advance previous pioneering work by promoting the theory, basic science and technology of photonics, optoelectronics, environmental monitoring, laser biomedical research and applications. This involves searching for new materials, new techniques, new devices and new applications.

STRATEGIC PLAN AND PRIORITIES FOR 2009 - 2013

The development is envisaged of research subjects and short- and long-term plans, including the prospects for strengthening the interdisciplinary co-operations within the Academy, at national level and internationally (in Europe and worldwide).

The physical and engineering sciences are key driving forces for research and innovation, providing fundamental insight and creating new applications. The Institute of Electronics’ strategic plan for scientific research is based on the results and achievements obtained by the most competitive researchers and laboratories. It coincides nowadays with several emerging fields. The research activity of the Institute has the tendency of becoming more complex and interdisciplinary. The following priority fields will be basic for the next five years:

- Photonics: femtosecond photonics; plasmonics; bio-medical photonics; optoelectronics; new optical sensors; and coherent laser spectroscopy. These research will correlate with the study of new advanced materials and structures, novel nanotechnologies and optical communications. They cut across many research activities, including applied physics, materials science, and nanoelectronics.
- Nanoelectronics and new materials: nanostructuring technology; fabrication and characterization of nano-dimension films, quantum wires and quantum dots; applications of the new generation of field-effect nano transistors; electron spin transport and modification of magnetic walls, as well as interaction of magnetic and superconducting thin film structures. Based on the experience and the results obtained, the efforts will also be focused on creating advanced materials for new generation of photovoltaics cells and displays.
- Optical and radio-wave technologies: lidar monitoring and diagnostics of the atmosphere and thermonuclear plasma; radio-wave sounding of land and sea; optical sounding of turbid media; imaging and characterization of small objects.

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**Abbreviations:*
IE BAS – Institute of Electronics of the Bulgarian Academy of Sciences
INRNE BAS – Institute for Nuclear Research and Nuclear Energy of the Bulgarian Academy of Sciences
TU Sofia – Technical University of Sofia
ISSP BAS – Institute of Solid State Physics of the Bulgarian Academy of Sciences

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RESEARCH SCIENTISTS: **4**
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M. Damyanova; E. Vasileva; P. Ivanova; K. Raykov.

RESEARCH ACTIVITIES

1. Diagnostics of edge plasma in tokamaks

Among the contact methods of plasma diagnostics, the electric probes are the most reliable diagnostic tools allowing one to measure the edge plasma parameters with a sufficiently high temporal and spatial resolution. In non-magnetized, low density plasmas the Langmuir probes (LP) allow local measurements of the plasma potential, the charged particles density and the electron energy distribution function (EEDF). In magnetized plasma, however, the interpretation of the electron part of the current-voltage (I–V) characteristics above the floating potential is difficult since it is distorted by the influence of the magnetic field. In order to solve this problem, an advanced novel method was developed and applied to Langmuir probe investigations carried out in the new COMPASS tokamak at the Institute of Plasma Physics of the Academy of Sciences of the Czech Republic (IPP-ASCR).

After installing and testing the Bulgarian-made electronics, a series of experiments on the COMPASS tokamak were performed to measure the Langmuir probe's I–V characteristics during shots with He and H_2. Results from a vertical reciprocating probe were obtained as well. The electron branch of the Langmuir probe I-V characteristic was used to retrieve the plasma potential and the electron energy distribution function using the first-derivative probe method. The comparison with both experimental and model first derivatives yields the value of the plasma potential $U_{pl} = 17$ V (shot 2473). Having this value, the EEDF was evaluated from the first derivative of the I–V characteristic. It was found that the EEDF is Maxwellian with a temperature $T = 6$ eV. The electron density was evaluated at $n = 5.7\ 10^{18}$ m^{-3}. The results obtained were compared with the data from the first Thompson scattering experiments and an acceptable agreement was found.

Similar results were obtained with divertor probes during the same shots. Experiments were carried out also with H_2 using both the reciprocating and the divertor probes.

The work on the above-mentioned topics is being pursued as Task 2.2.1 "Edge Plasma Diagnostics" of the Association EURATOM-INRNE in collaboration with St. Kliment Ohridski University of Sofia and IPP-ASCR.

Currently, Ms P. Ivanova is working on the completion of her PhD thesis devoted to probe diagnostics of plasma in tokamaks.

2. Modeling, simulation and computer-aided design (CAD) of high-power gyrotrons for fusion research

Modeling, simulation and computer-aided design (CAD) based on numerical experiments are essential tools for development, optimization and study of high-power gyrotrons used for electron cyclotron heating (ECRH) and electron cyclotron current drive (ECCD) of magnetically confined fusion plasma in various thermo-nuclear reactors (e.g. tokamaks, stelarators, most notably ITER and DEMO) as well as for plasma start-up, stabilization and diagnostics. The research on this topic is being pursued as Task 2.1.2 of the Association EURATOM-INRNE by a Bulgarian team from IE-BAS and from the Faculty of Physics of Sofia University (FP-SU) in a collaboration with the Institute for Pulsed Power and Microwave Technology at KIT (IHM-KIT), Karlsruhe, Germany, and Centre de Recherches en Physique des Plasmas École Polytechnique Fédérale de Lausanne (CRPP-EPFL), Switzerland.

The main activities of the work on Task 2.1.2 include: (i) theoretical investigations focused on the formulation of adequate, self-consistent and informative physical models; (ii) maintenance, upgrade and benchmarking of the available computer codes (most notably DAPHNE, ESRAY, and CAVITY) and the underlying numerical libraries, compilers, integrated development environments (IDE) etc.; (iii) development of novel software tools for simulation of the electron-optical system (EOS) of the tube (GYREOSS package) and the electro-dynamical system (resonant cavity) using efficient numerical methods and algorithms, advanced computing environments and programming techniques as well as (iv) conducting numerical experiments for analysis, computer aided design (CAD) and optimization of megawatt class gyrotrons.

Important components of the GYREOSS package were modified following the latest changes and improvements in the formulation of the boundary value problem based on mixed finite elements. Numerical experiments with the first version of the 3D field solver implemented as a FreeFEM++ and FreeFEM++cs script were carried out in order to study both the accuracy and the efficiency for different combinations of finite elements, linear solvers and methods for mesh optimization. The results of the numerical experiments point to some problems but, at the same time, suggest possibilities for improving the accuracy and increasing the speed of the calculations. A preparation for parallelization of the code is in progress now and will continue during 2012.

The codes outlined above were used in a series of numerical experiments carried out to study the designs of high-power gyrotrons that are under consideration and/or development at present. The simulations conducted allow deeper physical insight into the operation of high-performance gyrotrons of megawatt class and are benchmarks that demonstrate the improved capabilities and functionality of the upgraded codes. Moreover, these results suggest some further experiments for more detailed study of the correlation between the beam-quality parameters and efficiency, on one hand, and the particular design (configuration of the electrodes, tailoring of the magnetic field etc.), on the other hand. It is expected that the novel and upgraded versions of the simulation packages will contribute to the development of the next generation of high-power gyrotrons for fusion with improved performance.

3. Development, investigation and application of high-frequency gyrotrons

In recent years, the gyrotrons have demonstrated remarkable potential for bridging the so-called THz-gap of the electromagnetic spectrum providing high-power coherent radiation in the terahertz, sub-terahertz and millimeter wavelength ranges. The progress in the development of high-frequency gyrotron oscillators opens up possibilities for many novel and promising fundamental and technological applications. One of the leaders worldwide in the field of development, investigation and application of such gyrotrons is the Research Center for Development of the Far-Infrared Region (FIR FU Center) at the University of Fukui, Japan. Our longstanding (more than 13 years) and fruitful collaboration with it is in the framework of an Agreement for Academic Exchange between IE-BAS and FIR FU and a Memorandum of Understanding for creation of international consortium for “Promoting international collaboration for development and application of sub-millimeter gyrotrons”.

The results of this collaboration during 2011 have been in three main directions, namely: (i) further development of the physical models and computer codes of the problem oriented software package GYROSIM for analysis, CAD, and optimization of high-frequency gyrotrons; (ii) development of a concept for innovative and standard designs of compact and specialized tubes; (iii) development of novel members of the Gyrotron FU CW series covering a wide parameter space in the sub-THz and THz frequency range; (iv) extending the applications of gyrotrons to new fields.

A novel module consisting of several codes (RAYS, TRACE, COMODES), called GO&ART (which stands for Geometric Optics and Analytical Ray Tracing) was added to the problem-oriented software package GYROSIM which extends significantly its functionality and allows one to simulate quasi-optical components (Vlasov and Denisov launchers, reflectors and phase correcting mirrors) and systems based on them (e.g. internal mode converters for formation of a Gaussian beam and transmission lines). The upgraded version of GYROSIM was used successfully for CAD of several sub-terahertz gyrotrons for novel applications.

Some of the most characteristic features of the innovative designs for the next generation of high performance gyrotrons are: (i) use of compact cryo-free superconducting magnets; (ii) EOS based on high-performance magnetron injection gun (MIG), which forms high-quality electron beams with appropriate parameters for sufficient efficiency and stability of operation at low accelerating voltages and lower thermal loading of the emitter; (iii) development of the tube together with the transmission line and the auxiliary units of the experimental equipment (e.g. cavity resonator of the spectrometer); (iv) system approach in which both the design and the optimization loops of different subsystems (EOS, the electro-dynamical system, the quasi-optical system etc.) are carried out successively and iteratively in the course of the development of the entire tube; (v) carefully designed resonant cavities that allow a broad tunability band.

Among the most characteristic novel applications of the recently developed gyrotrons are electron spin resonance (ESR) spectroscopy, nuclear magnetic resonance (NMR) spectroscopy enhanced by dynamic nuclear polarization (DNP), X-ray detected magnetic resonance (XDMR), and studies of the energy levels and hyperfine splitting (HFS) of positronium (Ps). Since many materials have characteristic absorption fingerprints or spectral lines (e.g. rotational and vibrational resonances of complex molecules like proteins) in the sub-terahertz frequency range, one could envisage a constantly growing list of spectroscopic studies that will require coherent radiation sources that are bridging the so called THz-gap.

Both the feasibility and the conceptual design were recently investigated of a novel hybrid technique and equipment for experimental cancer therapy based on the simultaneous and/or sequential application of two beams, namely, a beam of neutrons and a CW (continuous wave) or intermittent sub-terahertz wave beam produced by a gyrotron (forming a so called “quantum beam”) for treatment of cancerous tumors. It is believed that building such novel irradiation facility will open many new opportunities for experimenting with different therapeutic techniques utilizing a quantum beam and will facilitate the development of effective methods and tools for a cancer treatment.

4. Investigation of the potentials of the interaction and the thermophysical properties of gases and binary mixtures at low pressures

In recent years, a series of studies focused on the investigation of the interactions between particles in pure gases and gas mixtures has been carried out in the laboratory. As a result of this research, novel data for the intermolecular interactions and thermo-physical properties of various gases and mixtures were obtained and published. The physical model used in order to predict the most important parameters affecting their thermo-physical properties is based on the well-known (*n*-6) Lennard-Jones temperature dependent potential developed by Stefanov and Zarkova. The tables created summarizing recommended values for potential-well depth, equilibrium distance, second virial coefficient, viscosity and diffusion in the temperature range 200-1200 K compensate for the lack of systematic experimental data in such wide temperature interval and can be used for both interpolation and extrapolation, as well as for calculation of other potential dependent properties of oxygen and oxygen containing mixtures.

In 2011, results from the study of both the electro-optical and the thermophysical properties of chlorine were published in a chapter of a book on the properties, applications and health effect of this gas.

Currently, Mrs M. Damyanova is working towards her PhD thesis, which is intended to present and summarize the recent results of the research under this topic.

5. Electron-micrograph image analysis of nanomaterials with biogenic origin

The need of reliable information about the structural characteristics (e.g. mean size, size distribution, shape etc.) of various nanosized materials makes the electron-micrograph image analysis an appropriate method of choice for their investigation. More specifically, both TEM and SEM micrograph processing (image analysis) allow the structure of different kinds of nanomaterials, such as powders, thin films, composites, carbon nanotubes etc., to be studied. Additionally, this universal method allows both hard and soft solid-state materials to be analyzed. Moreover, the SEM micrograph method can be used successfully for observation of biological samples.

Our research in this field has been motivated by the growing interest in recent years in the production of biogenic nano-materials. Among the most popular of them are the iron-oxidizing bacteria from the *Sphaerotilus–Leptothrix groups*. During their growth, they produce extracellular formations consisting of Fe-oxides and hydroxides. The formations produced have different sizes and shapes. For example, *Leptothrix ochracea* produces hollow microtubes (sheaths), while the *Gallionella ferruginea* produces twisted stalks, and, sometimes, perfect spheres. This makes the study of the morphology of the formations important.

In our investigation we usde SEM micrograph image analysis for studying the products of the biogenic activity of iron oxidizing bacteria. The knowledge about the morphology of the formations observed allows one to find the best cultivating conditions for production of a given type of bacteria. Additionally, the information about the size of the formations is essential for the intended applications of the products. One possible and very attractive application can be production of thin films that consist of ordered spherical Fe-oxides formations injected with magnetic material. Such films can serve as a recording media produced by natural products.

During the year, samples of iron-oxidizing bacteria produced in different standard culture media were investigated. The cultures obtained at different stages of their growth were isolated and SEM-micrographs of them were made, using a scanning electron microscope JEOL (JSN-5510, with magnification of x5 000, x10 000, and x13 000). A statistical analysis of the objects observed on the microphotographs was conducted using an image analysis computer code. It was found that most of the objects have tube-like size and are characterized by two sizes – diameter and length. In one of the samples, however, except the tubes, some formations having a nearly spherical shape were observed as well. Therefore, distributions corresponding to both of these sizes (diameters, lengths) were evaluated for the former cases, whereas in the latter, a distribution of the diameters was obtained.

The results obtained in this study show that the variation of the culture media (content and concentrations of different components) leads to a variation of the sizes and the shapes of the growing formations. In some cases the bacteria are preliminary of the *Leptothrix group***,** but in one of the samples formations belonging to the *Gallionella ferruginea* were observed as well.

6. Investigation of the physical properties of materials, surfaces and structures

The IE-BAS is one of the founding members of the *Center for Investigation of the Physical Properties of Materials*, *Surfaces and Structures at the BAS*. It is equipped with state-of-the art analytical measuring devices that include a scanning probe microscope DiMultimode V (Veeco). A member of our laboratory, (Eng. E. Vasileva) is among the certified operators who are using advanced techniques and methods for complex analysis of various nano-materials and structures.

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   Simulation tools for computer-aided design and numerical investigations of high power gyrotrons,
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   9th Int. Workshop on Electrical Probes in Magnetized Plasmas (21-23 Sept. 2011 Iasi Romania).

ONGOING RESEARCH PROJECTS

Funded by EC as 7 FP projects through Contract of Association with Association EURATOM-INRNE

1. Task 2.1.2: Development of numerical codes to describe the behavior of high power gyrotrons.
2. Task 2.2.1: Edge plasma diagnostics.

Funded by the National Science Fund

New materials for electronics and ecology on the basis of biogenic iron oxides.

Funded by the Bulgarian Academy of Sciences

Investigations in the field of the controlled thermonuclear fusion – powerful gyrotrons for plasma heating and probe plasma diagnostics in tokamaks, 2011-2013.

COLLABORATIONS

1. Analysis and optimization of electron guns for compact shower devices and submillimeter wave gyrotrons,
   in the framework of the Agreement for academic exchange between IE-BAS and FIR FU Research Center in Fukui, Japan.
2. Promoting international collaboration for development and application of submillimeter gyrotrons,
   in the framework of the Memorandum of Understanding between IE-BAS and FIR FU Research Center in Fukui, Japan for establishing an international consortium.
3. Development of numerical codes to describe the behavior of high power gyrotrons,
   Task 2.1.2 of the Association EURATOM–INRNE in collaboration with KIT-IHM, Karlsruhe (Germany) and EPFL-CRPP, Lausanne (Switzerland).
4. Edge plasma diagnostics,
   Task 2.2.1 of the Association EURATOM–INRNE in collaboration with the Institute of Plasma Physics, Czech Academy of Sciences, Prague, Czech Republic.
5. Langmuir probe diagnostics of Electron Energy Distribution Functions in fusion edge type magnetized plasmas,
   Project under the Bilateral Scientific Cooperation between St. Kliment Ohridski University of Sofia and

Faculty of Electrical Engineering, University of Ljubljana, Slovenia.

6. Edge plasma diagnostics on the COMPASS tokamak,
   Inter-academic collaboration BAS – ASCR, Bulgaria - Czech Republic.

LABORATORY VISITS

1. S. Sabchevski, Research Center for Development of the Far-Infrared Region, University of Fukui, Fukui, Japan – 6 months.
2. M. Dimitrova, Institute of Plasma Physics, Czech Academy of Sciences, Prague, Czech Republic – 45 days.
3. P. Ivanova, Institute of Plasma Physics, Czech Academy of Sciences, Prague, Czech Republic – 1 month.

GUESTS

1. R. Panek, J, Stockel, R. Dejarnac, Institute of Plasma Physics, Czech Academy of Sciences, Prague, Czech Republic.
2. Dr. E. Bouyer,
   CEA (French Atomic and Alternative Energy Research Center) – DRT/LITEN, Grenoble, France.

LABORATORY

PHYSICAL PROBLEMS OF ION TECHNOLOGIES

HEAD: **Prof. S. Tinchev, Dr.Sc.**

TOTAL STAFF: **5**
RESEARCH SCIENTISTS: **3**
P. Nikolova; Y. Dyulgerska; E. Petrova.

RESEARCH ACTIVITIES

1. Surface modification of diamond-like carbon films to graphene under low energy ion beam irradiation

Graphene has been the subject of research in recent years because of its unique electrical, optical and mechanical properties that make it a perfect material for many applications in electronics. Various methods have been demonstrated for deposition of large-area graphene films. In the most successfull chemical vapor deposition (CVD) methods, such films are deposited on a catalytic metal layer (Ni, Co) or on Cu (making use of the low solubility of carbon in Cu).

However, in the electronics usually graphene sheets on insulating substrates are needed. Therefore the graphene thin films deposited on metals are transferred to insulating substrates, which is a difficult step. Additionally, the properties of the transferred graphene deteriorate due to the large numbers of traps and phonon scattering in typical substrates used, like SiO_2. Graphene transistors fabricated from graphen on diamond-like carbon have better properties because of less impurities and phonon scattering. The disadvantages of graphene transfer, however, still remaine.

We developed a low-temperature method of fabrication of graphene layers on top of insulated diamond-like carbon films by low-energy ion-beam irradiation. Generally, ion bombardment causes structural damage in a crystalline material. However, in the ion-beam irradiation of an amorphous material, ion-beam induced epitaxial crystallization of amorphous layers is possible. The mechanism for such a crystallization process involves point-defect creation and enhanced diffusion caused by ion bombardment.

Different ions can be used to modify diamond-like carbon films. Three types of ions were analyzed as possible candidates for low-energy ion-beam modification of amorphous carbon films. The first two are carbon and hydrogen ions, which are inherent to our a-C:H films and are not expected to introduce chemical effects. The last one is argon ions, which are widely used in the microelectronic technology and, as a noble gas, should not react with the carbon.

The Monte Carlo SRIM program was used to estimate the necessary energy and doses of the ions in order to modify only about 1 nm on the surface of the amorphous carbon films. We calculated the profile of the vacancies produced in amorphous carbon films by 1 keV argon ion irradiation. As expected, only the surface of the film is modified.

From the maximal number of vacancies (~ 0.7 vacancies/angstrom/ion) one can estimate the dose needed to break all sp3 bonds in the amorphous carbon films. In the films used they were about 80%. Taking into account that every carbon atom has four bonds, we found that the dose should be ~ 4.5×10^{15} Ar^+/cm^2. This estimated value is in good agreement with the experimental value found in the literature.

The films used in our experiments were a-C:H films onto single-crystal (100) Si wafers fabricated by PE CVD from benzene vapor diluted with argon. They were modified in a DC magnetron system at unipolar pulsed discharges. Pulse biasing of the magnetron is needed because the diamond-like carbon films are highly insulating and ion bombardment with DC voltage would cause charging of the film. The voltage amplitude was 130 V, the pulse frequency, 66 kHz, and the pulse duration, 10 μs. During the modification, the pressure of the chamber was 6.6 Pa.

The electrical resistance and Raman spectra of the films were measured before and after film modification at room temperature. The electrical resistance measurements were performed by 2-point DC and standard lock-in techniques with excitation currents of 10 nA at 469 Hz. Silver paint contacts were applied to the corners of a rectangular sample. The Raman spectra were obtained using a laser with 633 nm wavelength.

The virgin diamond-like carbon film was highly insulating. After the ion beam modification, its sheet resistivity dropped. The measured resistivity of the modified film was ~ 245 kΩ/□. Assuming ~ 0.34 nm as the estimated thickness of the modified surface layer, one can obtain an estimation of the resistivity of the modified material of ~ 8×10^{-5} Ω m, which is close to the known resistivity of graphite.

The Raman spectrum of the virgin film was subtracted from the spectrum of the modified film. In the difference spectrum, a clear D-peak at 1316 cm^{-1} and a G-peak at 1595 cm^{-1} of the modified surface can be seen. The presence of the D peak indicates the presence of disorder in the modified material. The single and sharp second order Raman band (2D) at ~2670 cm^{-1} has been widely used as a simple and efficient way to confirm the presence of single layer graphene. The Raman spectrum of our sample in the 2D band regions is not as sharp as expected and can be fitted by two peaks at 2754 cm^{-1} and 2853 cm^{-1}. This feature is typical for defective graphene.

Further, the sample was annealed at 300^0C for 8 hours in order to enhance the diffusion of the displaced carbon atoms in the modified surface layer. The Raman spectrum shows two distinct D- and G-peaks, which is typical for partially crystalline carbon with small crystallite size. Without ion bombardment, such partial crystallization of DLC can be achieved by annealing at temperatures 800 - 900 ^{0}C. Thus, it is evident that ion bombardment enhances the diffusion of carbon.

This result is very encouraging and we hope that by improving this technology it will be possible to fabricate defect-free graphene.

2. Interference effects on the I_D/I_G ratio of the Raman spectra of diamond-like carbon thin films

Raman spectroscopy is a widely used method to characterize carbon-based materials. Basic structural properties, such as nanocluster size can be derived from the Raman measurements. In amorphous diamond-like carbon thin films Raman spectroscopy is probably the most important method for diagnostics of the material. Raman spectra of these films usually show two distinct peaks – the so called D- and G- peaks. The parameters of both peaks (position, width and intensity ratio) are used for the characterization of the thin film material. For example, an increase in I_D/I_G ratio is ascribed to an increase in the number and/or the size of sp^2 clusters.

However, if the film thickness is comparable to the wavelength of the laser/Raman light, interference effects in the film take place and the measured Raman spectra can be disturbed. We calculated the interference effect on the intensity ratio of the D- and G- peaks of the Raman signal and showed that in diamond-like carbon (DLC) films with thickness of some hundred nanometers this effect should be taken into account if conclusions are to be drawn made from the I_D/I_G ratio.

An a-C:H film on a Si surface acts as both a sample layer and a dielectric spacer layer. As a result, instead of the expected monotonic increase of the Raman intensity up to film thicknesses equal to the laser penetration depth, interference effect was observed. Strong oscillatory behavior of the Raman intensity of the main G-peak was predicted and experimentally verified.

However, the optical thickness of the investigated layer is different for each Raman frequency. Therefore, the I_D/I_G ratio will be different for films with different thicknesses even if these films have the same structure. We expect this effect not to be very strong, especially for a-C:H films on Si substrates. Nevertheless, it should be taken into account.

We investigated theoretically hydrogenated amorphous carbon thin films deposited on two different substrates – silicon and metal (Al). For the amplitude of the laser beam at a certain depth *x* taking into account its multiple reflections within the film and interference at the interface air/film we have:

$$E_L = const\,\frac{t_1 e^{-i\beta_1 x} + t_1 r_2 e^{-i\beta_1(2d-x)}}{1 + r_1 r_2 e^{-i2d\beta_1}}\, e^{i\omega_L t}.$$

Here $\beta_1 = (2\pi/\lambda_1)(n_1 - ik_1)$ is the wavenumber for the laser light, $(n_1 - ik_1)$ is the complex refractive index of the DLC film taken at the laser wavelength and d is the thickness of the sample layer. Calculated for the amplitude of the wave, t_1 is the transmission coefficient at the interface air/film and r_1 and r_2 are the reflection coefficients at the interface air/film and interface film /substrate, respectively.

Similarly, the Raman scattering amplitude could be expressed as:

$$E_R = const\,\frac{t_2 e^{-i\beta_2 x} + t_2 r_2 e^{-i\beta_2(2d-x)}}{1 + r_1 r_2 e^{-i2d\beta_2}}\, e^{i\omega_R t}$$

Here $\beta_2 = (2\pi/\lambda_2)(n_2 - ik_2)$ is the wavenumber of the Raman light, $(n_2 - ik_2)$ is the complex refractive index of the DLC film, t_2 is the amplitude transmission coefficient at the interface between the film and the air and r_1 and r_2 are the respective amplitude reflection coefficients. Each of these parameters is taken at a particular Raman wavelength.

The total Raman signal was calculated by:

$$I = const\,\frac{\mathrm{Re}\{n_2^L\}}{\mathrm{Re}\{n_2^R\}}\int_0^d |E_L|^2 |E_R|^2\, dx,$$

where $\mathrm{Re}\{n_2^L\}$ and $\mathrm{Re}\{n_2^R\}$ are the real parts of the sample layer's refractive indices at the laser and Raman wavelengths, respectively.

The calculations were carried out for three different laser wavelengths 514.5 nm, 633 nm and 458 nm. The positions of the Raman peaks are slightly different dependening on the laser excitation wavelength. As expected, the interference effects are more pronounced for 633 nm, because the attenuation of the Raman components is much stronger for shorter wavelengths. From the curves it is difficult to see the difference between G-peak and D-peak intensities corresponding to a certain laser wavelength because the wavelengths of G- and D-peaks are close to each other. However, the differences are more pronounced in the plotted relations of the I_D/I_G ratio on the film thickness *d*.

Obviously, depending on the film thickness, the real I_D/I_G ratio can be distorted up to about 10% for DLC films on Si substrates. On metals, however, for example on Al, which is the case in the solar thermal absorbers, large oscillations could be expected and distortion up to 40 % could significantly influence the I_D/I_G ratio and, therefore, the conclusions drawn.

PUBLICATIONS

1. Tinchev S S 2012 Surface modification of diamond-like carbon films to graphene under low energy ion beam irradiation *Appl. Surf. Sci.* **258** 2931 ISSN: 0169-4332
2. S S Tinchev S S 2011 Crystallization of diamond-like carbon to graphene under low energy ion beam modification *arXiv:1104.2976v3*
3. Petrova E, Tinchev S and Nikolova P 2011 Interference effects on the ID/IG ratio of the Raman spectra of diamond-like carbon thin films *arXiv:1112.0897v1* (Submitted to Diamond and Related Materials ISSN: 0925-9635)

ONGOING RESEARCH PROJECTS

Financed by the Bulgarian National Scientific Fund

VU-TH –964 Assistant microwave process in formation of nanocomposite materials.

Financed by the BAS

Nanofunctional thin films and structures.

LABORATORY

PHYSICAL PROBLEMS OF ELECTRON BEAM TECHNOLOGIES

HEAD: **Corr. Member of BAS Prof. G. Mladenov, Dr.Sc. (till October 2011)**
Prof. K. Vutova, Dr.Sc. (since October 2011)

TOTAL STAFF: **12**
RESEARCH SCIENTISTS: **8**

Assoc. Prof. P. Petrov, Dr.Sc.; Assoc. Prof. V. Vassileva, PhD; Assoc. Prof. E. Koleva, Ph.D.; Assoc. Prof. Y. Gueorgiev, Ph.D.; Assoc. Prof . M. Beshkova, Ph.D.; M. Petkov, Ph.D.; T. Nikolov, R. Nikolov, V. Donchev, D. Tabakov.
PhD Students: D. Petrova, D. Dimitrov.

RESEARCH ACTIVITIES

1. New materials and technologies for renewable energy sources

In ten scientific reports, presented on five scientific forums (three in Bulgaria, two abroad) the tendencies and the problems were analyzed and new solutions and approaches were discussed for solving the practical problems of future power generating technologies.

Important for our country conclusions were drawn:

- The goal Bulgaria to reach 16% increase in renewable energy sources up to 2020 year is lowered due to a wrong economical concept.
- At the end of the decade, instabilities will appear in Bulgaria's energy system and its transformation into an intelligent energy system should be planned earlier - from now.
- It is not correct, as it is done in our country, to focus the development of the renewable energy sources on large photovoltaic and wind parks, only which are independent investments. Investments should be made in the thermo-mechanical conversion of the solar energy combined with existing or new steam-turbine generators. A rapid development is forecast of thermal energy conversion in the Mediterranean countries (North Africa, the Near East and Southern Europe) and Bulgaria can not stay isolated from these energy projects.
- The following scientific priorities in the research and development of new energy sources are pointed to: development of third generation of photovoltaic cells and of power engineering to generate clean solar fuels, mainly hydrogen or methanol; thermo-chemical and photo-chemical conversion of solar energy into hydrogen, with fuel cells as generators of clean electrical energy; and also connecting the transport sector to an intelligent energy system.

The conclusions drawn represent our expert opinion and are of importance for the development of our country, as emphasized by the BAS President, Acad. N. Sabotinov.

The work preformed and the publications in this area were also useful as training of our laboratory's scientists on the subjects of future energy technologies. For the first time in our country, an International Symposium on Advanced Solutions in Applied Energy Technologies was held (19 – 21.09.2011) in Sofia, organized by the Union of Electronics, Electrical Engineering and Telecommunications in Bulgaria, the Institute of Electronics at the Bulgarian Academy of Sciences, the Federation of

Scientific and Technical Unions in Bulgaria, Union of Power Engineers in Bulgaria. Prof. G. Mladenov, Corresponding Member of BAS, was Chairman of the Organizing Committee, Prof. K. Vutova and Assoc. Prof. E. Koleva were members of the Organizing Committee. The subjects discussed during the symposium were: generation of renewable energy and energy storage, hydrogen power generation and fuel cells, nanomaterials and nanotechnologies in the power devices. During the symposium, 11 scientific reports from 7 Bulgarian and 13 foreign scientists were delivered, two Bulgarian and one German companies and the Bulgarian Industrial Cluster for Electric Vehicles were present.

2. Nanoelectronics, nanomaterials and fabrication of nanoelectronic structures with electron lithography

2.1. Nanoelectronics and nanomaterials

In 2011, the second part of the Nanoelectronics monograph was published by the Avers Ukrainian Publishing House under an intergovernmental collaboration project with Ukraine, our partner being the Faculty of Electronics of the Kiev Polytechnic Institute (KPI) with the First Pro-rector of KPI Acad. Uri Yakimenko as project coordinator from the Ukrainian side. This book presents discussions on the results of the investigation of carbon nano-materials, nano-structured silicon and silicon composites, the self arrangement of nano-sized materials, their properties and applications. Functional devices are also considered for photonics, bio- crio- and molecular- electronics, magneto-electronics and spintronics, sensors and mechanical electro-nano-components etc. The authors from the Bulgarian-Ukrainian team, G. Mladenov and E. Koleva, were awarded honorary diplomas by the Ministry of Science and Education of Ukraine, he Academy of Pedagogic Sciences of Ukraine and Kiev Chamber of Commerce and Industry for exceptional creative contribution to the educational process.

The collaboration with the Hiroshima Institute of Technology (HIT), Japan, blongs also in this field of research. A common Chapter (in the book “Practical Aspects and Applications of Electron Beam Irradiation”) was published as a result of this long term collaboration of which Prof. Takeshi Tanaka is the Japanese coordinator.

2.2. Nanosructuring by electron beam lithography

The nonlinear solubility behavior was investigated of the polymer resist SAL 110 and of the important negative oligomer resist hydrogen silsesquioxane (HSQ). The experimental data were obtained at different conditions of the development process by varying the time of development and the temperature of the developer solution used for thin and tick HSQ resist layers. Features were considered of the HSQ nonlinear development process due to the complicated mechanism of the resist removal from soluble resist areas and hypothesis was proposed for explanation of HSQ dissolution process.

During the year, one colleague of our team (Assoc.Prof. Y. Georgiev) has been working in Ireland on nanofabrication, in particular, on electron beam lithography (EBL) of various structures on silicon (Si) and silicon-on-insulator (SOI) substrates. Using a Jeol 6000FS EBL system, he took part in the development of a new procedure for mix-and-match lithography on small chips (down to 10×10 mm). Thus, a number of Si-nanowire (NW) field effect transistors on SOI substrates, applicable in sensing devices, were fabricated. The typical NW dimensions were: width between 50 and 70 nm, height of 70 nm, and length of 10 μm. An EBL process was developed for fabrication of very short Si NWs (length between 500 nm and 2 μm) connecting two large contact pads. This process has allowed the fabrication of such

NWs with homogeneous width along their entire length due to the proper compensation of the proximity effect. The width of these short NWs was varied in a wide range from about 15 nm up to 105 nm. These structures can further be used for fabrication of suspended NWs and, hence, for advanced CMOS devices.

Utilizing a double layer resist (PMMA bottom layer and HSQ top layer), an EBL process was applied for EBL-directed silver-assisted etching of vertical Si NWs. Using this process, arrays of nanopillars were fabricated in the double layer resist with diameters of 30-35 nm, pitch of 100 nm, and heights of about 150 nm. These arrays can be used as masks for EBL-directed silver-assisted etching of vertical Si NWs for sensing or for new photovoltaic (PV) applications.

3. Study of thin SiC films prepared by rapid thermal annealing (RTA)

Films with thickness of 50 and 300 Å were deposited on p-type (100) silicon substrates by RF sputtering at 0.5 Pa pressure in a gas mixture of 30% H_2 and Ar atmosphere. Further, the samples were subjected to RTA in vacuum of 5×10^{-5} Torr (6.7×10^{-3}Pa) for 3 min at temperatures of 800 and 1400 °C. Raman spectra of the layers were taken before and immediately after the RTA. The spectrum of the sample before RTA exhibited a peak in the range 1500 – 1550 cm^{-1}, which is characteristic for amorphous carbon. The Raman spectrum of the layer after RTA at 1400 °C for 3 min show peaks in the range of 910-1050 cm^{-1} and 775-850 cm^{-1},which is an indication for the existence of hexagonal and cubic SiC polytypes, respectively. Typically, the cubic phase is considerably smaller in quantity. Calculated as a percentage with respect to the basic phase (hexagonal SiC), it is about 14%. Thus, we can assume that the cubic SiC phase is distributed in the basic matrix of hexagonal silicon carbide. The Raman spectrum of the SiC layer subjected to RTA at 800 °C for 3 min shows a lower intensity of the peaks, which indicates that both phases increase with increasing the annealing temperature.

Analysis was carried out of the electrical cross conductance of the carbon and SiC layers deposited onto silicon substrates for samples with thickness of 300 Å because of their good homogeneity. For the as-deposited sample, the I-V curve shows that it behave as an additional resistance in series with the rectifying contact between the carbon layer and the silicon substrate. After the RTA procedure at 1400 °C for 3 min, the SiC layer behaves as a semiconductor with a large density of defects.

Using the light-induced transient grating (LITG) techniqueq we performed a comparative study of the non-equilibrium carrier dynamics in bulk and 3C-SiC layers grown by sublimation epitaxy on 6H-SiC (0001)Si substrate with and without a 3C-SiC seed layer and a bulk 3C-SiC layer grown by chemical vapor deposition (CVD) on undulant Si substrates.

The results revealed that the low carrier scattering rate in the bulk CVD layer and the bulk sublimation layer determine the high carrier mobilities, especially at lower temperatures. In the 3C-SiC layer, the mobility decrease and the carrier lifetime increase with the temperature were attributed to the charge state of defects, which is dependent on the temperature and excitation.

4. New materials regeneration through electron beam melting

We continued our experimental and theoretical studies of electron beam melting that is a key method for obtaining new materials for micro- and nano-electronics, for which high purity and quality are required. Using the ELIT-60 60 kW equipment, electron-beam melting of tungsten carbide and W-Mo alloy was performed at different technological regimes (beam power and casting velocity). It was found that regimes at low e-beam power and temperatures near the carbide melting temperature are more appropriate for effective e-beam melting of tungsten carbide at comparatively small changes in the proportion tungsten/ carbon.

The thermal transfer processes are important in the production of metal ingots with good quality (structure, surface and composition). The computer simulation of the heat transfer processes at electron beam melting and refining (EBMR) is a tool allowing better understanding, studying and control of these processes. The heat exchange at different interfaces between the casting ingot and both the water-cooled crucible and the pulling mechanism was studied. The temperature variations of the thermal conductivity and the heat capacity for the refractory metal Ta and for Cu (a low-melting-temperature metal), were estimated and taken into account in the heat model proposed. Using it, numerical experiments were conducted at different beam powers and casting velocities for the purpose of studying of the heat transfer in Ta and Cu. Useful practical data were obtained about the liquid pool geometry, the crystallization front and the thermal flows.

The results obtained show that the heat flow through the bottom of the Cu ingot aat casting velocities up to 6 mm/min is the main route of energy losses under the conditions investigated. The lower energy losses through the other ingot boundaries contribute to achieving a more efficient EBMR process. These conditions are appropriate for forming a flat crystallization front (liquid/solid boundary), which is connected with the quality of the pure ingot – this front permits the formation of dendrite structures parallel to the ingot axis and uniform impurity displacement toward the ingot top surface. It was shown that a flat crystallization front shape for Cu heated by a 20-30 kW beam can be obtained for casting velocity up to 6 mm/min. The calculated and the experimentally obtained crystallization front shapes were compared and good agreement was observed.

The data calculated about the molten pools, the heat flows and the liquid/solid boundaries can be used in the optimization and control of the EBMR process parameters, as well as for improving the quality of the pure materials produced.

A chapter devoted to the EBMR technologies was included in a book on the EB technologies applications, published in English, eds. M. Nemtanu, M. Brasoveanu, Research Signpost/Transworld Research Network Publishers.

5. Electron beam welding

5.1. The results presented above on applying a thermal EBW model to the heating of a sample by a linearly moving heat source, as well as on the statistical approach for forecasting the geometrical characteristics of the welding joints obtained, developed and implemented in the laboratory, were summarized in a book chapter, in a journal article and a presentation made at the specialized conference on EBW in St. Petersburg, Russian Federation. The report presented in St. Petersburg included an expert computer system assisting the operators' decision making that can find applications in personnel training and in the computer control and optimization of the technological process. As examples, regimes for stainless steel 1H18NT and steel 45 welding, based on experimental data sets, were shown and discussed. In the other two scientific reports in this field the implementation of artificial neuron networks for forecasting the EBW results were discussed and some problems of statistical models application to the quality improvement of the process were also discussed.

5.2. The microstructure changes and mechanical properties were studied of heat-treated Al-Si alloys resulting from additional alloying with Fe, Co, Ni, Cr by hybrid electron beam treatment techniques. These techniques perform an additional alloying in the zone treated, which has a substantial effect on the physical and mechanical properties of the materials processed.

The influence was investigated of the electron beam oscillation patterns and travel speed and the additional alloying in the weld zone on the melting efficiency, weld geometry, structure and mechanical properties welds of Al-Mg alloys. Electron beam welding process was used to connect components of up to 25 mm in thickness with beam oscillation (perpendicular to the weld direction, 45^o with respect to the weld direction, parallel to the weld direction, and elliptic) using 15 kW Leybold Heraeus welding equipment. Welding without beam oscillation was also carried out for comparison. The melting efficiency was determined from the welding seams cross-sections measured at given electron beam power and travel speed.

6. Automation

The design of an automatic control system of the vacuum system of available expensive installation for electron beam welding, evaporation and surface modification of materials is an important first step toward the development of integrated complete control systems for the processes of thermal treatment, movement of the electron beam and movement of samples and other components by a manipulator.

The development of the automation control system was performed at the following stages: A detailed description of the actions (sequence, conditions for action) necessary to set the installation into a working regime; its stopping and the appearance of emergency or break-down situations (absence of power and water supply etc); description of the available control mechanisms (valves, gauges, pumps, cocks, etc.), which are manually turned on and off; work on the project for automation control system. At the design stage, a comparison was made of different variants of choosing new components (PLC, electrical and mechanical components, valves, etc.). The work also continued on the development of software for the Siemens Simatic S7-300 programmable controller.

PUBLICATIONS

1. Shmireva A X, Mladenov G M, Spivak V M, Koleva E G and Bogdan A V 2011 *Nanoelectronics Series Book 2 Materials and Functional Devices* (Kiev-Sofia Avers Publishers) 394 pages (in Russian)
2. Vutova K, Mladenov G M and Tanaka T 2011 *Practical Aspects and Applications of Electron Beam Irradiation* **chapter** *Photoelectron Signal Simulation at Surface Analysis* Eds. Nemtanu M and Brasoveanu M, (Research Signpost/Transworld Research Network) pp 235-54
3. Mladenov G M, Vutova K, Koleva E and Vasileva V 2011 *Practical Aspects and Applications of Electron Beam Irradiation* **chapter** *Experimental and Theoretical Studies of Electron Beam Melting and Refining* Eds. Nemtanu M and Brasoveanu M, (Research Signpost / Transworld Research Network) pp 43-93
4. Mladenov G M, Koleva E and Vutova K 2011 *Practical Aspects and Applications of Electron Beam Irradiation* **chapter** *Electron*

Lithography of Submicron and Nano Structures Eds. Nemtanu M and Brasoveanu M, (Research Signpost / Transworld Research Network pp 135-166

5. Koleva E and Mladenov G M 2011 *Practical Aspects and Applications of Electron Beam Irradiation* **chapter** *Experience on electron beam welding* Eds. Nemtanu M and Brasoveanu M, (Research Signpost / Transworld Research Network) pp 94-134
6. Vutova K, Mladenov G M and Koleva E 2011 Simulation of thermal transfer process in cast ingots at electron beam melting and refining *Int. Rev.Mech. Eng.* **5**/2 257-65
7. Vutova K, Mladenov G M, Koleva E, Kostic I, Bencurova A, Nemec P and Tanaka T 2011 Nonlinear solubility behavior of polymer and oligomer resists at electron beam modification *Mater. Sci. Eng. B* **1** 523-9
8. Vutova K, Vassileva V, Mladenov G M, Koleva E, Prakash T and Munirathnam N 2011 Electron beam melting and recycling of hafnium *Supplem. Proc. General Paper Selections TMS* **3** (Wiley USA) pp 725-32
9. Mladenov G M, Koleva E and Vutova K 2011 Heat transfer and weld geometry at electron beam welding *Int. Rev. Mech. Eng.* **5**/2 235-43
10. Manolis G, Beshkova M, Syväjärvi M, Yakimova R and Jarašiūnas K 2011 Carrier dynamics in hetero- and homo-epitaxially sublimation grown 3C-SiC layers *Mater. Sci. Forum* **679-680**161-4
11. Mladenov G M 2011 The vacuum theory is one possible future idea for the world *J. BAS* **4** 23-30 (in Bulgarian)
12. Zgurev V, Kenderov P, Tsvetanov H, Kralchevski P, Hadjiiski P, Filipov F, Rumenin Ch, Popov A, Kovachev A, Mladenov G and Atanasov P 2011 Position on problems concerning the technological development of Bulgaria *J. BAS* **3** 55-70 (in Bulgarian)
13. Mladenov G M, Spivak V, Koleva E, Bogdan A and Zelensky S 2011 Micro- and nanostructures in modern memory devices *Electronics and comunications* thematic edition *Electronics and Nanotechnol.* **2** 5-8
14. Mladenov G M, Spivak V, Koleva E, Bogdan A and Zelensky S 2011 Prospects in spin transport electronics *Electronics and Comunications* Thematic edition *Electronics and Nanotechnol.* **3** 9-13
15. Mladenov G M, Spivak V, Koleva E and Bogdan A 2011 New technologies and materials for some conventional renewable sources of energy *Proc. 2nd Int. Conf. Energy Smart Systems* (Svalyavska district Transcarpatian region Ukraine) pp 56-63
16. Yakimenko Y, Mladenov G M, Spivak V, Bogdan A and Koval V 2011 Photoelectric converters: Current state analysis and prospects of evolution *Proc. Int. Conf. Nanotechnol. and Biomedical engine.* (Chişinău Republic of Moldova 7-8 July 2011) pp 67-71
17. Mladenov G M 2011 Nanotechnology and nanomaterials used in the renewable energy sources *Proc. 13th Int. Conf. Electrical Machines, Drives and Power Systems* (Varna Bulgaria) pp 9-16
18. Vassileva V, Vutova K, Mladenov G M and Koleva E 2011 Investigation of tantalum recycling by electron beam melting method *Proc. Int. Conf. Eng., Techn. & Systems* pp 263-8
19. Mladenov G M 2011 State of the art of concentrated solar power generation technologies *Proc. Int. Symp. Advanced Solutions in Applied Energy Technologies* (19-21 Sept. 2011 Sofia Bulgaria) pp 5-21
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22. Donchev V, Vutova K and Mladenov G M 2011 Computer simulation and mathematical modeling in solar thermal hydrogen reactors *Proc. Int. Symp. Adv. Solutions in App. Energy Technol.* (19-21 Sept. 2011 Sofia Bulgaria) pp 64-74
23. Tabakov D and Mladenov G M 2011 Hydrogen application in power engineering and transport *Proc. Int. Symp. Adv. Solutions in App. Energy Technol.* (19-21 Sept. 2011 Sofia Bulgaria) pp 104-110
24. Todorov D and Mladenov G M 2011 Some trends and problems of inverters for photovoltaic systems. *Proc. Int. Symp. Adv. Solutions in App. Energy Technol.* (19-21 Sept. 2011 Sofia Bulgaria) pp 83-97
25. Mladenov G M and Koleva E 2011 Calculation and optimization of geometric characteristics of the weld at EBW *Proc. Int. Conf. EBW Technol. & Equipment* (Sankt Petersburg Russia 23-26 May 2011) pp 116-130
26. Koleva E, Christova N, Velev K and Petrova D 2011 Model based approach for quality improvement of electron beam welding *Proc. Int. Conf. ASMDA* (7-10 June 2011 Italy) pp 134-141
27. Georgiev Y 2011 Technology for fabrication of sub 50 nm metal T- and Γ-gates *Nanosci. & Nanotechnol.* **11** 91-3
28. Vutova K, Vassileva V, Mladenov G M and Koleva E 2011 New material fabrication by electron-beam melting of wastes of titanium, hafnium and tantalum *Annual Report 2010 Institute of Electronics BAS* pp 84-92
29. Petrova D, Koleva E, Tzotchev V and Vuchkov I 2011 Model-based robust quality improvement of automatic cleaning process of IBC containers *Proc. Anniversary Sci. Conf. 40 years department Industrial Automation – UCTM - Sofia* (18 May 2011 Sofia Bulgaria) pp 111-4
30. Christova N, Koleva E and Velev K 2011 Neural network based approach for process optimization of electron beam welding *Proc. Anniversary Sci. Conf. 40 years Department Industrial Automation – UCTM - Sofia* (18 May 2011 Sofia Bulgaria) pp 149-152
31. Genchev D, Koleva E, Elenkov G and Velev K 2011 System for automatic control of electron beam machine, *Proc. Anniversary Sci. Conf. 40 years department Industrial Automation – UCTM - Sofia* (18 May 2011 Sofia Bulgaria) pp 33-36 (in Bulgarian)
32. Michailov V, Karhin V and Petrov P 2011 Fundamentals of welding *J. Stroitelstvo* **2** 2-26 **3** 3-25 **4** 2-26 **5** 2-26 **6** 3-25

PATENTS

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CONFERENCES

1. Mladenov G,
   Int. Conf. Technol.&Equipment EBW-2011 (22-26 May, 2011, Sankt-Petersburg, Russia).
2. Mladenov G,
   Int. Conf. Energy Smart Systems-ESS-2011 (6-11 June, 2011, Mukachevo Svaliava, Ukraine).
3. Vutova K,
   140 TMS 2011 (26.02–04.03.2011, San Diego, USA).
4. Petrov P and Beshkova M,

17th Int. Summer School on Vacuum, Electron and Ion Technologies (19-23 Sept., 2011, Sunny Beach, Bulgaria).

5. Koleva E,
Int. Conf. ASMDA (6-12 June, 2011, Rome, Italy).
6. Donchev V,
1st Central and Eastern European Conf. Thermal Analysis and Calorimetry, Summer School on Thermal Analysis and Calorimetry (05-11 Sept., 2011, Craiova, Romania).
7. Mladenov G, Vutova K, Koleva E, Vassileva V, Donchev V, Tabakov D and Dimitrov D,
Int. Symp. Advanced Solutions in Applied Energy Technologies (19-21 Sept., 2011, Sofia, Bulgaria).
8. Beshkova M,
Int. Workshop 3C-SiC Hetero-epitaxy Hetero–SiC and Workshop on Advanced Semiconductor Materials and Devices for Power Electronics Applications, Hetero SiC-WASMPE (27-30 June 2011, Tours, France).
9. Koleva E and Petrova D,
Anniversary Sci. Conf. 40 Years Department Industrial Automation – UCTM - Sofia (18 May 2011 Sofia Bulgaria)

ONGOING RESEARCH PROJECTS

Financed by the National Science Fund

1. DO 02-200 New materials regeneration through electron beam melting and refining of refractory and reactive metals and alloys in vacuum.
2. NTS 01-193 New materials, nano-dimensional devices and electron control systems for/or created by beam technologies, with the Kiev Polytechnic Institute (KPI), Ukraine, under Bulgarian-Ukrainian inter-governmental program of cooperation in science and technology.
3. BIn-5 New materials regeneration through electron beam melting and refining of refractory metal wastes in vacuum, with the Centre for Materials for Electronics technology (C-MET), Hyderabad, India, under Bulgarian-Indian inter-governmental program of cooperation in science and technology.
4. VUI 307, Integrated information medium for modeling and control of the process of electron beam melting and refining of metals.
5. Robust lithography of submicron and nano-dimensional structures,
Institute of Informatics, Slovak Academy of Sciences, under Bulgarian - Slovak inter-governmental program of cooperation in science and technology.

Financed by the BAS

1. Pure metal obtaining, thin film deposition by e-beam evaporation and computer simulation of nano-lithography processes.
2. Physical and heat processes at electron beam welding.

COLLABORATIONS

EU, NATO and other international organizations projects

1. Contract No MRTN-CT-2006-035735 Promoting and structuring a multidisciplinary academic-industrial network through the heteropolytype growth, characterization and application of 3C-SiC on hexagonal substrates, Dr. Gabriel Ferro, Coordinator, Financed by the European Community through the Marie Curie RTN MANSiC project.

Other scientific institutions

1. Computer simulation of the processes of electron, ion and X-ray irradiation of electronic materials,
Hiroshima Institute of Technology, Hiroshima, Japan.
2. Generation and use of intense electron beam created by plasma emitter electron gun,
Institute of High Current Electronics, Russian Academy of Sciences,

Siberian Branch.

3. Investigation of nanosystems and new materials by neutron scattering,
   Joint Institute for Nuclear Research, Dubna, Russia.

LECTURE COURSES

1. Electron and Ion Technologies,
   MS Program in Microelectronic Technology at the Faculty of Electronics Engineering, Technical Univ. Sofia.
2. Applied Statistics (in English),
   MS Program in Materials Science and Engineering at the Univ. Chem. Technol. and Metallurgy, Sofia, Bulgaria.
3. Methods for experimental investigations, Univ. Chem. Technol. and Metallurgy, Sofia, Bulgaria.

GUESTS

1. Dr. Goesta Mattausch, Fraunhofer Institute for Electron Beam and Plasma Technology, Dresden, Germany, Sept. 2011.
2. Prof. Julia Yamnenko, National Technical University, Kiev, Ukraine, 19-21.09.2011.
3. Prof. Takeshi Tanaka, Hiroshima Institute of Technology, Hiroshima, Japan, May, 2011.
4. Imamura Ko, Hiroshima, Japan, May, 2011.
5. Hartmut Schacke, Vistec Electron Beam GmbH, Jena, Germany, 07.10.2011.
6. Genadi Georgiev DREBERIS GmbH, Dresden, Germany, 07.10.2011
7. Thomas Nel, Director, Walmer Investments, Cape Town, South Africa, March 2011.
8. Steve Clement, Walmer Investments, Cape Town, South Africa, March 2011.

LABORATORY

SUPERCONDUCTIVITY AND CRYOELECTRONICS

HEAD: **Assoc. Prof. T. Nurgaliev, Dr.Sc.**

TOTAL STAFF: **7**

RESEARCH SCIENTISTS: **6**
Assoc. Prof. E. S. Mateev, Ph.D.; Assoc. Prof. N. Donkov, Ph.D.; B. S. Blagoev, Ph.D.; L. I. Neshkov; Pl. Petkov.

RESEARCH ACTIVITIES

The field of activity of the laboratory is in compliance with the research field of the Institute of Electronics BAS "Nanoscience, New Materials and Technologies" and with the priorities of the National Scientific Program for 2009-2013 "Nanoelectronics and New Materials". The main tasks of the laboratory in 2011 were:
- deposition of oxide films and layered structures of submicron thickness which demonstrate magnetic or high temperature superconducting properties;
- deposition of submicron oxide films which could be used in biomedicine or in sensors;
- fabrication and investigaton of oxide thin film configurations which could be used for practical applications.

1. Effect of DC current injection on AC current carrying ability of ring shaped HTS thin films

The effect of DC current injection on the AC current carrying characteristics of superconducting thin film samples of ring shape were analyzed because of the possibility of using similar ferromagnetic/ high temperature superconducting (FM/HTS) structures for contactless investigation of the spin-injection process. It was shown that injecting DC current leads to a decrease in the critical current value I_C, as determined from the response of the HTS ring to the AC magnetic field, due to the superposition effect of AC and DC currents in the sample. If the DC current provokes a breaking of Cooper pairs in the superconductor, this causes an additional decreasing of I_C. The effect was investigated experimentally at 77 K in HTS $YBa_2Cu_3O_x$ (YBCO) and HTS/FM $YBa_2Cu_3O_x/La_{0.7}Sr_{0.3}MnO_3$ (YBCO/LSMO) thin film configurations, prepared using magnetron sputtering, conventional photolithography and wet etching procedures. The DC current was injected (from HTS YBCO or ferromagnetic LSMO electrodes) into an HTS YBCO ring and the critical current I_C was determined from the HTS ring third harmonic's response to the AC magnetic field. The experiments demonstrated a sensitivity of I_C to the current injection process (especially in the case of a FM LSMO current-injecting electrode). The results allowed us to conclude that a change in the I_C caused by the superposition process of AC and DC currents and by possible Cooper pairs breaking process can be evaluated separately by a contactless method and the latter can be used for studying the spin-injection effect.

2. Transformations of head-to-head domain walls in $La_{0.7}Sr_{0.3}MnO_3$ thin films

In collaboration with the Institute of Solid State Physics, RAS (Moscow, Chernogolovka), the kinetics of the in-plane magnetization reversal in a $La_{0.7}Sr_{0.3}MnO_3$ thin film was studied at different temperatures (6–340 K) using a magneto-optic visualization technique. In addition to changes of the domain wall coercivity and mobility, dramatic transformations of the domain wall structure were observed. The motion of a single zig-zag domain wall, typical for high temperature magnetization reversal, was replaced by the formation of a complicated diffuse structure between the two principal domains at low temperature. Generation of secondary bubble domains in front of a moving wall was observed for the first time in a quasistatic regime, contrary to previous superfast experiments. Competition between the long-range stray fields and local pinning forces is considered as a likely origin of the observed phenomenon.

3. Structure and superconductivity of bulk BPSCCO/LPMO composite

Bulk superconducting (SC) ceramics containing BPSCCO and LPMO (lanthanum/lead-manganite phase) were prepaared and investigated in collaboration with the Institute of Solid State Physics BAS (Bulgaria), the University of Chemical Technology and Metallurgy (Bulgaria), the Institute of Low Temperature and Structure Research PAS (Poland) and the Tallinn University of Technology (Estonia). The composites obtained were analyzed by scanning electron microscopy (SEM) and by energy-dispersive X-ray spectroscopy (EDX). They contain several phases. It was established that the SC 2212 phase predominates in the composite. 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 coexist stably in the composite sintered by 60 h heat treatment at 840 C.

4. Preparation and investigation of new ceramic covers for biomedicine

Ceramic covers of Ta_2O_5 were prepared on $Ti_4Al_{16}V$ substrates by electron-beam evaporation. The structure, stoichiometry and surface properties were investigated of these covers annealed at temperatures between 450 ^oC and 700 ^oC. The interaction between stem cells (including messenhymal stem cells – MSCs) and the modified surface properties biomaterial substrates, such as nano-roughness, surface free energy, adhesive potential, were investigated as well. Enrichment of these layers with oxygen leads to an improvement of their surface properties and to an increase in their hydrophilicity.

PUBLICATIONS

1. Nurgaliev T, Mateev E, Blagoev B, Neshkov L, Nedkov I and Uspenskaya L S 2011 Effect of DC current injection on AC current carrying ability of ring shaped HTS thin films *Physica C* **471** 577-81
2. Uspenskaya L S, Tikhomirov O A and Nurgaliev T 2011 Transformations of head-to-head domain walls in (La,Sr)MnO thin films *J. Appl. Phys*. **109** 113901
3. Stoyanova-Ivanova A K, Staneva A D, Shoumarova J M, Blagoev B S, Zaleski A J, Mikli V and Dimitriev Y B 2011 Microstructure and superconductivity of bulk BPSCCO / LPMO composite *Philosophical Magazine Letters* **91/3** 190-9
4. Uspenskaya L S, Nurgaliev T and Miteva S 2010 Domain wall dynamics in ultra thin manganite film *J. Phys.: Conf. Series* **200** 042025
5. Nurgaliev T, Mateev E, Blagoev B, Neshkov L, Nedkov I and Uspenskaya L S 2010 Investigation of the current injection on J_C of a HTS YBCO ring *J. Phys.: Conf. Series* **253** 012074

6. Donkov N, Zykova A, Safonov V and Luk'yanchenko V 2011 Ta_2O_5 ceramic coatings deposition on $Ti_4Al_{16}V$ for biomedical applications *J. Problems of Atomic Sci. and Technol. Series Plasma Physics* **17**/1
7. Koutzarova T, Kolev S, Nedkov I, Krezhov K, Kovacheva D, Blagoev B, Ghelev C and Zaleski A 2011 Magnetic properties of nanosized $Ba_2Mg_2Fe_{12}O_{22}$ powders obtained by auto-combustion *J. Supercond. and Novel Magnetism* pp 1-5 DOI 10.1007/s10948-011-1232-3

CONFERENCES

1. Nurgaliev T, Blagoev B, Mateev E, Štrbík V, Beňačka S, Šmatko V, Gaži S and Chromik S, Planar homogeneity of the electrical properties of $YBa_2Cu_3O_7/La_{0.7}Sr_{0.3}MnO_3$ bi-layers, *17th Int. Summer School on Vacuum, Electron and Ion Technologies* (19-23 Sept. 2011, Sunny Beach, Bulgaria).
2. Mateev E, Blagoev B and Nurgaliev T, Impedance investigation of epitaxial and polycrystalline LSMO thin films, *17th Int. Summer School on Vacuum, Electron and Ion Technologies* (19-23 Sept. 2011, Sunny Beach, Bulgaria).
3. Štrbík V, Beňačka S, Šmatko V, Gaži S, Blagoev B, Mateev E and Nurgaliev T Influence of focused-on-beam technique on the properties of SFS heterostructures, *17th Int. Summer School on Vacuum, Electron and Ion Technologies* (19-23 Sept. 2011, Sunny Beach, Bulgaria).
4. Blagoev B, Slavov L, Bineva I, Vandenberghe R E, Zaleski A J and Nedkov I, Magnetic and morphology investigation of hybrid magnetite/β-cyclodextrin nanosized material, *13th Int. Simp. Nanosci. and Nanotechnol.* (25-26 Nov., 2011, Sofia, Bulgaria).
5. Safonov V, Donkov N, Zykova A, Smolik J, Rogovska R, Goltsev A, Dubrava T and Rassokha I, Nano scale biomaterial interface modifications for advanced tissue engineering applications, *17th Int. Summer School on Vacuum, Electron and Ion Technologies* (19-23 Sept. 2011, Sunny Beach, Bulgaria).
6. Radeva R, Georgieva V, Donkov N, Lazarov J and Vergov L, Plasma deposited polymers as gas sensitive films, *17th Int. Summer School on Vacuum, Electron and Ion Technologies* (19-23 Sept. 2011, Sunny Beach, Bulgaria).
7. Georgieva V, Donkov N, Stefanov P, Sendova-Vassileva M, Grechnikov A and Gadjanova V, NO_2 sensing properties of amorphous silicon films, *17th Int. Summer School on Vacuum, Electron and Ion Technologies* (19-23 Sept. 2011, Sunny Beach, Bulgaria).

ONGOING RESEARCH PROJECTS

Financed by the National Science Fund

1. No. 109 Investigation of HF and MW recharges supported by surface electromagnetic waves (2010-2011).

COLLABORATIONS

1. Nanofilms and heterostructures of magnetic manganites and high temperature superconductors, preparation, investigation of the electric characteristics and magnetic domain structure (2009-2011), Institute of Solid State Physics, Russian Academy of Sciences, Chernogolovka, Russia.
2. Elaboration of technology for deposition of nanostructure dielectric oxide covers of new generation, used as biomaterials and biosensors, EP - 12a (2011-2013), National Scientific Center "Kharkov Institute of Physics and Technology", Ukraine.

3. Investigation of the proximity effect and spin injection in epitaxial bi-layer structures of ferromagnetic manganites and high temperature superconductors, Institute of Electrical Engeneering, Slovak Academy of Sciences.

LABORATORY VISITS

1. Dr. B. Blagoev,
Institute of Low Temperature and Structure Research, Polish Academy of Sciences, Wroclaw, Poland.
2. Dr. B. Blagoev,
Institute of Electrical Engineering, Slovak Academy of Sciences, Bratislava, Slovak Republic.

VISITS OF FOREIGN SCIENTISTS

1. Prof. V. Safonov, Prof. A. Zykova, National Scientific Center “Kharkov Institute of Physics and Technology”, Kharkov, Ukraine.

LABORATORY

MICRO- AND NANO-PHOTONICS

HEAD:**, Prof. P.A. Atanasov, Dr.Sc., Corresponding Member of BAS**

TOTAL STAFF: **12**
RESEARCH SCIENTISTS: **7**

Assoc. Prof. N.N. Nedialkov, Ph.D.; Assoc. Prof. A.Og. Dikovska, Ph.D.; M.E. Koleva, Ph.D.; N.E. Stankova, Ph.D.; A.S. Nikolov, Ph.D.; E.L. Pavlov; T.R. Stoyanchov; Ro.G. Nikov; Ru.G. Nikov; I.G. Dimitrov; R.B. Rangelov.

RESEARCH ACTIVITES

1. Nanoscience and nanotechnologies

1.1. Nanostructuring and nanomodification

ZnO nanorods were produced by pulsed laser deposition (PLD). Drops of nanoparticle colloid (gold or silver) were placed on silica substrates to form growth nuclei. All nanoparticles were monocrystalline, with well-defined crystal surfaces and a negative electrical charge. The ZnO nanorods were produced in an off-axis PLD configuration at oxygen pressure of 5 Pa. The growth of the nanorods started from the nanoparticles in different directions, as one nanoparticle could become a nucleus for more than one nanorod. The low substrate temperature used indicates the absence of a catalyst during the growth of the nanorods. The diameters of the fabricated 1-D ZnO nanostructures were in the range 50 – 120 nm and their length was determined by the deposition time.

The particle size distribution, morphology and optical properties of the Au nanoparticle (NP) structures for surface enhanced Raman signal (SERS) application were investigated in dependence on the preparation conditions. The structures were produced from relatively thin Au films (10–20 nm) sputtered on fused silica glass substrate and irradiated with several pulses (6 ns) of laser radiation at 266 nm and at fluencies in the range 160–412 mJ/cm^2. The SEM inspection revealed nearly homogeneously distributed spherical gold particles. Their initial size distribution in the range 20–60 nm broadened towards the larger particle diameters as the irradiation was prolonged. This was accompanied by an increase in the uncovered surface of the glass substrate and no particle removal was observed. The broad peak centered at 546 nm in the absorption profiles of the nanostructures was ascribed to resonant absorption by surface plasmons (SPR). The peak position, halfwidth and intensity depended on the shape, size and size distribution of the nanostructured particles in agreement with results reported by other authors. Relative signal enhancement by a factor between 20 and 603 for individual peaks was estimated from the peak intensities of the Raman spectra recorded for Rhodamine 6G in the range of 300–1800 cm^{-1},. The results confirm that the structures produced can be applied for SERS measurements and sensing.

1.2. Optical scattering and plasmonic nanopaterning of surfaces

Experimental and theoretical results were obtained on plasmonic control of far-field interference for regular ripple formation on semiconductor and metal. Interference ripple patterns on Si substrate originating from the gold nanosphere irradiated by femtosecond laser was observed experimentally. The gold nanosphere was found to be the origin of the ripple formation. Arbitrary intensity ripple patterns are theoretically controllable by depositing desired plasmonic and Mie scattering far-field pattern generators. The plasmonic far-field generation has been demonstrated not only by metallic nanostructures but also by the controlled surface structures such as ridge and trench structures on various material substrates.

Interference ripple pattern between surface plasmon far field by gold nanosphere and the incident laser on silicon substrate were directly observed. The ripple formation is explained using a three-dimensional finite-difference time-domain simulation method. The nanosphere is the origin of regular ripple formation due to Mie scattering. A new method was presented to control the plasmonic far-field pattern using an arbitrary gold nanostructure on the silicon substrate. Previously, the formed ripples have not been regular but wavy because they were formed incoherently through a self organization process originating from the random surface roughness. Our ripple structure was well controlled coherently.

1.3. Noble metal nanoparticles production by laser ablation in liquid environment

Pulsed laser ablation of Ag and Au targets immersed in double-distilled water was used to synthesize metallic nanoparticles (NPs). The targets were irradiated for 20 min by laser pulses at different wavelengths - the fundamental and the second harmonic (SHG) (λ = 1064 and 532 nm, respectively) of a Nd:YAG laser system. The ablation process was performed at a repetition rate of 10 Hz and with pulse duration of 15 ns. Two boundary values of the laser fluence for each wavelength under the experimental conditions chosen were used - it varied from several J/cm^2 to tens of J/cm^2. Only as-prepared samples were measured not later than two hours after fabrication. The NPs shape and size distribution were evaluated from transmission electron microscopy (TEM) images. The suspensions obtained were investigated by optical transmission spectroscopy in the near UV and in the visible region in order to obtain information about these parameters. Spherical shape of the NPs at the low laser fluence and appearance of aggregation and building of nanowires at the SHG and high laser fluence were observed. Dependence of the mean particle size at the SHG on the laser fluence was established.

Colloidal solutions of gold and silver nanoparticles (NPs) were prepared using pulsed laser ablation of a target in a liquid media. Gold and silver targets immersed in double distilled water were irradiated for 20 min by laser pulses with duration of 15 ns at repetition rate of 10 Hz. In order to study the influences of the laser wavelength and fluence on the particle size, shape and optical properties, the experiments were preformed by using two different wavelength – the fundamental and the second harmonic (SHG) (λ = 1064 and 532 nm, respectively) of a Nd:YAG laser system. Two different values of the laser fluence for each wavelength at the experimental conditions chosen were used and; thus, it was varied from several J/cm^2 to tens of J/cm^2. To characterize the NPs shape and size distribution, we used transmission electron microscopy (TEM) and optical transmission spectroscopy in the near UV and in the visible region. Spherical shape of the nanoparticles at the low laser fluence and appearance of aggregation and building of nanowires at the SH and high laser fluence was observed. Dependence of the mean particle size at the SH on the laser fluence was established. The mean diameter of the gold NPs decreased with the decrease of the laser wavelength.

1.4. Gold nanoparticles production by ultra-short laser ablation of thin films

The process of ultrafast laser ablation of a gold thin film was studied and compared with that of a bulk target, with particular emphasis placed on the process of nanoparticles generation. The process was carried out in conditions whereby a single laser shot remove the entire irradiated film spot. The experimental results revealed interesting differences and, in particular, a reduction of the nanoparticles size, and a narrowing by a factor two of their size distribution in the case of ablation of a thin film target, a feature which we relate to a more uniform heating of the target material. We thus showed that ultrashort laser ablation of thin films provides a promising way of controlling the plume features and the nanoparticles size.

2. Nanosecond laser heating of gold NPs. Application in photo-thermal cancer cells therapy

Theoretical and experimental studies were performed on the heating process and near field localization arising when gold nanoparticles are irradiated by ultrashort laser pulses. The system under consideration consisted of nanoparticles with radii of 20, 40, or 100 nm in vacuum or deposited on different substrates. Substrate materials with different dielectric properties were used to sense and visualize the nanoparticle heating and the near electromagnetic field distribution. The theoretical analysis was based on a two-temperature heat model allowing one to estimate the nanoparticle temperature and the finite difference time domain (FDTD) method describing the near field distribution in the vicinity of the particles. It was found that at even moderate laser fluences, the particle temperature can reach a value sufficient for bubble formation in biological tissues. The analysis of the near field distribution indicated that when a particle is deposited on a substrate surface, the dielectric properties of the substrate define the localization and enhancement of the near field intensity. The efficiency of this process determines the contribution of particle heating or near field intensity enhancement in the surface modification process. The localization of the near field intensity in the vicinity of the contact point between the particle and substrate was proven experimentally for metal and silicon substrates, where the experimentally obtained surface modifications resemble the theoretically predicted intensity distribution.

Theoretical and experimental studies on the heating process of gold nanoparticles irradiated by nanosecond laser pulses were also conducted. The particle heating efficiency was demonstrated by in-vitro photothermal therapy of human tumor cells. Gold nanoparticles with diameters of 40 and 100nm were added as colloid in the cell culture and the samples were irradiated by nanosecond pulses at wavelength of 532nm delivered by a Nd:YAG laser system. The results pointed to the cytotoxic effect of using nanoparticle being more efficient than using particles with diameter of 100 nm. The theoretical analysis of the heating process whn a nanoparticle interacts with laser radiation was based on the Mie scattering theory, which was used for calculation of the particle absorption coefficient, and on a two-dimensional heat diffusion model describing the evolution of the temperature of the particle and the surrounding medium. Using this model, the dependence of the maximal particle temperature achieved on the laser fluence applied and the time evolution of the particle temperature were obtained.

PUBLICATIONS

1. Nedyalkov N N, Imamova S, Atanasov P A, Tanaka Y and Obara M 2011 Interaction between ultrashort laser pulses and gold nanoparticles: Nanoheater and nanolens effect *J. Nanoparticle Res.* **13**/5 2181-93
2. Dikovska A Og, Nedyalkov N N and Atanasov P A 2011 Fabrication of ZnO nanorods using metal

nanoparticles as growth nuclei *Mater. Sci. Eng. B* **176** 1548–51

3. Obara G, Maeda N, Miyanishi T, Terakawa M, Nedyalkov N N and Obara M 2011 Plasmonic and Mie scattering control of far-field interference for regular ripple formation on various material substrates *Optics Express* **19**/20 19093-103
4. Groshowska K, Nedyalkov N, Atanasov P and Śliwiński G 2011 Nanostructuring of thin Au films by means of short UV laser pulses *J. Opto−Electr. Rev.* **19**/3 327–32
5. Nedyalkov N N, Imamova S E, Atanasov P A, Toshkova R A, Gardeva EG, Yossifova L S, Alexandrov M T and Obara M 2011 Interaction of gold nanoparticles with nanosecond laser pulses: Nanoparticle heating *Appl. Surf. Sci.* **257** 5456–9
6. Nikolov A S, Nedyalkov N N, Nikov R G, Atanasov P A and Alexandrov M T 2011 Characterization of Ag and Au nanoparticles created by nanosecond pulsed laser ablation in double distilled water *Appl. Surf. Sci.* **257** 5278–82
7. Nikov R G, Nikolov A S and Atanasov P A 2011 Preparation of gold and silver nanoparticles by pulsed laser ablation of solid target in water *Proc. SPIE* **7747** 774708-1
8. Obara G, Tanaka Y, Nedyalkov N N, Terakawa M and Obara M 2011 Direct observation of surface plasmon far field for regular surface ripple formation by femtosecond laser pulse irradiation of gold nanostructures on silicon substrates *Appl. Phys. Lett.* **99**/6 061106
9. Amoruso S, Nedyalkov N N, Wang X, Ausanio G, Bruzzese R and Atanasov P A 2011 Ultrafast laser ablation of gold thin film targets *J. Appl. Phys.* **110** 124303

ONGOING RESEARCH PROJECTS

Financed by the Bulgarian Academy of Sciences

Pulsed laser deposition of thin films.

Financed by the National Science Fund

FNI – DO 02 -293 Plasmon and optical properties of metal nanoparticles and its application to high sensitive Raman spectroscopy and biophotonics.

COLLABORATIONS

Femtosecond laser processing and novel methods for nanofabrication, Department of Electronics and Electrical Engineering, Keio University, Yokohama, Japan.

Nanoparticles generation by ultrashort laser ablation of metals and dielectrics: theory and experiments, Coherentia-INFM, Istituto Nazionale per la Fisica della Materia; 80126 Napoli, Italy.

Fabrication and characterization of noble metal nanoparticles arrays, Institute of Fluid-Flow Machines, Polish Academy of Sciences, Gdansk, Poland.

Pulsed laser deposition of thin oxide films, Institute of Lasers, Plasma and Radiation Physics, Romanian Academy of Sciences, Bucharest, Romania.

Laser nanostructuring of different materials and nanoparticles generation, Institute of Physics, Czech Academy of Sciences, Prague, Czech Republic.

GUESTS

Dr. Salvatore Amoruso,
Coherentia-INFM, Istituto Nazionale per la Fisica della Materia; 80126 Napoli, Italy, 1 week, 03.07.2011.

Dr. Wang Xuan, Coherentia-INFM, Istituto Nazionale per la Fisica della Materia; 80126 Napoli, Italy, 1 week, 03.07.2011.
Ms. Anna Iwulska,
Institute of Fluid-Flow Machines, Polish Academy of Sciences, Gdansk, Poland, 11 days, 16.10.2011.
Ms. Katarzina Grohovska,
Institute of Fluid-Flow Machines, Polish Academy of Sciences, Gdansk, Poland, 11 days, 16.10.2011.
Prof. Jon Mihailescu, National Institute for Lasers, Plasma and Radiation Physics, Magurele, Romania, 6 days, 13.12.2011.
Dr. Felix-Nicolae Sima,
National Institute for Lasers, Plasma and Radiation Physics, Magurele, Romania, 6 days, 13.12.2011.
Dr. Gabriel Sokol,
National Institute for Lasers, Plasma and Radiation Physics, Magurele, Romania, 6 days, 13.12.2011.
Dr. Carmen-Georgeta Ristoscu,
National Institute for Lasers, Plasma and Radiation Physics, Magurele, Romania, 6 days, 13.12.2011.

LABORATORY VISITS

Prof. Dr.Sc. P.A. Atanasov, Institute of Fluid-Flow Machines, Polish Academy of Sciences, Gdansk, Poland.
Assoc. Prof. Dr. N.N. Nedyalkov, Institute of Fluid-Flow Machines, Polish Academy of Sciences, Gdansk, Poland.
Prof. Dr.Sc. P.A. Atanasov, Institute of Physics, Czech Academy of Sciences, Prague, Czech Republic.
Dr. M. Koleva, Institute of Physics, Czech Academy of Sciences, Prague, Czech Republic
Prof. Dr.Sc. P. A. Atanasov, Coherentia-INFM, Istituto Nazionale per la Fisica della Materia; Napoli, Italy.
Assoc. Prof. Dr. N.N. Nedyalkov, Coherentia-INFM, Istituto Nazionale per la Fisica della Materia; Napoli, Italy.
Prof. Dr.Sc. P.A. Atanasov, TUBITAK, Marmara Reserch Center, Istanbul, Turkey.
Prof. Dr.Sc. P.A. Atanasov, Institute of Materials in Electrical Engineering, RWTH, Aachen University, Aachen, Germany.

LABORATORY

BIOPHOTONICS
HEAD: **Prof. Latchezar Avramov, Dr.Sc.**
TOTAL STAFF: 11
RESEARCH SCIENTISTS: 5

Assoc. Prof. E.G. Borisova, Ph.D.; Assoc. Prof. D.G. Slavov, Ph.D.; A.T. Daskalova-Shivarova, Ph.D.; A.I. Gisbrecht; I.A. Bliznakova; Al.Zh. Zhelyazkova; D.S. Petkov; L.P. Angelova; R.G. Krastev; I.I. Balchev.

RESEARCH ACTIVITIES

1. Biophotonics: Laser medical and biomedical research and development of new diagnostic and therapeutic methods and equipment

1.1. Initial diagnosis and monitoring of treatment using light-induced autofluorescence and diffuse reflectance spectroscopy of skin cancer

These investigations were a part of an initial clinical trial for introduction of spectroscopic diagnostic system for skin cancer detection in the common practice of the dermatological department of Queen Giovanna - ISUL University Hospital. Based on our preliminary results, obtained in the National Oncological Center, Sofia, during 2009-2010, we developed an easy-to-use spectrometric system for optical biopsy based on light-emitting diodes used for excitation of endogenous fluorescence from normal skin and its benign and malignant pathologies. Broad-band halogen lamp was used as an illumination source for diffuse reflectance measurements of human skin and its neoplasia.

We studied spectra obtained by multiple wavelength excitation of the endogenous fluorescence of benign and malignant cutaneous lesions. Initially, the lesions were classified visually by an experienced dermatologist and dermatoscopically using ABCD scoring criteria. The second step consisted in detection of lesion's and surrounding normal skin's fluorescence using different excitation wavelengths, namely 365, 385, and 405 nm. Optical fibers were used to deliver the light from LEDs and a halogen lamp and to collect the fluorescence and reflectance signals. The spectra were recorded and stored by means of a fiber-optic microspectrometer (USB4000, Ocean Optics, Dunedin, FL, USA). A personal computer was used to control the system and to store and display the data using the specialized microspectrometer software OOI Base ("Ocean Optics", Inc., Dunedin, FL, USA).

The histological examination was used as a "gold" standard for determination of the lesion type and the final analysis of spectroscopic techniques feasibility was conducted by comparison with this histological examination in all cases reported.

The specific features observed in the cutaneous lesions investigated were as follows:

1) Basal cell carcinoma lesions have lower fluorescence than normal skin;
2) Squamous cell carcinoma lesions have higher fluorescence than normal skin;
3) Keratoacantoma lesions have strong keratin fluorescence signal in the green spectral region;
4) The fluorescing compounds are collagen type I – at 400-405 nm; its cross-links – at 460-490 nm; elastin – with maxima at 400-420, 460 nm; elastin cross-links – about 500 nm; NADH – at 440-470 nm; keratin – at 430-460, and around 500-520 nm, and flavins;

5) Red-band fluorescence, related to endogenous porphyrins accumulation in the lesions, is also observed for advanced stage BCC lesions and in dysplasitc lesions with high metabolic activitiy;
6) The hemoglobin and melanin pigments influence is well pronounced in the obtained in vivo fluorescence spectra and is manifested as a relative decrease of the short-wavelength vs. long-wavelength intensity, as well as the appearance of minima at 420, 543 and 575 nm;
7) Reflectance spectroscopy shows a higher specificity compared to fluorescence spectroscopy in differentiating pigmented skin pathologies, including malignancies, which makes this technique very useful for early detection of malignant melanoma appearance and monitoring and evaluation of changes occurring in dysplastic nevi;
8) Fluorescence is very sensitive (>85%) for non-melanoma skin pathologies and could be applied in routine clinical practice for BCC and SCC early diagnosis.

A system for optical biopsy of human skin was applied for monitoring tumor therapy; we used it in joint studies with colleagues from the Institute of Biophysics and Biomedical Engineering and Specialized Hospital for Active Treatment in Oncology for monitoring electrochemotherapy procedures. The electrochemotherapy (ECT) combines chemotherapy and electroporation to increase the locally cytostatic drug delivery to the cancer cells. The electroporator was battery supplied and connected to isolated ECG signals amplifier, QRS detection and synchronization circuits. The injection of local anaesthetic (1% lidocaine) and cytostatic drug (bleomycin) in very small concentration directly to the tumour lesion was followed by application of electrical pulses. The drug delivery conditions (electric field intensity) and the cytostatic drug dose were chosen individually for every single case. To monitor the effects of the electrochemotherapy application, fluorescence spectra were taken from the lesion and surrounding healthy skin, prior to, immediately after treatment and at the control check-ups. Patients were followed up to the first week, first month and third month after treatment. An immediate response was clearly observed after the therapeutic procedure application – appearance of specific minima at 543 and 575 nm, related to increased haemoglobin absorption. One week later, the fluorescence intensity of the lesion area was higher and approached the “normal skin” spectral shape, which was an indication of the successful treatment of the tumor. This monitoring using spectral techniques is on its initial stage of development and will be extended in the next year.

Spectra and dermatoscopic evaluations have been so far obtained from more than 400 patients. The spectral properties of a variety of benign cutaneous lesions were also evaluated in view of developing more precise discrimination algorithms for cancer lesions diagnosis. The origins of diagnostically significant spectral features were evaluated and differentiation schemes were developed and are under examination. A clinical trial for initial diagnosis of skin cancer is currently under implementation in Queen Giovanna-ISUL University Hospital. By broadening the database of fluorescence spectra of major skin benign and malignant pathologies, we expect to develop an objective tool for cancer detection and treatment monitoring.

1.2. Surface foaming of thin collagen films

Tissue engineering requires the use of a temporary porous matrix in order to guide the regeneration of the tissue to the desired three-dimensional shape. The surface properties of biomaterials play an important role in biomedicine, as the majority of biological reactions occur on the surface of the implanted material. Collagen possesses a major advantage in being biodegradable, biocompatible, easily available and highly versatile. It has been hypothesized that artificially created porous collagen, known as scaffolds, may be seeded with cells and encouraged to develop into the desired tissue. The cell's shape, size, and growth orientation depend on the environment. Ultra-short laser irradiation of thin collagen films leads to development of a foamy layer with a fibrous structure. The foam created simulates the natural environment of the fibrillar network of the extracellular matrix and permits the adhesion and growth of cells for fabrication of tissue scaffolds.

The laser-induced structuring of collagen easily yields an expanded micro foam material with interconnected pores and properties that mimic the native collagen-based extracellular matrix. The structured matrix obtained is formed via a cavitation and bubble growth mechanism. The surface properties of collagen thin films before and after Ti-sapphire laser irradiation at 800 nm were investigated by means of field emission scanning electron microscopy (FESEM). It showed that a single pulse of ultra-short laser radiation is capable of inducing morphological changes in the irradiated collagen films. The size of the observed features can be controlled by selecting the laser fluence and pulse number. By tailoring the biomaterial nanostructure, it is fully expected to influence the mechanical, physical and chemical properties of scaffolds, which is a highly desirable variable to be able to control. Collagen-based biomaterials were developed and explored for the purposes of tissue engineering. Biomaterials are expected to function as cell scaffolds to replace native collagen. The ultra-short laser ablation induced nano-foaming of biomaterials will improve the currently available techniques. Artificial collagen nano-fibers are increasingly significant in numerous tissue engineering applications and seem to be ideal scaffolds for cell growth and proliferation.

1.3. Scattering of a laser beam in turbid media with sharply forward directed Henyey-Greenstein indicatrices

We studied the propagation of a c.w. laser beam through homogeneous tissue-like liquid turbid media having forward-peaked Henyey-Greenstein indicatrices. The in-depth on-axis and cross-sectional radial distributions of the detected forward-propagating light power were experimentally determined. The spatial distribution of the detected power was described analytically by solving the radiative transfer equation in the so-called small-angle approximation. The experimental results were found to be consistent with the analytical expressions obtained that allow one to estimate the extinction, reduced-scattering and absorption coefficients and the g-factor of the media investigated. The values of the optical coefficients obtained behave, depending on the dilution turbidity, in a way observed formerly in other similar experiments.

The measurements of the spatial distribution of the forward-propagating light power were performed on a setup comprising a laser diode emitting a collimated optical beam of about 1 mm radius and 27 mW power at a wavelength of 850 nm used as a NIR light source. The probed object is a hollow plexiglass box filled with a liquid tissue-like turbid medium. It is either a parallelepiped (12 cm×12 cm×22 cm) or a cube with 25 cm sides. The axis of the incident laser beam is perpendicular to the entrance wall of the container. The phantoms of different optical properties are prepared by diluting different amounts of Intralipid-20% by distilled water. The forward propagating light power inside the medium is measured by using an optical fibre of 0.1 mm core diameter connected to an optical radiometer, a 14 bit analog-to-digital converter and a computer for appropriate data processing. By a transverse scan of the fibre at each stepwise-varied depth of interest, a set of data is obtained for any of the turbid media investigated. The scanning procedure in three mutually perpendicular directions is implemented by using three Thorlabs LTS 300/M translation stages ensuring a minimum sampling step of 4μm. The transverse intensity distribution of the laser beam and the receiving directional diagram of the fibre in air, as mentioned above, were measured and shown to have an approximately Gaussian shape. The angle of view of the fibre in the phantom is estimated to be ~90^o or 0.16 rad. Despite the wide use of Intralipid as a phantom for biological tissues, there exist discrepancies in the optical parameters reported in the literature. These differences are mainly due to the fact that the emulsions of different brands and concentrations have been investigated by different measurement techniques.

The investigations performed are important for the development of methods for measuring the optical characteristics of turbid media, such as tissues and experimental tissue-like phantoms. They would also be especially useful in the process of establishing the mechanisms governing the radiative transfer inside the optically investigated biological objects. The results were published in Physica Scripta Proceedings of the III International School and Conference on Photonics, September, 2011.

1.4. Laser-induced tissue oxygenation: new method of elimination of tissue hypoxia

It has been shown that the photodissociation of oxyhemoglobin in cutaneous blood vessels and oxymyoglobin in muscle tissue play a dominant role in the mechanism of biostimulation and therapeutic effect of low intensity laser radiation. We obtained in vivo experimental results on the arterial oxygen blood saturation dependence on the temperature and the laser radiation wavelength. We suggested that laser therapy should be based on regulating the local concentration of free oxygen in tissue. The esults obtained demonstrated that in order to make the laser therapy method really efficient one has to control the oxygen concentration in the tissue and keeping it at the necessary level. This goal could be reached by the use of laser-induced photodissociation of oxyhemoglobin in tissue blood vessels.

1.5. In vitro investigations of chemo - hormonal synergic effects

Methotrexate (MTX) is a widely used drug in standard chemotherapy. Large amounts of efforts have been invested in improving its selective targeting in order to enhance its efficiency and reduce its adverse effects. One of the possible pathways, which have been subject to intensive studies, is investigating the synergic effects of chemotherapy drugs with hormones, e.g. insulin (Ins).

We started *in vitro* experiments to test the combined effect of MTX and Ins with two types of cell lines – HepG2 (human hepatocellular carcinoma) and 3T3 (standard fibroblast line obtained from mouse embryo tissue). For each cell line, five cell culture plates were compared – one with MTX only (at different concentrations) and four with MTX (at the same concentrations) and different concentrations of Ins. The cells were subjected to treatment for 7-9 days, whereby the culture medium and drugs were replaced every 48 hours. MTT test was used for estimation of the cell cytotoxicity, as compared to the control groups (without MTX) in each plate.

The results from the experiments can be summarized as follows:
For the 3T3 cells, at the level of IC_{50} (half maximal inhibitory concentration), there is no difference between the application of MTX only and MTX+Ins. For low concentrations of MTX (< 120 ng/ml) a significant anti-proliferative effect is observed for the MTX+Ins combinations, while the MTX only gives results which are not significantly different from the controls.

For the HepG2 cell line, a significant difference is observed in the anti-proliferative effect of the MTX+Ins combinations with respect to the MTX in the region of IC_{50} MTX concentration (MTX 5,67 ng/ml, Ins 100 nU/ml = 3,39 ng/ml). Quantitatively, IC_{50} for MTX is 40 % higher than IC_{50} for the combination MTX+Ins 100 nU. For the lowest MTX concentration investigated (2 ng/ml), the MTX+Ins combination cytotoxicity is higher by more than 120% than that of MTX only.

1.6. Investigation of the cell surface effect on the coherent population trapping resonances in Rb vapor

Under a contract between the Catholic University in Leuven, Belgium and IE BAS, the interaction of Rb atoms of with nanostructured surfaces is under investigation. Based on an experimental setup built for studying coherent population trapping (CPT) resonances, a comparative study was carried out in two configurations. In the first one, the signal is obtained by irradiating the inner volume of the cell along the entire cell length. The second configuration provides the opportunity to obtain signal only from the Rb atoms situated close to the inner surface of the cell window. This comparison reveled the presence of basic differences in the CPT resonances obtained in the two cases. Irradiating the group of transitions Fg=3→Fe=2,3,4 of ^{85}Rb, dominated by the closed transition F_g=3 → Fe=4, in configuration one we observed the so called “bright resonances” of increased absorption (increased fluorescence). In the second configuration, in total internal reflection, we observed a resonance sign reversal that represent electromagnetically induced transparency – decreased absorption and fluorescence signal. The signal is obtained as a result of the light penetrating in the cell volume in the vicinity of the window inner surface and its nature and parameters reveal the influence of the cell surface properties and structure on the nearly situated alkali atoms.

The results of this investigation show a potential for studying the properties of active and passive nanostructured surfaces and for comparing the properties of different cell-window materials.

Project title: Confinement of Atomic Vapors in Chiral Optical Metamaterials and Plasmonic Structures (Short title: Atomic Vapors in Metamaterials).

PUBLICATIONS

1. Pavlova P, Borisova E, Avramov L, Petkova E and Troyanova P 2011 Investigation of relations between skin cancer lesions‘ images and their reflectance and fluorescent spectra, melanoma in the clinic-diagnosis, management and complications of malignancy *Melanoma in the clinic-diagnosis, management and complications of malignancy* ed Mandi Murph (In Tech Open Access Publisher) **chapter 6** 87-104 ISBN: 978-953-307-571-6
2. Borisova E, Bliznakova I, Mantareva V, Angelov I, Avramov L and Petkova E 2011 Photodiagnosis and photodynamic therapy of cutaneous melanoma, current management of malignant melanoma *Current management of malignant melanoma* ed Ming Y Cao (In Tech Open Access Publisher) **chapter 7** 141-56 ISBN: 978-953-307-264-7

3. Borisova E, Vladimirov B, Ivanova R and Avramov L 2011 Light-induced fluorescence techniques for gastrointestinal tumour detection, new techniques in gastrointestinal endoscopy *New techniques in gastrointestinal endoscopy* ed Oliviu Pascu and Andrada Seicean (In Tech Open Access Publisher) **chapter 14** 231–52 ISBN: 978-953-307-777-2
4. Cartaleva S, Krasteva A and Slavov D 2011 Coherent population trapping resonances in Cs atomic vapor layers of micrometric thickness *Int. J. Optics* 2011 683415 DOI**:**10.1155/2011/683415
5. Yesman S S, Mamilov S A, Asimov M M and Gisbreht A I 2011 Noninvasive methods of measuring oxygen saturation in venous blood *J. Appl. Spectroscopy* **78**/3 406-13
6. Tsvetkova T, Balabanov S, Avramov L, Borisova E, Angelov I and Bischoff L 2010 Photoluminescence of Si+ and C+ implanted polymers *J. Phys.: Conf. Series* **223** 012033 ISSN: 17426588 DOI: 10.1088/1742-6596/223/1/012033
7. Gosh P, Zabov P, Cartaleva S, Mitra S, Petrov N, Roy B, Sarkisyan D and Slavov D 2011 CPT resonanses in micrometric cells with Cs vapours *News of Higher Education Institutions, Physics*, **2**/2 126-31 ISSN: 0021-3411 (In Russian)
8. Balabanov S, Tsvetkova T, Borisova E, Avramov L, Bischoff L and Zuk J 2010 Optical properties of Si+ implanted PMMA *J. Phys.: Conf. Series* **223** 012032 ISSN: 17426588, DOI: 10.1088/1742-6596/223/1/012032
9. Carstea E, Ghervase L, Pavelescu G, Savastru D, Forcea A and Borisova E 2010 Combined optical techniques for skin lesion diagnosis: short communication *OAM-RC* **4**/12 1960-3 ISSN: Print: 1842-6573
10. Koev K, Borisova E and Avramov L 2010 He-Ne low level laser therapeutic applications for treatment of acute iridocyclitis *Acta Medica Bulgarica* **37**/1 22-9
11. Koev K, Borisova E and Avramov L 2010 Laser-induced autofluorescence spectroscopy of basal cell carcinoma and papilloma of eyelids and comparison with the results from the histological investigation *Acta Medica Bulgarica* **37**/1 51-4
12. Dreischuh T, Stoyanov D, Gurdev L, Vankov O, Bliznakova I, Avramov L and Borisova E 2011 Method for detection and analysis of small turbid inclusions in turbid media using single-sided laser sensing *Bulgarian Academy of Sciences News* **1**/89 1-3 ISSN 1312-2436
13. Borisova E 2011 Development of interdisciplinary thinking and training of young scientists working in the field of light-matter interactions *Bulgarian Academy of Sciences News* **7**/95 1-3 ISSN 1312-2436
14. Uzunov Tz, Angelov I and Gisbrecht A 2009 Comparative study of the penetration of LED light of variuos wavelengths in dental tissues *Problems of Dental Medicine* **35**/2 16-20 (In Bulgarian)
15. Uzunov Tz, Angelov I, Mantareva V, Gisbrecht A and Vulkanov S 2010 Novel express method for enamel bleaching process control *Problems of Dental Medicine* **36**/2 29-32 (In Bulgarian)
16. Daskalova A, Manousaki A, Gray D and Fotakis C 2011 Microprocessing of thin collagen films by ultra-short laser ablation *Proc. SPIE* **7747**
17. Borisova E, Avramov L, Pavlova P, Pavlova E and Troyanova P 2010 Qualitative optical evaluation of malignancies related to cutaneous phototype *Proc. SPIE* **7563** 75630X
18. Koev K, Avramov L and Borisova E 2011 He-Ne low level laser therapeutic applications for treatment of corneal trauma *Proc. SPIE* **7747** 774711
19. Uzunov Tz, Uzunova P, Angelov I and Gisbrecht A 2009 Comparative investigation of the penetration of different wavelength visible LED radiation into dental tissue *Proc. SPIE* **7027** ISBN: 9780819472410
20. Asimov M M, Asimov R M, Rubinov A N and Gisbrecht A I 2011 Optical dosimetry for controlling the efficiency of laser phototherapy *Proc. Int. Conf. Nanotechnol. and Biomedical Eng.* (7-8 July 2011 Chisinau Moldova) pp 257-62 ISBN 978-9975-66-239-0

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22. Lazarova E P, Gacheva L I, Deneva M A, Gisbekht A Y and Nenchev M N 2010 Development of an original technique for dye and semiconductor laser emission spectrum narrowing *Proc. 10th Int. Conf. Laser and Laser Inform. Technol. and 6th Int. Symp. Laser Technol. and Lasers* (18-22 Oct. 2009 Smolyan Bulgaria) 277-83 ISSN 1314-068X
23. Uzunova P, Uzunov Tz, Macsimova V, Deneva M and Nenchev M 2010 Experimental study of the penetration of laser radiation in human teeth: the waveguide propagation of the light in the tooth's channel *Proc. 10th Int. Conf. Laser and Laser Inform. Technol. and 6th Int. Symp. Laser Technol. and Lasers* (18-22 Oct. 2009 Smolyan Bulgaria) 396-400 ISSN 1314-068X
24. Asimov M, Asimov R, Gisbrecht A, Mamilov S and Plaksiy Yu 2010 Novel laser-optical technology of blood carboxyhemoglobin photodecomposition and elimination of carbon monoxide poisoning effect *Proc. 10th Int. Conf. Laser and Laser Inform. Technol. and 6th Int. Symp. Laser Technol. and Lasers* (18-22 Oct. 2009 Smolyan Bulgaria) pp 381–8 ISSN 1314-068X
25. Asimov M, Asimov R and Gisbrecht A 2010 Laser-optical methods of detection and elimination the local tissue hypoxia: new approaches in prediction and prevention the risk of solid tumor formation *Proc. 10th Int. Conf. Laser and Laser Inform. Technol. and 6th Int. Symp. Laser Technol. and Lasers* (18-22 Oct. 2009 Smolyan Bulgaria) pp 373 –80 ISSN 1314-068X
26. Angelov I, Gisbrecht A, Mantareva V, Valkanov S and Uzunov Tz 2010 Light control of tooth bleaching process *Proc. 10th Int. Conf. Laser and Laser Inform. Technol. and 6th Int. Symp. Laser Technol. and Lasers* (18-22 Oct. 2009 Smolyan Bulgaria) pp 350-60 ISSN 1314-068X
27. Asimov M, Asimov R, Gisbrecht A, Mamilov S and Plaksiy Yu 2011 Novel laser-optical technology of blood carboxyhemoglobin photodecomposition and elimination of carbon monoxide poisoning effect *Proc. 10th Int. Conf. Laser and Laser Inform. Technol. and 6th Int. Symp. Laser Technol. and Lasers* (18-22 Oct. 2009 Smolyan Bulgaria) pp 381-8 ISSN 1314-068X
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30. Mamilov S A, Yesman S S, Misura A, Asimov M M and Gisbecht A Y 2010 Breathing rhythm separation for invasive venous blood oxygen saturation measurement *Proc. Int. Congress Medicinal Bioinformatics and Cybernetics* (23-26 June Kiev Ukraine) pp 235-7 ISBN 966-642-161-5 (In Russian)
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33. Asimov M, Asimov R, Gisbrecht A, Mamilov S and Plaksiy Yu 2009 In vivo determination of relative carboxyhemoglobin concentration in cutaneous blood vessels by the method of near infrared spectroscopy *Proc. 6^th Int. Symp. Modern Problems of Biophysical Medicine* (14-17 May 2009 Kiev Ukraine) pp 7-8 (In Russian)

CONFERENCES

1. Prof. Dr .Sci. Latchezar Avramov
   6^th Int. Summer Student School on Nuclear Physics Methods and Accelerators in Biology and Medicine – JINR
   03-12 July 2011, Dubna, Russian Federation.
2. Assoc. Prof. Dr. Ekaterina Borisova
   Ideal-ist face2face brokerage event at the ICT Proposers' Day
   19-21 May 2011, Budapest, Hungary.
3. Assoc. Prof. Dr. Ekaterina Borisova
   20^th Int. Laser Physics Workshop
   July 11–15, 2011, Sarajevo, Bosnia and Herzegovina.
4. Prof. Dr. Sci. Latchezar Avramov Assoc. Prof. Dr. Ekaterina Borisova, Irina Bliznakova, Alexandra Jeliazkova
   19^th Int. Conf. on Advanced Laser Technologies – 2011 (ALT'2011)
   3-8 Sept. 2011, Golden Sands Resort, Bulgaria.
5. Assoc. Prof. Dr. Ekaterina Borisova
   Int. School for Junior Scientists and Students on Optics, Laser Physics and Biophysics - Saratov Fall Meeting'2011
   Oct. 2011, Saratov, Russian Federation.
6. Alexandra Zhelyazkova,
   European School of Medical Physics 2011, Nov. 2011, France.

ONGOING RESEARCH PROJECTS

Financed by the National Science Fund

1. Contract **№ DMU 03/15** 3D Femtosecond laser microprocessing of biomaterials for application in medicine.
2. Contract **№ MU-03/245** Development and introduction of optical biopsy system for early diagnostic of malignant tumors 2011-2013.
3. Contract **№ V-UL-01/05** Optical biopsy of dysplasia and tumors in upper part of gastrointestinal tract.
4. Contract **№ BR-14/07** Optimization of photodetection and photodynamic inactivation of microbial pollution.
5. Contract **№ BIN-04/07** Inactivation of pathogenic bacteria of periodontal diseases – fluorescence diagnostics and photodynamic therapy.
6. Contract **№ DO-02-112/2008** National Center on Biomedical Photonics.
7. Contract **№ DO-02-58/2008** Development of infrastructure for neutron therapy in Bulgaria.

Financed by the European Social Fund

Contract **№ BG051PO001.3.3.04/56/2009** Development of interdisciplinary thinking and training of young scientists working in the field of light-matter interactions, 2009-2011.

Financed by other institutions

1. Agreement between Institute of Electronics and Institute of Organic Chemistry with Photochemistry Center "Application of biologically-active compounds for improvement of tumor tissues' fluorescent abilities".
2. Bilateral agreement between Institute of Electronics and Institute of Nuclear Research – Dubna, Russian Federation, "Radiation and radiobiological investigations in the

irradiation fields of Joint Institute of Nuclear Research Facilities and from environment".

COLLABORATIONS

1. In the frames of project National Center on Biomedical Photonics:
   - Center for Optical Diagnostics and Therapy, Erasmus Medical Center, Rotterdam, The Netherlands;
   - School of Pharmacy & Biomolecular Sciences, University of Brighton, UK;
   - University of Ioannina, Greece;
   - Institute of General Physics, Vienna University of Technology, Austria;
   - Optics and Biomedical Physics Department, Research-educational Institute of Optics & Biophotonics, Saratov State University, Russia;
   - Department of Electrical Engineering and Electronics University of Liverpool, Liverpool, UK;
   - Frederick University, Department of Mechanical Engineering, Cyprus;
   - University of Siena, Italy;
   - Organic and Natural Products Chemistry Group, Chemistry Department, University of Aveiro, Portugal;
   - Institute of Organic and Macromolecular Chemistry, University of Bremen, Germany;
   - Biophotonics Laboratory & Head Atmospheric Sciences Division, Centre for Earth Science Studies, India;
   - Biophysics and PDT group, Institute for Cancer Research, Norwegian Radium Hospital, Norway;
   - A. M. Prokhorov General Physics Institute, Russian Academy of Sciences, Moscow;
   - School of Science and Technology, University of Sussex, UK;
   - Physics Department, National Technical University of Athens, Greece;
   - Department Constructive and Technological Engineering, National Institute of Research and Development for Optoelectronics – INOE - 2000, Romania;
   - National Institute of Research and Development for Optoelectronics – INOE - 2000, Romania.
2. Coherent Population Trapping Effect in Potassium – CNR, Pisa, Italy.
3. Atomic vapors in metamatherials – University of Leuven, Belgium.
4. High resolution spectroscopy in quantum optics and metrology - Institute of Physics, Belgrade, Serbia.
5. P09073A HCI-induced ToF-SIMS studies of hard dental tissues, France.
6. ITSLEIF-exchange program of the EU Study of mechanisms of ultra-short laser ablation and desorption of biomolecules, 2010.
7. Development of new methods for laser diagnostics and therapy of dermatological and oncological diseases, Institute of Physics, National Academy of Sciences of Belarus, Minsk, Belarus.

LECTURE COURSES

Prof. M. Nenchev: Lecture courses on Quantum Electronics and Physics - 200 h, TU -Sofia, branch Plovdiv.

LABORATORY VISITS

1. Prof. Dr.Sc. L. Avramov,
   JINR, Dubna, Russia, Feb. 2011 and June 2011.
2. Assoc. Prof. Dr. E. Borisova,
   SGMU, Saratov, Russia, Sept. 2011.

LABORATORY

LASER SYSTEMS

HEAD: **Assoc. Prof. S. Gateva, Ph.D.**

TOTAL STAFF: **11**
RESEARCH SCIENTISTS: **9**
Assoc. Prof. S. Cartaleva, Ph.D.; Assoc. Prof. E. Alipieva, Ph.D.;
Ch. Andreeva, Ph.D.; E. Taskova, Ph.D.; P. Todorov, Ph.D.;
O. Vankov, K. Vaseva; N. Petrov; V. Sarova; A. Krusteva.

RESEARCH ACTIVITIES

The growing interest in coherent-population-trapping (CPT) resonances, prepared and detected under different conditions, has been stimulated by their numerous applications in high-resolution spectroscopy, quantum information storage and processing, metrology (atomic clocks), magnetometry, lasing without inversion, laser cooling, ultraslow group velocity propagation of light, etc. Building miniature and highly sensitive sensors ensuring reliable operation requires good knowledge of the CPT resonance shape and of the processes influencing it. In 2011 in our laboratory, systematical investigation of the contrast and width of the CPT resonances was performed in conventional vacuum cells, cells with antirelaxation coating, micro- and nanometric cells, and of laser cooled atoms.

The measurement of CPT resonances in uncoated Rb vacuum cells has shown that the shape of the resonances is different in different cells. In some cells, the resonance has a complex shape - a narrow Lorentzian structure, of the order of a few kHz, which is not power broadened and is superimposed on the power broadened CPT resonance. The results of the investigations performed on the fluorescence angular distribution are in agreement with the assumption that the narrow structure is a result of the atoms interacting with Rayleigh-scattered light. The results are interesting in view of indicating the cells vacuum cleanness and building magnetooptical sensors.

The narrowing of the resonances in cells with weak antirelaxation coating, observed for the first time in the Institute of Electronics, is used as basis of a methodology of controlling the antirelaxation coating quality. The detailed study of CPT in sodium atoms in a glass cell showed a narrow resonance with width of the order of 1 mG. The small width and the small amount of power broadening exhibited by this narrow spectral structure are related to the time spent by the atoms to re-enter the laser beam volume after collisions that preserve the orientation. This study offers insight into the mechanisms of atoms depolarization caused by collisions with the cell walls and represents a starting point for the development of techniques for the diagnostics of cell-coating parameters and new applications in metrology and magnetometry. This work was performed in collaboration with the University of Siena and CNR-Pisa and Institute of Automation and Electrometry, Novosibirsk.

The experimental study of CPT in potassium in a cell containing a buffer gas showed that the CPT resonance width is reduced by more than three orders of magnitude as compared to the cell containing pure potassium vapor. In K, this resonance narrowing occurs with high resonance contrast; such behavior is not observed in buffered cells containing Rb or Cs, where the optical pumping to the ground level non-interacting with the light is very efficient and depletes the population of the working ground Zeeman sublevels. The narrow CPT resonance of reduced fluorescence is transformed to one of enhanced fluorescence as the cell temperature is raised. The transformed resonance exhibits a higher contrast and lower width than those of the reduced fluorescence resonance. Hence, beside its scientific importance, the resonance sign reversal can be used for the improvement of the CPT resonance parameters. The experiments were performed in CNR – Pisa.

The shape and width of the CPT resonances were investigated in paraffin-coated Rb vapor cells at different laser power densities. To explain the bright structure in the resonance shapes at low laser powers analysis of the influence of different processes was performed. The resonances measured with high quality antirelaxation coatings showed that the resonance widths are determined by the shielding, so that higher quality of the laboratory and Earth magnetic field shielding is needed.

For miniaturization of the cells, a series of measurements of micro and nano size cells were performed with colleagues from Armenia and India and compared with the results observed in conventional cells of centimeter dimensions.

A new experimental approach was proposed, ensuring a width of the resonances narrower by an order magnitude than that evaluated by the atom-wall collisions model. The electromagnetically induced absorption (EIA) resonance was investigated on the D_2 line of Cs for atoms confined in cells with micrometric thickness. As the light intensity is raised, a resonance sign reversal takes place and electromagnetically induced transparency (EIT) resonance is observed. A similar EIA-to-EIT resonance transformation has not been observed in conventional cm-size cells. A theoretical model was proposed involving elastic interactions between the Cs atoms and elastic interactions between the Cs atoms and the micrometric-cell windows, both resulting in depolarization of excited states. The effect of excited state depolarization is confirmed also by the fluorescence (absorption) spectra measurement in micrometric cells with different thicknesses.

In a joint experiment with Armenian colleagues, a new narrow reduced fluorescence dip in the profile of the completely closed transition on the D_2 line of ^{133}Cs vapor confined in a cell of nanometric thickness was observed as well. The theoretical modeling of the fluorescence based on the optical Bloch equation for a two-level atomic system showed that the narrow dip in the fluorescence could be attributed to a very small loss in the excitation process of the degenerate transition examined. While the population in the atomic system remains constant, the depolarization of the excited level can lead to some loss in the efficiency of the optical transition excitation. Under the conditions of our experiment, no dip in the fluorescence was registered for cell thickness where a well pronounced Dicke peak in the absorption takes place. For the cells with nanometric thickness, previous investigations have demonstrated that the optical transitions fluorescence profiles differ significantly from the absorption profiles. However, our experiment showed that some traces of the coherent Dicke process contributing to the absorption line still remain in the fluorescence, which is a result of noncoherent processes.

The investigations performed at the Institute of Physics in Warsaw on the CPT resonance shapes with laser cooled atoms in magneto-optical trap (MOT) are of fundamental interest, because the investigations are in small volumes without Doppler broadening.

These investigations are interesting for the development of new sensors for photonics, their miniaturization and application for precise magnetic field measurements and metrology.

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2. Gateva S, Gurdev L, Alipieva E, Taskova E and Todorov G 2011 Narrow structure in the coherent population trapping resonances in rubidium and Rayleigh scattering *J. Phys.* B*: At. Mol. Opt. Phys.* **44** 035401 1-6 ISSN 0953-4075
3. Krasteva A, Slavov D and Cartaleva S 2011 Coherent population trapping resonances in Cs atomic vapor layers of micrometric thickness *Int. J. Optics* **2011** 683415 1-11 ISSN 1687-9384A
4. Gosh P N, Zabov P T, Cartaleva S S, Mitra S, Petrov N P, Roi B, Sarkisan D and Slavov D G 2011 Coherent population trapping resonances in micrometric cells with Cs vapor *News of Higher Education Institutions, Physics* **12**/2 126–31 (in Russian) ISSN 0021-3411
5. Gateva S, Alipieva E, Taskova E and Todorov G 2011 Coherent population trapping resonance structure in paraffin-coated Rb vacuum cells *Proc. SPIE* **7747** 77470G 1-6 ISBN 978-0-8194-8237-2
6. Mitra S, Hossain M M, Ray B, Ghosh P N, Cartaleva S and Slavov D 2011 Coherent laser spectroscopy of rubidium atoms *Proc. SPIE* **7747** 77470B 1-9 ISBN 978-0-8194-8237-2
7. Cartaleva S, Sargsyan A, Sarkisyan D, Slavov D and Vaseva K 2011 New narrow resonance in the fluorescence of closed optical transition observed in nanometric Cs-vapor layer *Proc. SPIE* **7747** 77470H 1-8 ISBN 978-0-8194-8237-2
8. Gozzini S, Marmugi L, Slavov D, Lucchesini A and Cartaleva S 2011 Coherent population trapping resonances in potassium with amplitude-modulated light *Proc. SPIE* **7747** 77470O 1-8 ISBN 978-0-8194-8237-2
9. Paul-Kwiek E, Głódź M, Kowalski K, Szonert J, Gateva S and Vaseva K 2011 Multiple peaks due to EIT and Autler-Townes effect in Lambda probing of the strongly driven 5P3/2 manifold of cold 85Rb atoms in MOT *Proc. SPIE* **7747** 77470I 1-10 ISBN 978-0-8194-8237-2
10. Głódź M, Kowalski K, Szonert J, Paul-Kwiek E, Gateva S and Vaseva K 2011 On the use of effective Rabi frequency as a global MOT parameter depending on the mean trapping beam power *Proc. SPIE* **7747** 77470J 1-8 ISBN 978-0-8194-8237-2
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12. Bliznakova I, Gurdev L, Dreishuh T, Vankov O, Stoyanov D and Avramov L 2011 A dual interpretation of experimental data concerning the propagation of laser light through tissue-like turbid media *Proc. SPIE* **7747** 774711 1-5 ISBN 978-0-8194-8237-2

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2. Biancalana V, Dancheva Y, Mariotti E, Moi L, Cartaleva S and Andreeva Ch Method and device for measurement of magnetic induction Eur. Patent No EP1570282 Priority 03122002/2009
3. Stoyanov D, Gurdev G, Dreischuh T, Vankov O and Protochristov Ch Radar on single spontaneously emitted gamma-photons Reg. № 65770 B1/2009

4. Stoyanov D, Gurdev G, Dreischuh T, Vankov O, Avramov L and Borissova E Optical multichannel transceiving system Reg № 65769 B1/2009

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3. Paul-Kwiek E, Glodz M, Kowalski K, Szonert J and Gateva S, The influence of Zeeman D2 transitions on probe absorption spectra in a multi-level Λ scheme for cold ^{85}Rb atoms *5th Workshop on Quantum Chaos and Localisation Phenomena* (May 20-22 2011 Warsaw Poland).
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ONGOING RESEARCH PROJECTS

Financed by the Bulgarian National Science Fund

1. Grant No: DO-02-108
   Coherent spectroscopy of alkali nano-layers for miniaturization of photonics sensors.
2. Grant No: BIn-2-07
   All–optical diode-laser-based magnetometer:

miniaturization and parameters optimization, Bulgarian-Indian inter-governmental program of cooperation in science and technology (2008-2011)
3. Grant No: DMU-02-17.
   Velocity distribution of alkali atoms in micrometric thin cell,
4. Grant No: DO-02-112/2008
   National Center on Biomedical Photonics.
5. Grant No: DO-02-107/2009,
   Improving the resolution of Thomson scattering lidars by deconvolution-based algorithms.

Financed by the European Funds

1. Development of interdisciplinary thinking and training of young scientists working in the field of light-matter interactions, Financed by the European Social Fund, Human Resources Development Operational Programme, Contract No BG051PO001. 3.3.04/56/2009 2009-2011.
2. Improving the resolution of Thomson scattering LIDARs by application of novel deconvolution-based algorithms, Contract of Association between the European Atomic Energy Community (EURATOM) and INRNE in the frame of 7th Framework Programme of the European Atomic Energy Community (Euratom), No.FU07-CT-2007-00059.

Financed by BAS

1. Coherent spectroscopy of alkali nano-layers for miniaturization of photonics sensors.
2. Nonlinear magnetooptical effects on Zeeman sublevels of alkali atoms.

COLLABORATIONS

1. University of Siena, Siena, Italy Framework agreement of academic cooperation, Establishment of PhD School on Laser Spectroscopy – Common Doctorate.
2. National Institute of Optics (INO-CNR), Pisa, Italy.
3. University of Calcutta, Kolkata,India.
4. Jadavpur University, Kolkata, India
5. Institute for Physical Research, NAS of Armenia, Ashtarak-2, Armenia.
6. Institute of Automation and Electrometry, RAS, Siberian Branch, Novosibirsk, Russia.
7. Institute of Physics, Polish Academy of Sciences, Warsaw, Poland.

LABORATORY VISITS

Gateva S,
Institute of Physics, Polish Academy of Sciences, Warsaw, Poland, 14 days.

GUESTS

Gosh P, University of Calcutta, Kolkata, India.
Moi L, University of Siena, Siena, Italy
Mabud Hossain, University of Calcutta, Kolkata, India.

LABORATORY

NONLINEAR AND FIBER OPTICS

HEAD: **Assoc. Prof. L. Kovachev, Ph. D.**

TOTAL STAFF: **5**
RESEARCH SCIENTISTS: **2**
Assoc. Prof. L. M. Ivanov, Ph.D.; K. L. Kovachev, Ph.D.; A. Dakova; V. Slavchev.

RESEARCH ACTIVITIES:

1. Filamentation of femtosecond laser pulses

When a femtosecond laser pulse with power above the one critical for self-focusing propagates in air, a number of new physical effects have been observed, such as long-range self-channelling, coherent and incoherent THz and GHz emission, asymmetric pulse shaping, super-broad spectra etc. A remarkable effect is also that some of the light pulses propagate over distances of several kilometres, while preserving their spectrum and shapes. In one typical experiment in the near zone, up to 1-3 m from the source, when the pulse intensity exceeds $I>10^{12}$ W/cm^2, an initial self-focusing and self-compressing starts. This leads to an expansion of the k_z spectrum to a super-broad asymmetric one ($\Delta k_z \sim k_0$). The process increases the core intensity up to 10^{14} W/cm^2, where a short plasma column in the nonlinear focus is observed. The standard model describing the propagation in the near zone is a scalar spatio-temporal nonlinear paraxial equation including additional terms with plasma ionization, higher order Kerr terms, multiphoton ionization and others. The basic model works well partially in the near zone because of the fact that the paraxial approximation is valid only for pulses with narrow-band spectrum $\Delta k_z << k_0$. In the far-away zone, plasma generation and higher-order Kerr terms are also included as necessary for the balance between the self-focussing and plasma defocusing and for obtaining long range self-channelling in gases.

However, the above explanation of filamentation is difficult to be applied in the far-away zone. The plasma density at long distances from the source is too small to prevent self-focusing. There are basically two main characteristics which remain the same at these distances - the super broad spectrum and the width of the core, while the intensity in a stable filament drops to a value of 10^{12} W/cm^2. The higher-order Kerr terms for pulses with intensities of this order are also too small to prevent self-focussing. The experiments, where observation of long-range self-channelling without ionization was realized, show the need to change the role of the plasma in the laser filamentation. In addition, there are difficulties with the physical interpretation of the coherent THz radiation as a result of plasma generation. The light pulse near the nonlinear focus emits incoherent and *non-homogenous* plasma, while the coherent THz radiation requires *homogenous* plasma with fixed electron density of the order of 10^{16} cm^{-3}. Only *homogenous* plasma can generate coherent THz emission, but such kind of plasma is absent in the process of filamentation. The contribution from ionization in the far-away zone is negligible and this is the reason to look for other physical mechanism which could lead to emission of coherent THz or GHz radiations. Our analysis of the third-order nonlinear polarization of pulses with broadband spectrum indicates that the nonlinear term in the corresponding envelope equation oscillates with frequency proportional to the group and phase velocity difference. Actually, this exceeds by a factor of three well-known carrier-to-envelope phase (CEP) difference. This oscillation induces THz generation, where the generated frequency is exactly $\omega_{nl} = 93$ GHz for a pulse with superbroad spectrum $\Delta k_z \sim k_0$ with a carrier wavelength of $\lambda_0 = 800$ nm. All contradictions pointed to above between the latest experiments and the standard model make it necessary to look for other physical mechanisms and a new mathematical model for the description of these processes.

In our investigations, we attempted to answer the following main question: What will happen in the linear and nonlinear regime of propagation, when the pulse acquires a super-broad spectrum? To solve this problem, we presented a mathematical model based on the amplitude envelope (AE) equation, up to the second order of dispersion, without using paraxial approximation. The diffraction of pulses with super-broad spectrum or pulses with few cycles under the envelope is closer to a wave type one. Another important difference from the standard model is in the nonlinear part. We showeed that if CEP is used, the third-order nonlinear term for fs pulses cannot be separated into a self-action and a higher harmonics (GHz) term. For such pulses, a new physical mechanism of balance between non-paraxial (wave-type diffraction) and third-order nonlinearity appears. An exact analytical three-dimensional soliton solution in this regime was found.

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2. Belyaeva T L, Serkin V V, Aquero M, Hernandez-Tenorio C and Kovachev L M 2011 Hiden features of the soliton adaptation law to external potentials: optical and matter-wave 3D nonautonomous soliton bullets *Laser Phys.* **21**/1 258-63 DOI 10.1134/ S1054660X11010038 ISSN 1054-660X
3. Kovachev L M and Kovachev K L 2011 Ionization-free filamentation in gases *Proc. SPIE* **7751** 7775128-1-9 DOI 10.1117/12.87921
4. Belyaeva T L, Hernandez-Tenorio C, Perez-Torres R, Kovachev L M and Serkin V N Enigmas of optical and matter-wave nonlinear soliton tunneling effects *Proc. SPIE* **7747** 77471N ISSN 0277786X ISBN 978-081948237-2 DOI 10.1117/12.881617
5. Perez-Torres R, Belyaeva T L, Hernandez-Tenorio C, Kovachev L M and Serkin V N 2011Enhanced soliton spectral tunneling effect of self-compressing nonautonomous colored femtosecond solitons *Proc. SPIE* **7747** 77471L ISSN 0277786X ISBN 978-081948237-2 DOI 10.1117/12.881660
6. Hernandez-Tenorio C, Belyaeva T L, Perez-Torres R, Kovachev L M and Serkin V N Hidden features of soliton adaptation law to external potentials: Optical and matter-wave soliton bullets in nonautonomous and nonlinear systems *Proc. SPIE* **7747** 77471G ISSN 0277786X ISBN 978-081948237-2 DOI 10.1117/12.881663
7. Belyaeva T L, Hasegawa A, Kovachev L M and Serkin V N 2011 3D soliton-

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8. Kancheva P, Dakova A, Dakova D, Slavchev V and Pavlov L 2011 Three-dimensional solutions of a vector type NLS equation with spatial dependence of the nonlinear refractive index *Proc. SPIE* **7747** 77476L ISSN 0277786X ISBN 978-081948237-2

ONGOING RESEARCH PROJECTS

Financed by the Bulgarian National Science Fund

1. DVU01/0114 - Linear and nonlinear interaction of ultra short optical pulses with submicron structures (2009).

Financed by the Bulgarian Academy of Sciences

1. Propagation of ultra short optical pulses in media with non-sstationary optical and magnetic response (2009-2011).

LECTURE COURSES

Fiber Optic Communication Systems; Optics; Electricity and Magnetism;
South-Western University, Blagoevgrad, Bulgaria.

LABORATORY

LASER RADARS

HEAD: **Prof. D. Stoyanov, Dr.Sc.**

TOTAL STAFF: **13**
RESEARCH SCIENTISTS: **11**

Assoc. Prof. L. Gurdev, Ph.D.; Assoc. Prof. T. Dreischuh, Ph.D.; Assoc. Prof. V. Mitev, Ph.D.; Assoc. Prof. V. Pencheva, Ph.D.; Z. Peshev, Ph.D.; S. Penchev, Ph.D.; N. Kolev, Ph.D.; A. Deleva, Ph.D.; Ts. Evgenieva, Ph.D.; I. Grigorov.

RESEARCH ACTIVITIES

1. Lidar monitoring of the atmosphere

Sofia Lidar Station at the Institute of Electronics, being one of the stations working in the framework of the EARLINET – ASOS project (European Aerosol Lidar Network – Advanced Sustainable Observation System), was involved mainly in the following research activities:

- Regular lidar measurements aimed to establish a common database from measurements of the atmospheric aerosol backscatter coefficient profiles. The measurements are performed twice weekly, every Monday at noon when the sun is in the zenith and in the evening during sunset, and every Thursday at sunset. A specialized EARLINET database collects the results from the longtime monitoring of atmospheric aerosols by regular lidar measurements. It contains valuable information for the atmospheric processes over Europe and offers an opportunity for further improvement and validation of atmospheric models and retrieving algorithms applied for climatological investigations;
- Observation of special phenomena, such as unusually high concentrations of aerosols in the troposphere. Their appearance may be due to transportation of dust from Sahara over the Mediterranean Sea to Europe, volcanic eruptions, formation of smoke layers as a result of forest or industrial fires, intense photochemical smog, etc. This type of lidar observations were carried out upon notification by the program coordinator for upcoming dust events above the territory of Europe. The notification was based on satellite observations and weather forecasts;
- Measurements in the frame of cooperation with satellite missions with the objective of conducting a detailed comparison of ground-based and spaceborne lidar data sets over Europe. These measurements are related to the *Quid pro Quo* (QPQ) validation measurements of the project Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations CALIPSO (http://calipsovalidation.hamptonu. edu/ QPQ_plan062206.htm). CALIPSO is a free-flying lidar in space and provides data on atmospheric clouds and aerosols needed for climate studies. Ground located EARLINET stations were deemed an optimal tool for validating CALIPSO lidar data and providing the information necessary to fully exploit the information from that mission.

Each lidar measurement lasts for 1-4 hours. The data-processing applies a 30-min time-integration interval, so that each lidar measurement yields about 2 to 8 data files of an atmospheric parameter measured – backscatter or extinction coefficient profile. The lidar group in Sofia has collected data from more than 430 lidar measurements that correspond to

about 880 data-files uploaded on the common EARLINET database.
(I. Grigorov, D. Stoyanov, G. Kolarov, Z. Peshev, A. Deleva)

A lidar with a CuBr-vapor laser, operating in a photon-counting mode, located at IE BAS, a ceilometer located at the Astronomical Observatory in Borisova Gradina Park) and meteorological stations located at the Central Geophysical Station (Plana Mountain) and the Astronomical Observatory were used in this investigation. The lidar and ceilometer data are compared and analyzed.

We also obtained such information by examining the weather-forecast maps for the Euro-Mediterranean zone issued by Barcelona Supercomputing Center (BSC) and accessible via Internet. These maps give an image of the wind direction and speed, the position of cloud fields and the magnitude of the dust load in the atmosphere above North Africa and Europe. Another source of information about the origin of the aerosol layers is offered by the HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) model.

We obtained results from the joint use of a lidar, a ceilometer and meteorological stations. The comparison between the lidar and ceilometer data about the ABL height showed good agreement. The lidar data revealed the ABL structure better in the hours after sunset, together with the presence of a dense aerosol layer between ABL and the free atmosphere, which was the assumed to be due to trans-border transport of volcanic ash from Iceland. The results obtained were juxtaposed with HYSPLIT back trajectories simulations and confirmed the assumption about volcanic ash transport. The ceilometer data about the ABL height were juxtaposed with the behavior atmospheric meteo-parameters at two heights; good agreement was obtained. This set of devices can be used for scientific research, as well as for ecological purposes in the region of the ABL and in the whole troposphere including in case of long-range transport.
(N. Kolev, I. Grigorov, Ts. Evgenieva, G. Kolarov, I. Kolev, D. Stoyanov)

Based on a novel combination of approaches and instruments, we obtained campaign-based results from atmospheric boundary layer height and aerosol optical depth measurements carried out at two different experimental sites in Sofia, as well as from three-point measurements of the aerosol number concentration. Several instruments (a lidar, a ceilometer, an aerosol particle counter, a sun photometer and meteorological sensors) were used. Based on joint interpretation of the instruments' data, we assessed the influence of the atmospheric aerosol on the planetary boundary layer and the significant influence of aerosol layers and high clouds on the aerosol optical depth. The measurements of the aerosol optical depth in the city yielded values in the range 0.22 to 0.41 for cloud-free skies, and up to around 0.8 under partly cloudy conditions. The information obtained during the two campaigns indicates that the aerosol particle concentrations were lower in park areas than along heavy-traffic thoroughfares in the city, but higher than in the mountain area. In conclusion, our study demonstrated the potential of employing several instruments for the study of the boundary layer and the aerosol over large, valley-situated and heavily urbanized city areas.
(Ts. Evgenieva, N. Kolev, I. Kolev)

Regular two-wavelength lidar measurements (at λ_1=1064nm and λ_2=532nm) were conducted, related to the short-term dynamics of aerosol layers in the low troposphere over urban and mountainous areas, as well as of Saharan dust during events of dust-transport. Distinguished were the behavioral peculiarities of the fine- and coarse-mode aerosol fractions. In progress are additional measurements and processing of the lidar data obtained.

(Z. Peshev, T. Dreischuh, A. Deleva, D. Stoyanov, E. Toncheva)

Results of prior lidar observations on aerosol layers located in the upper troposphere, the tropopause, and the low stratosphere (at altitudes 8-14 km ASL) over Sofia, Bulgaria, by using a two-wavelength elastic scattering lidar were processed and analyzed. Layers are identified as comprising ashes ejected into the atmosphere by Alaska's Mt. Redoubt volcano during its explosive activity in March – April 2009. A number of peculiarities concerning the layer's origin, content, density distribution and variations, temporal evolution, and particle size distribution were revealed. The NOAA HYSPLIT backward- and forward air-parcel transport trajectories undoubtedly proved the volcanic origin of the high-altitude aerosol layers as emitted by the Mt. Redoubt volcano. As supported by the available jet stream analysis maps, the volcanic layers observed have been subjected to a long-range (18 000 km) air-mass transport at tropopause altitudes, mainly driven by the North-Polar Jet Stream and partially by the Subtropical one, as a result of stream interaction, which, in combination with regional winds, have delivered volcanic ashes to the lidar station site. The first day of lidar measurements, immediately after the initial incursion of the volcanic aerosol over the Sofia region, provided an opportunity to measure the aerosol fields in their motion, whereas the second one (five days later), being a period of relative equilibrium, provided conditions for revealing after-effects and results of the layer's local evolution. In the first case, two close but well distinguished volcanic layers at and above the tropopause and one below it were identified. The qualitative particle size characterization, based on profiling and frequency-count analysis of BAE, revealed two-component aerosol content in an ongoing process of gravitational settling of the coarser fraction. Estimations of the BSC-related layer equivalent mass-center height showed a relatively stable structure without considerable density re-distribution. The dominating particle size modes were estimated to be in the submicron range. The measurements conducted on the second day revealed a quite different picture of volcanic aerosol distribution. The atmospheric processes at altitudes around the tropopause and, in particular, the process of ash particle gravitational settling, have transformed the well-expressed stratified aerosol field structure previously observed to one dominated by a compact distinct volcanic layer from above and an intense thick cirrus cloud from below, with a relatively smooth aerosol density in between. The cirrus cloud was assumed to be formed by volcanic ash nucleation. Analyzing the upper volcanic layer by using the temporal evolutions of the BSC profiles at the two wavelengths, as well as by estimating the evolution of the layer's equivalent backscatter-related mass center and integral optical depth, different pictures of the internal mass and density redistributions were ascertained for the coarser and the finer volcanic aerosol fractions. The peculiarities observed were regarded to be a result of internal redistribution of the volcanic ash fractions, rather than of the layer translational motion. Anomalously low values of BAE were obtained for the volcanic layer at 14 km height. Based on the analysis of the BAE profile obtained and the BAE frequency-count distribution, as well as on a comparison to data of a previous measurement, it was ascertained that the anomaly observed was a result of and indication for aggregation of the finest volcanic ash particles composing the layer. The results of the reported two-wavelength lidar measurements showed that, by using an appropriate additional treatment of lidar data only, such as the introduced BSC versions of the equivalent aerosol layer mass center, layer optical depth, and frequency-count analysis of BAE,

additional valuable information and data can be obtained for better characterization of the aerosol content, motion, and particle size distribution, as well as for revealing peculiarities remaining hidden after the usual determination of the aerosol BSC or extinction profiles.
(Z. Peshev, T. Dreischuh, D. Stoyanov)

2. Some experimental and theoretical research

A theoretical method was employed to investigate the spectral application of pulsed broad-line laser diodes for the development of a differential absorption hygrometer. These lasers' high-power radiation is particularly advantageous in monitoring the atmospheric humidity within the water-vapor rotational-vibrational absorption spectrum, namely, 0,9-0,915 μm. The strong spectrum at the selected wavelength of measurement is free of spectral species of other gases with an optimal coefficient of absorption throughout the troposphere. The dual-beam set-up proposed employs successive pulses of a complementary pair of two similar types of laser diodes tuned in and out of the relevant spectrum. The explicit contribution to the DIAL signal is determined by computer convolution summing all absorption lines and integrating numerically in the relevant frequency range. The resultant integral atmospheric laser radiation absorption over the measured lidar path is investigated by a convolution integral, taking into account the dependence of the complex profile of the laser line on the pulse duration and the theoretical HITRAN line strengths of absorption lines. The contribution to the laser radiation extinction due to the spectral dependence of the interfering processes of atmospheric Mie and Rayleigh scattering in the absorption of the DIAL signal detected was assessed within a systematic error of 1 %. Retrieval of the atmospheric humidity content from a typical DIAL measurement profile was performed by using measurement intervals referring to real atmospheric sonde data under daytime dry meteorological conditions in Sofia. The dependence of the integral absorption used is practically insensitive to variations in the atmospheric pressure and temperature due to the preservation of the lines strengths in the spectrum. The estimated total absolute error of DIAL measurement including HITRAN database is within 10 %, which demonstrates that accurate lidar atmospheric humidity measurements are feasible.
(S. Penchev, V. Pencheva)

A method of photothermal modulation of the optical reflectance and a laser system were implemented with the purpose of studying nanostructured ferromagnetic and antiferromagnetic materials and multiferroics, as such materials are expected to find applications in next-generation of electronic devices in spintronics and optoelectronics. The theoretical analysis verified the method, based on Drude model, for investigating the surface of nanolayers of $La_{0,7}Sr_{0,3}MnO_3$ (LSMO) and other conductive nanolayers.

Magnetic materials characterized by strong magnetoresistive effect and spin polarization around phase transitions were investigated theoretically and experimentally by considering the of colossal magnetoresistance dependence on the photothermal reflectance coefficient. The optical reflectance modulation is a dominant effect in the model of photothermal spectroscopy of magnetoresistive multiferroics.

A contactless photothermal spectroscopy laser system was developed with purpose of studying the homogeneity of nanolayers. The method's selective ability was verified by scanning the boundary surface of a deposited layer and the adjacent substrate. The spatial resolution of the employed system was determined by a step of 50 μm between the experimental points on both axes. The possibility was demonstrated to visualize the quality of nanolayers surface and to detect structural defects with reliable resolution. The method is suitable for implementation of new electronic elements, such as magnetic memories and sensors.

Photothermal non-destructive analysis of magnetoelectric, ferromagnetic and antiferromagnetic media was conducted based on the effect of modulated optical reflectance (MOR).

The potential was explored of a laboratory setup for photothermal non-destructive analysis based on modulated high-power CW laser diodes.

The thermal behavior of samples around the Curie phase transition in a magnetic field was examined.

A system was implemented for temperature regulation and thermostatting of magnetoelectric samples in view of conducting photothermal nondestructive analysis.

(V. Pencheva, S. Penchev)

3. Lidar diagnostics of thermonuclear plasma.

Further development and generalization were performed of a series of results obtained formerly by us concerning the advantages and limitations of software deconvolution-based approaches to improving the resolution of lidar sensing of the atmosphere, thermonuclear plasmas, dense media, etc. New, more general expressions were obtained of the statistical error increase accompanying the lidar profiles deconvolution. The new expressions take into account the difference between the correlation time of the noise induced by the signal and that of the noise due to background radiation.

(L. Gurdev, T. Dreischuh, D. Stoyanov)

Detailed simulations were performed of deconvolution procedures for the case of Thomson scattering lidar sensing of thermonuclear plasmas. As a result, an excellent confirmation was demonstrated of the aforementioned theoretical expressions. The results from the simulations also showed that the deconvolution methods would be still more effective in the new generation of thermonuclear reactors such as ITER, DEMO, etc.

(T. Dreischuh, L. Gurdev, D. Stoyanov)

An extended set of simulations was performed based on the novel approach developed earlier for recovering, on the basis of Thomson scattering lidar data, of the electron temperature and concentration pedestals in the thermonuclear JET reactor in H-mode of operation. The method is based on the use of an original technique for superfine sampling of the lidar response and a nonlinear fit of a model of the convolved lidar profile (taking into account the system response function and models of both pedestals) to the experimentally measured lidar profile. It was shown that the approach proposed ensures a high-resolution recovery of the pedestals, with resolution intervals below 1 cm.

(D. Stoyanov, T. Dreischuh, L. Gurdev)

A novel method was developed and analyzed for determining the full set of numerical parameters (position, width and amplitude) of the electron temperature pedestal function from upgraded JET core lidar data. The method's performance was tested by computer simulations confirming the possibility to obtain novel important information about the high-temperature plasma processes on the torus edge. An important advantage of the method is the possibility to use the same lidar profile data in the same time scales for the analysis of the mutual links between the plasma processes on the edge and inward the torus. These links contain important information connected with the appearance of the edge localized modes (ELM) on the torus wall.

(D. Stoyanov, T. Dreischuh, L. Gurdev)

A set of experimental JET core lidar data was processed; the data was obtained using the partially upgraded lidar (detector

in the first spectral channel only). The lidar profiles were deconvolved by the instrument function generated using a computer model developed by us. The very good quality was demonstrated of the deconvolved lidar profiles, as well as of the deconvolved electron density profiles.
(D. Stoyanov, T. Dreischuh, L. Gurdev)

4. Laser probing of turbid media for optical tomography applications

It was shown that not only in the case of Gaussian, but in the case of Henyey-Greenstein scattering indicatrix as well, the small-angle approach to solving the radiative-transfer equation allows one to achieve relatively simple analytical description of the spatial distribution of the intensity of the forward propagating and scattered laser radiation in turbid media. Experiments were conducted in view of determining the spatial distribution of the intensity of the forward-propagating laser light. The results obtained are consistent with the theoretical predictions and show that the analytical expressions derived allow one to determine, on the basis of the experimental data, the optical characteristics of the turbid media,i.e., the extinction, scattering, absorption and reduced-scattering coefficients, and the factor of scattering anisotropy.
(L. Gurdev, T. Dreischuh, I. Bliznakova, O. Vankov, L. Avramov, D. Stoyanov)

A detailed theory was developed, based on the small-angle approximation, of the forward propagation and scattering of laser radiation in turbid media. The validity limits of the theory were also outlined. Analytical expressions were obtained of the optical characteristics of turbid media through experimentally-measurable characteristics of propagating laser radiation beams. The intensity distributions of forward-propagating laser light beams in different media under investigation were determined experimentally. Then, using the analytical expressions derived, the optical parameters of the media were estimated. The turbid media used in the experiments were solutions of different amounts of Intralipid – 20% emulsions in 14 l distilled water. The experimental results are in agreement with the analytical results within the validity limits of the theory. The values obtained of the extinction and reduced-scattering coefficients and the anisotropy factor of the media depend, in general, nonlinearly on the solution turbidity.
(I. Bliznakova, L. Gurdev, T. Dreischuh, O. Vankov, L. Avramov, D. Stoyanov)

5. Signal processing

An algorithm for removing noise and background radiation from measured lidar profiles was theoretically motivated and developed. The algorithm is based on the calculation of model profile of a hypothetical lidar response from an only molecular atmosphere (no aerosols). Standard models of molecular atmospheric scattering were used in the calculations. Using the analytical expression obtained, the lidar response was calculated with an accuracy to a constant to be determined from the measured lidar profiles. Varying the value of this constant, in accordance with the values of the lidar profile at the end of the sounding path, we were able to determine the best agreement between the model calculations and the lidar profiles. This defines the precise value of the noise contained in the measured lidar profile to be removed when retrieving the backscattering coefficient (or extinction) of the atmosphere.
(I. Grigorov)

An additional package to the system LIDAR (in MATLAB v.5.3) was developed that makes use of the algorithm theoretically developed for fitting real lidar profiles with calculated model profiles for molecular atmosphere. This package calculates the value of the parasitic background and white noise from the electronics and removes it from the lidar data. The procedure is visualized through a

graphics interface. Calculation was carried out of the statistical error due the application of this procedure in the processing of lidar data by Fernald's inverse algorithm.
(I. Grigorov)

A study was conducted on the effects of spatial and temporal variations of the optical signal detected from the backscattered laser light. A new pattern was also created, together with a laser detector, intended to detect simultaneously the presence, the location and the level of an air turbulence, along with measuring the aerosol content in the atmosphere. This makes it possible to apply corrections to the aerosol backscattering ratio profile according to the level of the air turbulence. Spatial and temporal realizations derived from the backscattered laser light during laser sounding of the atmosphere could be captured by an image receiver. We can use them for extracting interferograms by using an interferometer. To determine the presence, the location and the level of an air turbulence, the interferograms must be analyzed and processed. To determine the aerosol content ratio in the atmosphere, the fluctuating intensity of the interference fringes must be analyzed and processed.
(V. Mitev)

6. Lidar hardware & software

A new CuBr-vapor laser was purchased, with a lower pulse repetition rate (~ 9 kHz, instead of 13.5 kHz) and higher emitted power. The laser was incorporated into the lidar system, thus allowing an increase of the height of atmospheric probing up to 14-15 km. This enhanced the reliability of calculating the profiles of backscattering (or extinction) of the atmosphere by inverse methodology. Bearing in mind that at a such a height the laser radiation backscattering is mainly due to molecules of atmospheric gases (Rayleigh scattering), by selecting a reference point for starting the calculations at the end of the lidar path (14-15 km), we can assume with more accuracy equality between the model and reference point values of atmospheric backscatter profiles.
(I. Grigorov, G. Kolarov, D. Stoyanov)

The wavelength-separating module of the 3-channel combined Mie-Raman lidar was upgraded and optimized. The opto-mechanical configuration of the module was changed by introducing new dichroic beam-splitters and interference filters, with optimized reflection and transmission. The renovated module was adjusted and mounted on the lidar and test measurements were carried out. The tests showed excellent separation of the backscattered radiation spectral components (~98%), resulting in considerable enhancement of both the signal intensity and the signal-to-noise ratio in each channel. This allows substantial improvement of the spectral purity, reliability, and accessible ranges of lidar sounding.

The optical background discrimination level of the lidar's Raman channel was increased from 10^4 to 10^8 (to optical density OD=8), meeting the requirements to Raman lidar measurements, including the EARLINET standards (OD≥6). Initial results of measurements with the Raman cannel were obtained. Reliable detection of Raman signals from up to 8 km was achieved. After installing the corresponding software, the Raman channel will be involved in regular atmospheric measurements in order to retrieve more precisely the aerosol extinction and backscattering coefficients.

The assembling and mounting are in progress of a movable opto-mechanical design unfolding and folding back a set of lidar mirrors (including a large-area one) for vertical sounding of the atmosphere. Applying the device, about two-fold increase of the accessible height of lidar measurements (from 16 km to 30 km) will be achieved, providing an opportunity for

lidar detection and observation of objects in the high stratosphere.
(Z. Peshev, A. Deleva)

An improved version of the software developed in the laboratory for sorting, initial treatment, and statistical processing of lidar data was adopted for use. The program enhances considerably the rate and efficiency of processing lidar data.
(Z. Peshev, T. Dreischuh, E. Toncheva)

Microprocessor system for regulating the thermostat and temperature scanning of magnetic samples.

Registration system of modulated reflectance signals off a sample surface and their transmittance to the computer system for further processing.

Linear analogue thermostat with Peltier elements and a vacuum chamber allowing external temperature manipulation and control.

A two-channel high-frequency buffer transimpedance amplifier for synchronization of low-impedance high-rate registration input with a high-impedance signal source.

Models of algorithms and specialized software were developed for the system of laser photothermal nondestructive control.

Models and performance for transition to another standard of interface connections. such as USB v 2.0, between the computer and the separate registration systems were investigated concerning hardware, software and technological support. The potential of adapting high-rate input data to the real interface input during lidar operation was analyzed.
(S. Penchev, V. Pencheva)

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2. Evgenieva Ts, Wiman B, Kolev N, Savov P, Donev E, Ivanov D, Danchovski V, Kaprielov B, Grigorieva V, Iliev I and Kolev I 2011 Three-point observation in the troposphere over Sofia-Plana mountain, Bulgaria *Int. J. Remote Sensing* **32**/24 9343-63
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14. Kolev N, Evgenieva Ts, Donev E, Savov P, Nenchev R and Kolev N 2011 Lidar determination of the atmospheric boundary layer height over Sofia, Bulgaria, *Proc. 5th Workshop on Optoelectronic Techniques for Environmental Monitoring* (2011 Magurele Romania) pp 64-70
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   Method for determining optical and spatial characteristics of an inclusion in a turbid medium using multiple-scattering optical tomography,
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ONGOING RESEARCH PROJECTS

Financed by the National Science Fund

1. DO O2-112/2008, National centre for biomedical photonics (in part for optical tomography).
2. DO- 224/2008, Novel magnetic and magnetoelectrical materials for the next generation electronic components.
3. DO 02-107/2009, Improving the resolution of Thomson scattering LIDARs by application of novel deconvolution – based algorithms.
4. DO 02-127/08 Tropospheric ozone in a city and a mountain. A comparative study of the air quality and sustainable ecological development in Plana Mountain and the city of Sofia.

Financed by the Steering Council of the Bulgarian Academy of Sciences

1. Investigation of the temporal dynamics of fine and coarse aerosol components in the troposphere by two wavelengths lidar.
2. Remote determination of some statistical characteristics of non-uniform media by image processing.

3. Lidar-radiometric probing of aerosol characteristics in the PBL and the free atmosphere above a mountain valley.
4. Laser sensing of tissue-like turbid optical media for localizing characteristic inhomogeneities.
5. Laser system and methodology for optical probing of novel magnetic and magnetoelectrical materials for the next generation of electronics components.
6. Lidar atmospheric system using high-power diode lasers.
7. Error analysis of the lidar Thomson scattering probing of the electron temperature and density of thermonuclear plasma.
8. Lidar investigation of aerosol pollutions in the troposphere by Raman-aerosol lidar.

European projects

1. European aerosol research lidar network: advanced sustainable observation system, EARLINET – ASOS, **FP6**, 2006-2011, Contract No 025991 (http://www.earlinet.org).
2. Improving the resolution of Thomson scattering LIDARs by application of novel deconvolution–based algorithms, Contract of Association between the European Atomic Energy Community (EURATOM) and INRNE in the frame of 7th Framework Program of the European Atomic Energy Community (Euratom) No FU07-CT-2007-00059.
3. Aerosols and Clouds. Long term data base from space-borne lidar measurements, CALIPSO Program, European Space Agency, ESA.
4. Aerosols, clouds, and trace gases research infrastructure network, ACTRIS, **FP7**, 2011-2014. Contract Number 262254, WP2.

COLLABORATIONS

1. Optical remote sensing studies of the atmospheric boundary layer characteristics using laser radar,
   Institute of Tropical Meteorology, Pune, India (in the framework of the Indo-Bulgarian inter-governmental program of cooperation in science & technology, Grant № INT/Bulgaria).
2. Advanced lidar technologies for tropospheric aerosol studies,
   Istituto di Metodologie per l'Analisi Ambientale, CNR, Italy.
3. Lidar investigation of aerosol fields transformations in urban industrial zones, Institute of Physics, National Academy of Belarus, Minsk, Belarus.

LABORATORY

MICROWAVE PHYSICS AND TECHNOLOGIES

HEAD: **Assoc. Prof. O. Yordanov , Ph.D**.

TOTAL STAFF: **14**
RESEARCH SCIENTISTS: **12**

Assoc. Prof. V. Atanassov, Ph.D.; Assoc. Prof. I. Sirkova, Ph.D.; Assoc. Prof. M. Taslakov, Ph.D.; E. Krasteva, Ph.D.; P. Zabov, Ph.D.; B. Simeonova Ph.D.; I. Atanasov, PhD; K. Kostov; V. Ranev; L. Mladenov; L. Vulkova.

RESEARCH ACTIVITIES

1. Emerging simple and extended chaotic systems

A pilot study was carried out of the dynamics and the propagation of information in extended communication networks. On the basis of different estimates of correlation and cross-correlation functions, it was established that the traffic in such networks exhibits approximate scale invariance. This symmetry is expected to furnish new tools for studying and modeling of communications in complex systems.

The methodology for modeling rough morphologies based on approximate scale invariance was extended and applied to soil surfaces measured using a laser profilometer and images of technological coatings obtained by an atomic force microscope. The soil morphologies correspond to different treatments.

2. Microwave radiometers for remote sensing applications

A new algorithm for sky calibration of L-band radiometers with built-in cold and hot noise sources for internal calibration was developed jointly with scientists from the Institute of Bio- and Geosciences, Research Center Jülich, Germany. An effective transmission coefficient was introduced, which accounts for antenna and cable losses, and for the variations of the radiometer gain due to air temperature changes. The effective transmission coefficient was estimated from the recorded radiometer data, the measured air temperature and the downwelling cosmic and atmospheric radiation calculated using the model of Pellarin et al. This effective transmission coefficient was then used for correcting the radiometer estimates of brightness temperature of the object under investigation obtained using the internal calibration only. The new algorithm was tested with data obtained with the L-band radiometer Jülbara at the Selhausen experimental site of the Institute of Bio- and Geosciences, Research Center Jülich, Germany. The brightness temperature estimates were compared with the brightness temperature calculated using the measured cable losses and measured air temperature. Significant improvements were achieved by the new calibration routine.

The low-cost X-band radiometer, developed previously under a Bulgarian-Vietnamese joint research project, was used as a supporting instrument for field investigations of smooth and rough bare soils at the Selhausen experimental site of the Institute of Bio- and Geosciences, Research Center Jülich, Germany. The experimental data obtained with the

L-band radiometer Jülbara at the Selhausen experimental site will be used for testing of models for soil roughness effects correction.

A coupled inversion procedure for estimating soil hydraulic properties of ploughed bare soil from time lapse L-band brightness temperature data was investigated thoroughly jointly with scientists from the Institute of Bio- and Geosciences, Research Center Jülich, Germany. The complex inversion procedure connected a one-dimensional vertical water flow modeling (hydrological simulator HYRDUS 1D) and a coherent radiative transfer model. Correction for the soil surface roughness effects was also applied. The coupled inversion was performed to estimate five parameters of Mualem-van Genuchten model minimizing the difference between the measured and the modeled brightness temperatures. The estimated soil hydraulic properties were in good agreement with the hydraulic properties obtained from laboratory analysis of soil samples. The results confirmed the potential for non-invasive characterization of soil hydraulic properties using L-band brightness temperature data.

3. Tropospheric ducting

Refractivity profiles for Bulgarian Black Sea coast were restored using meteorological data provided by the European Centre for Medium-Range Weather Forecasts. A preliminary classification of the profiles in clusters was made and "characteristic" profiles for the rich in anomalous microwave propagation conditions summer season were proposed for every cluster. The combined effect of refraction, roughness and shadowing on microwave propagation over rough sea surface was studied applying the parabolic equation method.

4. Bibliometric indicators and their evolution for a group of scientists in a narrow, highly specialized area

Analyzing a variety of bibliographic measures, specific characteristics that define "mainstream science" and "outliers" were identified. The latter include both well recognized researchers and scientists working somewhat in isolation. To avoid the differences that might exist between the different scientific disciplines and to focus on the impact of "scientific and educational environment" and on national specifics, we considered a "clean sample" of researchers. Namely, we took a group of 164 individuals working in the highly specialized scientific area of high-power gas lasers. A summary of the finding includes: (a) When computed with no self-citations, the distributions seem to closely follow a power-law function. (b) The empirical dependence N_c vs. N_{ch} (citations vs. Hirsch's index) closely follows the dependence $N_c = ah^2$ suggested by Hirsch. The fit also suggests that for a "uniform sample", N_c and h are likely to be equivalent measures. (c) The diagram of Hirsch's excess, $h_{exc} = h - h^*$ vs. h, shows that scientists seem to form a band, which was identified as the "mainstream science". Within the "mainstream" strip, the excess scales crudely as $h^{1/2}$. The "outliers" with large h_{exc} often form co-authorship teams or are clustered by their nationalities. (d) The evolution patterns of ***h***, ***e*** and ***g***-indexes were also followed for four scholars residing in different regions of the h_{exc}-h diagram.

5. Dynamics of public opinion under rational choice local probabilistic rules

Several were studied models for public opinion dynamics based on local, rational decisions between partisans of two global parties (societal views). When involved in a discussion, each participant (agent) changes or does not change her/his view with certain different probabilities for the adherents of the parties. The probabilities reflect on both the mean social status and interest of the agents and on the persuasion resourcefulness of the opponent party argumentation. Preserving the status quo in such a framework does not require special rulings and corresponds to the probability for no change of opinion of all agents involved. More specifically, models of low size discussion groups only, $k=2$ and 3 were considered. Further, a modification of the model was introduced which allows for a variable size discussion groups by giving relative weight to each of them. Such a model involves an additional parameter and yields a richer behavior.

The model was further amended by considering existence of inflexible minorities of variable sizes. In contrast to the majority of the citizens, the inflexible people never change their view. As in the case of "the bare" model, the amended models fall into the class of Galam's general probabilistic models. Versions of the model with sizes of the discussion groups two and three were considered in detail. For them, full phase diagrams for typical fractions of the "hard-core" devotees are computed and analysed. The analysis is carried out by a combination of numerical and analytical methods.

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6. Simeonova B, Simeonov L and Schmitt Chr 2011 In situ elemental and isotopic analyses of heavy metals in environmental water solutions *Proc. Advanced Research Workshop on Environmental Heavy Metal Pollution and Effects on Child Mental Developmentt - Risk Assessment and Prevention Strategies* (Springer Science & Business Media BV Dordrecht The Netherlands) pp 215-23 ISBN 978-94-007-0255-3
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4. Sirkova I, Proposal for clustering of refractive index profiles, *COST IC0802 6th MCM* (28-30 Sept. 2011, Prague, Czech Republic).
5. Krasteva E, Atanassov V, Vulkova L, Zubov P, Dikovska A and O. Yordanov O, Bibliometric indicators and their evolution for a group of scientists in a narrow, highly specialized area, *MP0801 Annual Meeting* (18-20 May 2011, Eindhoven, The Netherlands).
6. Yordanov O I and Iordanova V, Dynamics of public opinion under different conditions, *MP0801 Annual Meeting* (18-20 May 2011, Eindhoven, The Netherlands).
7. Yordanov O I and Iordanova V, Dynamics of public opinion under rational choice local probabilistic rules, *Meeting and Conf. COST MP0801* (14-16 November 2011, Paris, France).

ONGOING RESEARCH PROJECTS

Financed by the National Science Fund

Co-financing of COST Action MP0801, Physics of Competition and Conflicts.

COLLABORATIONS

Design and development of a microwave X-band radiometer Dicke-type and its utilization for research natural resources and environment,
Institute of Space Technology - Vietnamese Academy of Science and Technology, Hanoi, Vietnam.

LABORATORY VISITS

I. Sirkova, Sixth MCM of European COST Action IC0802, Propagation tools and data for integrated Telecommunication, Navigation and Earth Observation systems, Prague, Czech Republic.
O. Yordanov, Third Annual Meeting, European COST Action MP0801, Physics of competition and conflicts, Eindhoven, The Netherlands.
L. Vulkova, Third Annual Meeting, European COST Action MP0801, Physics of competition and conflicts, Eindhoven, The Netherlands.
O. Yordanov, Ecole Polytechnic, Meeting and Conference of COST MP0801, Paris, France.
O. Yordanov, IFISC University, Meeting and Conference of COST MP0801, Palma de Mallorca, Spain.
O. Yordanov, African University of Science and Technology, Abuja, Nigeria.
I. Atanasov, Universite Libre de Bruxelles, one year, Belgium.
K. Kostov, Research Center Jülich, Deutschland.

LABORATORY

MICROWAVE MAGNETICS

HEAD: **Prof. I. Nedkov, Dr.Sc.**

TOTAL STAFF: **6**
RESEARCH SCIENTISTS: **6**
Assoc. Prof. K.G. Grigorov, Ph.D.; Assoc. Prof. T. Koutzarova, Ph.D.;
S. Kolev, Ph.D.; Ch. Ghelev; L. Slavov.

RESEARCH ACTIVITIES

The Microwave Magnetics Laboratory has long years of experience in studying the processes of electromagnetic radiation interaction with magnetic media.

The research activities of the laboratory staff are interdisciplinary and a combine technological approaches with physical studies. In the past year we have focused our efforts on the preparation and investigation of nanomagnetic materials – particles, hybride structures, composites, thick films. The rapid development of the nanotechnologies allowed the preparation of nanosized magnetic particles, which, in turn, opened possibilities for applications of monodomain and superparamagnetic hybrid structures in electronic components.

The main tasks in this respect had to do with studying **magnetic multiferroics**. The Y-type hexagonal ferrites are an important type of high-frequency soft magnetic materials due to their strong planar magnetic anisotropy. Owing to its planar magnetocrystalline anisotropy and high permeability, the Y-type hexaferrite is attractive for practical applications, such as microwave devices. The Y-type hexagonal ferrite $Ba_2Mg_2Fe_{12}O_{22}$ is a multiferroic material. It has a relatively high spiral-magnetic transition temperature (~200 K), shows multiferroic properties at a zero magnetic field, and the direction of the ferroelectric polarization can be controlled by a small magnetic field (< 0.02 T).

We studied the magnetic properties of nanosized $Ba_2Mg_2Fe_{12}O_{22}$ powder obtained by citrate auto-combustion synthesis. The powder consists of agglomerates with mean crystallite size of 100 nm. A phase transition from ferromagnetic to spiral spin order was observed at 183 K, together with a transition to a longitudinal-conical spin state below 40 K. The presence of these two effects is a precondition for this material's exhibiting multiferroic properties and are important for the realization of $Ba_2Mg_2Fe_{12}O_{22}$ as a multiferroic compound.

One of the subjects of our research was deposition and investigation of barium fexaferrite $BaFe_{12}O_{19}$ thick films.

A stable suspension was prepared in view of producing oriented magnetic structures by deposition and drying in a magnetic field. For this purpose, an experimental setup was designed and implemented for thick-films deposition in an external magnetic field. The process conditions for preparing thick oriented $BaFe_{12}O_{19}$ films were optimized. The effects were established of varying the deposition process parameters ($BaFe_{12}O_{19}$ concentration in the suspension, film deposition time, drying time and temperature, temperature of high-temperature film treatment) on the properties of the layers produced. Figure 1 presents XRD analysis of a sample oriented in a magnetic field and annealed at various temperatures.

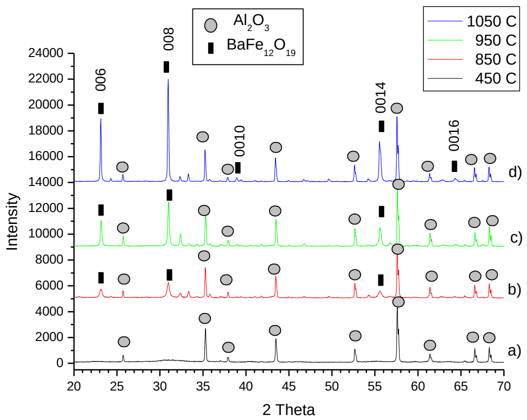

Figure 1. XRD analysis of a sample oriented in a magnetic field and annealed at various temperatures.

Besides the peaks characteristic for the $BaFe_{12}O_{19}$ structures, one can see peaks corresponding to the substrate (Al_2O_3). The high strength of the (*00l*) peaks can be observed appearing at temperatures over 850 ºC.

The magnetic properties of the magnetic structures were determined by applying a magnetic field perpendicular (Figure 2a) and parallel (Figure 2b) to the substrate plane. The hysteresis curves presented are of samples annealed at various temperatures and external magnetid field applied of 10 kOe.

A sample oriented in a magnetic field contains particles in a stable monodomain state. The annealing process alters the sample's magnetic properties, namely, the oriented particles begin to grow and undergo a transition to a polydomain state.

By varying the annealing temperature, one can vary both the coercive field *Hc* and the M_r/M_s ratio in a controlled way.

The oriented structures obtained possess very good magnetic properties and are characterized by a high value of the hysteresis squareness (SQR=0,96). This makes them suitable for applications as narrow-band microwave absorbers and circulators at frequency around 50 GHz, since these structures exhibit a ferromagnetic resonance in this range of the elecromagnetic spectrum.

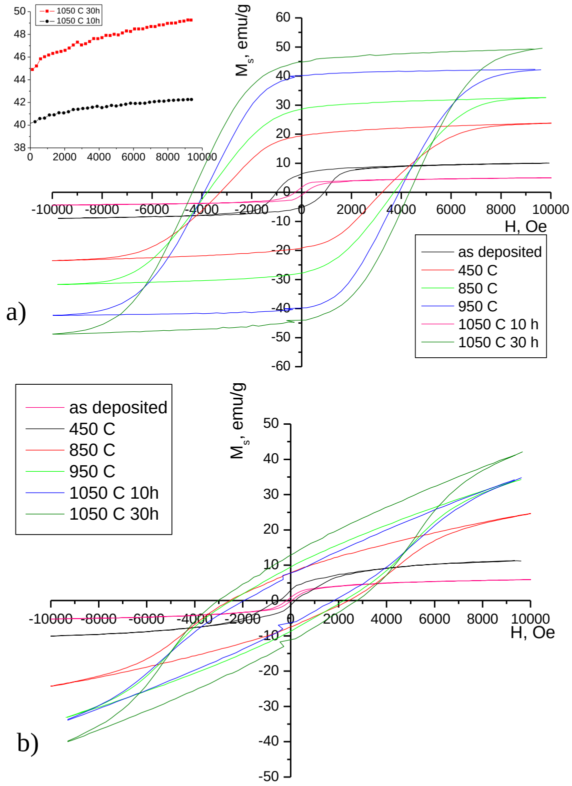

Figure 2. Hysteresis curves of $BaFe_{12}O_{19}$ structures oriented in a magnetic field perpendicular a) and parallel b) to the substrate plane.

PUBLICATIONS

1. Kolev S, Lisjak D, Ovtar S, Gyrgyek S and Drofenik M 2011 Thermal treatment influence on the magnetic properties and degree of orientation of $BaFe_{12}O_{19}$ films *J. Supercond. Novel Magnetism* DOI 10.1007/s 10948-011-1273-7
2. Kolev S, Lisjak D and Drofenik M 2011 Preparation and characterization of magnetically ordered columnar structures of barium ferrite particles *J. Experim. Nanosci.* **6** 362-73
3. Koutzarova T, Kolev S, Nedkov I, Krezhov K, Kovacheva D, Blagoev B, Ghelev Ch, Henrist C, Cloots R and Zaleski A 2011 Magnetic properties of nanosized $Ba_2Mg_2Fe_{12}O_{22}$ powders obtained by auto-combustion *J. Supercond. Novel Magnetism* DOI: 10.1007/s10948-011-1232-3

4. Grigorov K G, Oliveira I C, Maciel H S, Massi M, Oliveira Jr M S, Amorim J and Cunha C A 2011 Optical and morphological properties of N-doped TiO_2 thin films *Surf. Sci.* **605** 775-82
5. Yamamoto R K, Pessoa R S, Massi M, Grigorov K, M R Gongora-Rubio and Maciel H S 2011 Surface modification of polyethylene by a medium pressure micro-plasma generator *Surf. Engin.* **27** 80-6
6. Nurgaliev T, Mateev E, Blagoev B, Neshkov L, Nedkov I and Uspenskaya L S 2011 Effect of DC current injection on AC supercurrent carrying ability of ring shaped HTS thin films *Physica* C **471** 577-81
7. Ivanova T, Harizanova A, Koutzarova T and Vertruyen B 2011 Preparation and characterization of $ZnO–TiO_2$ films obtained by sol-gel method *J. Non-Cryst. Solids* **357** 2840–45
8. Balabanova E, Slavov L, Merodiiska T, Nedkov I and Kusano Y 2011 Assessment of the particle size and morphology in ferroxide nanosized powders *Comptes Rendus de l'Academie Bulgare des Sciences* **64** 1541-48
9. Pencheva V, Alipieva E, Penchev S , Nedkov I and Kutzarova T 2011 Investigation of ferromagnetic properties of LSMO nanolayers by laser modulated reflectance probe *Proc. SPIE* **7747** 774709
10. Cherkezova-Zheleva Z, Paneva D, Grudeva V, Iliev M, Shopska M, Merodiiska T, Slavov L, Nedkov I, Kadinov G and Mitov I 2011 New materials based on biogenic iron oxides: physico-chemical properties *Nanosci.&Nanotechnol.* **11** 142-5
11 Ghelev Ch and Guerassimov N (eds), 2011 *Institute of Electronics Annual Report 2010* (Sofia, Bulgaria)

PATENTS

1. Nedkov I, Merodiiska T,
Patent № 65609 Method for preparation of nanosized ferrite particles.

ONGOING RESEARCH PROJECTS

Financed by the National Science Fund

1. Project DID 02/38/2009 New materials for electronics and ecology based on biogenic iron oxides of nanosized ferrite particles.
2. Project DO 02-224/2008 New magnetic and magneto-electric materials for the new generation of electronic elements.
3. Project DO 02-343/2008 Oriented $BaFe_{12}O_{19}$ layers for microwave elements.
4. Project DO 02-99/2008 Thick ferrite films preparation by deposition in a magnetic field.
5 Project DHTC 01/4/2011 Room temperature multiferroics based on Y-type hexaferrites.

COLLABORATIONS

1. Magnetic, structural and microwave properties of new thin films composite materials,
University of Liege, Liege, Belgium.
2. Surface anisotropy and magnetic behavior in superparamagnetic ferroxides particles with two and more magneto-crystalline sublattices,
Institute of Low Temperatures and Structure Research, PAN, Wroclaw, Poland.
3. Magnetic, structural and microwave properties of new thin films composite materials,
Instituto Tecnologico de Aeronautica (ITA), Brazil.

LABORATORY VISITS

1. T. Koutzarova – University of Liege, Belgium, Structural investigation of multiferroic materials basee on oxides with perovskite and hexagonal structure, 14 days.
2. K. Grigorov – International Laboratory for High Magnetic Fields and Low Temperatures, 14 days.
3. L. Slavov –University of Gent, Gent, Belgium, 13 days.

GUESTS

1. Prof. B. Vertruyen from University of Liege, Belgium, 6 days, Joint Research Project Magnetic Structural and Microwave Properties of New Thin Films Composite Materials, between IE-BAS and University of Liege, Belgium.

LABORATORY

PHYSICAL TECHNOLOGIES

HEAD: **Assoc. Prof. R. Enikov, Ph.D.**

TOTAL STAFF: **5**
RESEARCH SCIENTISTS: **4**
Assoc. Prof. I. N. Martev, Ph.D.; D. A. Dechev; N. P. Ivanov; N. Lutakova.

1. Nanolaminated TiN/W_2N hard multilayer coatings

Multilayer coatings consisting of successively deposited thin films of nanometric thickness of homologous compounds of transition metals are characterized generally by better mechanical properties compared to those of single film coatings from the respective compound. Such type of monolayer coatings, termed as nanolaminated structures (or super-lattices), are often formed on the basis of transition metal nitrides that are characterized on their own by good mechanical properties (hardness, wear-resistance). A generally accepted physical model for explanation of this effect is the blocking of dislocations in the interfaces of single layers. The thickness of the interfaces usually increases due to the effect of interdiffusion of the elements involved. Forming high-quality coatings requires suppressing the interdiffusion processes, which can be achieved through decreasing the growth temperature and, to some extent, the thickness of the single layers. The activities on this topic were a continuation of the work on a previous stage related to optimizing the deposition of TiN/W_2N thin films and investigating their characteristics, mechanical properties and adhesion. The work was performed in the framework of research project “Physical Characteristics and Mechanical Properties of Monolayer Nanostructures of Complex Nitrides of Transition Metals”, funded by the Bulgarian National Science Fund.

Nanolaminated TiN/W_2N multilayer structures were synthesized by alternative deposition of TiN и W_2N thin films using DC magnetron sputtering. The deposition was preceded by a process of ion treatment of the substrate surfaces in an argon gas discharge at high pressure for enhancing the coating adhesion to substrates of different types (tool steel, hard alloyed materials). The deposition was performed in a process gas mixture of nitrogen and argon in different ratios for the two types of films. Special attention was paid to decreasing the deposition temperatures so as to make it suitable for the synthesis of polycrystalline TiN и W_2N with the desired phase. The thickness of the films was significantly reduced to about 6-6.5 nm. Twenty pairs of TiN и W_2N films were grown for analysis and characterization. 105 pairs (2×105 TiN/W_2N NLMLS) of the same films were synthesized for the investigation of their mechanical properties.

The structural characteristics were analyzed by transmission electron microscopy (TEM) and cross-section scanning electron microscopy (CSSEM) with very high resolution. The results showed that the growth of the structures at the initial stages is smooth, uniform and homogenous. Further, a small deviation from the planarity is observed as a result of stress accumulated by defects presumably generated in the interface zones. For the complex characterization of the structures, some investigations and analysis are foreseen, namely, Rutherford back scattering (RBS) and X-ray Diffraction (XRD).

The mechanical properties namely, hardness, Young's modulus, energy of plastic deformation, etc., of the 2×105 TiN/W_2N NLMLS were investigated by a FISHERSCOPE H100 nanotester. The results showed that these structures possess extremely high hardness (50-60 GPa) comparable with the best examples of super lattices based on transition metal nitrides. The adhesion was tested qualitatively by Rockwell-C Indent Test and was evaluated as acceptable. The wear resistance was tested by the so called "KALO - Test" (erasing the film by a rotating metal sphere). The morphology was observed by a Minicon Optiphot metallographic microscope.

PUBLICATONS

1. Lambov S I, Krastev P G, Ilieva N I, Dechev D A, Ivanov N P, Chobanov P N and Raichev V P 2010 Study of some mechanical characteristics of NiCr alloys thin films deposited by magnetron sputtering on dielectric substrates *Bulletin of the Union of Scientists in Bulgaria*, *Sliven Branch* **17** 37-9 ISSN 1311 2864 (In Bulgarian)
2. Slavova V, Petrov St, Lambov S, Ivanov N and Ivanova N 2011 Operating characteristics of composite ultrafiltration membranes prepared by magnetron sputtering of NiCr alloys on polymer substrates *Machine building and machine science* **2** 88-91 (ISSN 1312 8612) (In Bulgarian)
3. Krastev P G, Ilieva N I, Lambov S I, Dechev D A and Ivanov N P 2011 Preparation of sample electric heating elements and study of their operating cgharacteristics – possibilities for research learning in a group *Bulletin of the Union of Scientists in Bulgaria, Sliven Branch* **19** 236-40 (ISSN 1311 2864) (In Bulgarian)

ONGOING RESEARCH PROJECTS

Financed by the Bulgarian Academy of Sciences

Working characteristics of metal-nitride coatings obtained in vacuum.

Financed by the Technical University of Sofia

Working characteristics of Cr-Ni allow coatings obtained by ion sputtering in vacuum.

COLLABORATIONS

Deposition and investigation of mechanical properties of nanostructured multilayer systems of transition metal nitrides,
Nanotechnology Centre for PVD Research, Materials and Engineering Research Institute, Sheffield Hallam University, UK.

SELECTED PROJECTS

- **Modeling and Simulation of Gyrotrons for ITER**
- **Nanotechnology and Nanomaterials**
- **Coherent Population Trapping Resonances for Magnetooptical Sensor Diagnostics**
- **EC 7th Framework Program Research Infra-structures for Atmospheric Research**
- **New Materials for Application in Electronics, Based on Biogen Ferroxides**
- **Preparation of Thick Ferrite Coatings by Deposition in Magnetic Field**
- **Oriented $BaFe_{12}O_{19}$ Films for Microwave Elements**
- **Development of Interdisciplinary Thinking and Training of Young Scientists Working in the Field of Light-matter Interactions**

EC–Project EURATOM of FP7

Contract № FU07-CT-2007-00059/Fusion CSA/EURATOM

MODELING AND SIMULATION OF GYROTRONS FOR ITER

S. Sabchevski[1], M. Damyanova[1], I. Zhelyazkov[2], P. Dankov[2], P. Malinov[2], E. Balabanova[1], E. Vasileva[1] and R. Enikov[1]

[1] Emil Djakov Institute of Electronics, Bulgarian Academy of Sciences, Association EURATOM-INRNE, 72, Tsarigradsko Chaussee, 1784 Sofia, Bulgaria
[2] Faculty of Physics, St. Kliment Ohridski University of Sofia, Association EURATOM-INRNE, 5, James Bourchier Blvd., 1164 Sofia, Bulgaria

1. Introduction (scope and main activities of the project)

The gyrotrons are among the most powerful sources of coherent radiation in the sub-THz and millimeter wavelength regions of the electromagnetic spectrum that can operate in a CW (continuous wave) mode. One of their most characteristic applications is in the field of fusion research, where they are used for electron cyclotron resonance heating (ECRH) and current drive (ECCD) of magnetically confined plasmas in various reactors (e.g. tokamaks) for controlled thermonuclear fusion. Additionally, they are used for plasma start up, stabilization and diagnostics. The current state-of-the-art in the development of high-power gyrotrons is well represented in the annually updated database [1]. The progress demonstrated recently by the megawatt class gyrotrons has consisted in innovative designs based on significant breakthroughs as, for example, utilization of a synthetic diamond output window, advanced internal mode converters, depressed collectors for recuperation of energy etc. The world record for the energy belongs to the 170 GHz gyrotron developed by JAERI (Japan), which has demonstrated energy of 2.88 GJ, maintaining power of 0.8 MW in a CW mode for 3600 s. This gyrotron also holds the efficiency record, namely, 57%, while the Russian prototype of the 170 GHz ITER tube has achieved output power of 0.8 MW and efficiency of 55 % in a pulse of 800 s duration and 1 MW and 53 % in a pulse of 280 s, respectively. The European 140 GHz gyrotron for the stellarator Wendelstein W7-X has also achieved record output parameters, namely 0.92 MW power in a pulse 1800 s long with efficiency about 45 % and mode purity of the Gaussian beam of 97.5 %. In contrast to these gyrotrons, which utilize cylindrical resonant cavities and are characterized by the abovementioned parameters (notably output power around 1 MW) the European Gyrotron Consortium (EGYC) of several research institutions (KIT, Germany; CRPP, Switzerland; CNR and ENEA, Italy; HELLAS, Greece) led by KIT-IHM and CRPP-EPFL, is developing a coaxial 170 GHz gyrotron with output power of 2 MW and higher. In a recent experiment, the pre-prototype tube has delivered an output power of 2.2 MW with efficiency of 30 % in a short (1ms) pulse.

The modeling, simulation and computer aided design (CAD) based on numerical experiments are essential tools in the development, optimization and study of high-power gyrotrons for ITER and DEMO. The research on this topic is being pursued as Task 2.1.2 *Development of numerical codes to describe the behavior of high-power gyrotrons* of the Association

EURATOM-INRNE by a Bulgarian team from the Institute of Electronics of the Bulgarian Academy of Sciences (IE-BAS) and the Faculty of Physics of Sofia University (FP-SU) in a collaboration with the Institute for Pulsed Power and Microwave Technology at KIT (IHM-KIT), Karlsruhe, Germany and the Centre de Recherches en Physique des Plasmas at École Polytechnique Fédérale de Lausanne (CRPP-EPFL), Switzerland.

The main aims of the work are: (i) formulation of adequate, self-consistent and informative physical models; (ii) selection of efficient numerical methods and algorithms, programming libraries, integrated development environments (IDE), software for code optimization and debugging and their implementation and usage in the numerical codes for simulation of gyrotrons; (iii) development of pre-processing, processing and post-processing modules; (iv) maintenance, testing, benchmarking and improvement of the codes; (v) planning and conducting numerical experiments; (vi) analysis of the results and their use in the course of the computer aided design (CAD) of optimized constructions of gyrotrons with improved performance (e.g., increased efficiency and stability of the output parameters in a CW mode of operation). An essential task of the work planned is also the integration of all available simulation tools (newly developed and various legacy codes) in a set of problem-oriented software packages.

These activities are motivated by the problems that are being experienced in the development of the latest generation of multi-megawatt tubes and are in fact a continuation of the preceding investigations in this field. It is expected that the research in the aforementioned area will yield a better insight in the underlying physical processes that influence both the stability and the efficiency of the extremely high-power (megawatt class) gyrotrons and will facilitate the CAD of novel tubes with improved performance.

2. Numerical codes and computational platforms

Both the hierarchy and structure of the simulation tools is presented in figure 1 together with the computational platforms on which the different packages are operational. Although some of them (e.g., DAPHNE, ESRAY-IHM, CAVITY-IHM, and various components of GYROSIM) are well validated, benchmarked and debugged, they are undergoing constant adaptation and upgrade to the ever-changing computational environments (hardware, operating systems, novel versions of the compilers and numerical libraries). Along with the maintenance of these codes and their usage in numerical experiments, we are working on the further development of the GYREOSS and GYROSIM packages.

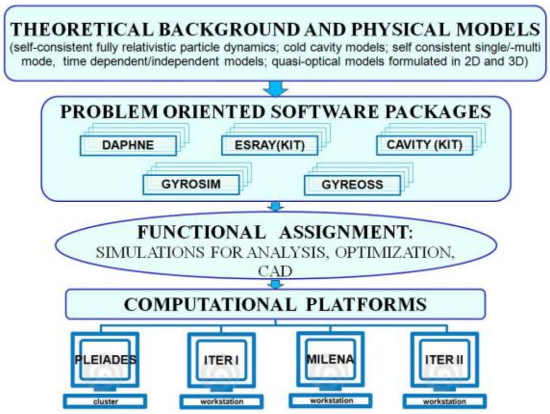

Figure 1. Hierarchy and structure of the simulation tools.

GYROSIM [2] is a heterogeneous package that includes a large number of codes for simulation of the electron-optical system (EOS), resonant cavity and the quasi-optical system using 2D and 2.5D physical models. GYREOSS is specialized only to the EOS but is based on a 3D physical model and an advanced concept developed recently [3-9]. According to this concept, the codes under development must be: (i) **portable** (developed on laptops, run on workstations, supercomputers, clusters, Grid); (ii) **extensible** (possessing flexibility in adding new physics); (iii) **efficient** (using optimal numerical methods and algorithms and utilizing parallel calculations for minimization of the required computational resources); (iv) **well validated** (being able to recover the results of the 2-l/2D numerical codes); (v) **user friendly** (offering convenient pre- and post-processing and visualization, as well as comprehensive and detailed documentation).

3. Current status of the work on GYROSIM and GYREOSS packages

The latest upgrade of the GYROSIM package was carried out in parallel with the development of a novel module called GO&ART (which stands for Geometric Optics and Analytic Ray Tracing). It consists of several codes for analysis of quasi-optical components (Vlasov and Denisov type launchers, reflectors and phase–correcting mirrors and so on) as well as systems based on them (e.g. internal mode converters and transmission lines). As an illustration, some screenshots of these programs are shown in figure 2.

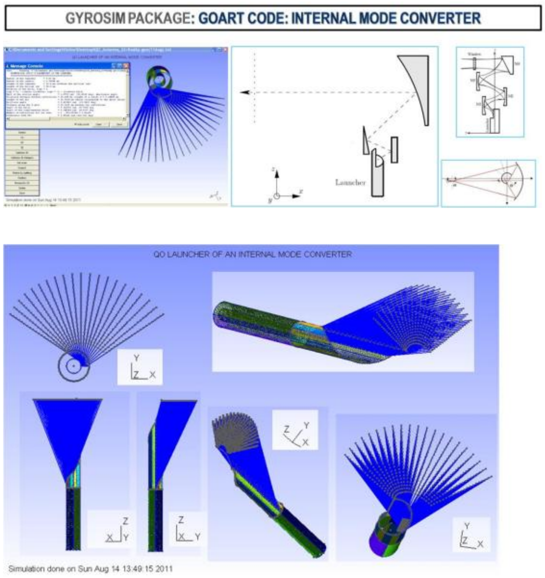

Figure 2. Simulation of quasi-optical components by GO&ART module of GYROSIM package.

Work is also in progress on the development of a novel quasi-optical code utilizing the boundary element method (BEM) and a parallel multilevel fast multiple algorithms (MLFMA) for the solution of the electric field integral equations (EFIE).

The latest version of GYREOSS is based on a hybrid (system) weak formulation (FEM variational formulation) of the boundary value problem for the electric potential distribution, which is governed by the Poisson equation with Dirichlet and Neumann boundary conditions. A significant advantage of such an approach is the possibility to approximate the electric field with accuracy higher than when applying the conventional formulation and calculating it through numerical differentiation of the potential. This is especially important for the PIC algorithm since it is the electric field rather than its potential that is required for the calculation of the Lorentz force in view of tracing particle motion. Figure 3 shows a NETGEN optimized tetrahedral mesh used by GYREOSS. An illustration of the visualization capabilities of FreeFEM++cs IDE[11] is presented in figure 4.

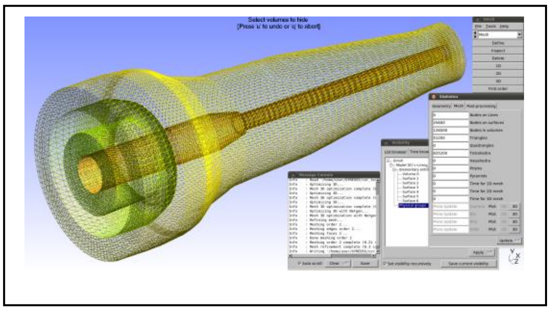

Figure 3. Tetrahedral mesh for the solution of the boundary value problem in a coaxial magnetron injection gun (CMIG).

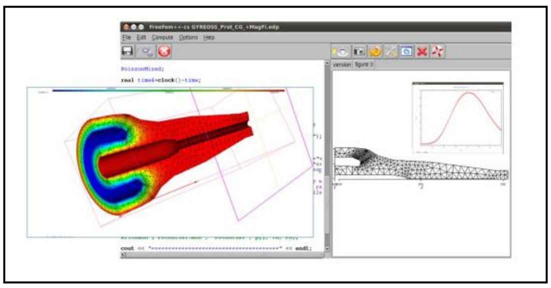

Figure 4. Screenshot of GYREOSS showing both the 2D and 3D meshes of a coaxial gyrotron and visualization of the solution by FreeFEM++cs.

A series of experiments were carried out in order to study both the accuracy and the speed of the solver for various combinations of finite elements (e.g. Raviart–Thomas finite elements RT3d vector–valued H(div)-conforming elements and continuous piece-wise linear elements P03) and method for solving the system of the resulting linear system.

4. Conclusions and outlook

The research team working on Task 2.1.2 maintains and develops several problem-oriented packages (DAPHNE, CAVITY, ESRAY, GYROSIM, GYREOSS as well as the corresponding underlying IDEs, numerical libraries, compilers etc.) on a diverse computational infrastructure (workstation ITER I, ITER II, MILENA, PLEIADES2 cluster) for simulation and CAD of gyrotrons. The work on them during 2011 was carried out as planned and the main goals of the working program were achieved. The improvements of the codes are in two main directions. The first one aims at better adequacy of the physical models (i.e. increasing the functionality of the simulation tools by adding more physics). The second one is focused on the improvement of the program realization of the codes through: debugging; optimization of the algorithms (for minimization of the necessary computational resources and for speeding up the calculations); utilization of more informative visualization of the simulation results; improving the GUI and data input/output and so on.

The main results of the activities on the Task 2.1.2 presented in the previous section could be summarized as follows:

- A novel module consisting of several codes (RAYS, TRACE, COMODES), called GO&ART was added to the problem-oriented software package GYROSIM, which extends significantly its functionality and allows one to simulate quasi-optical components. The upgraded version of GYROSIM was used successfully for CAD of several sub-terahertz gyrotrons for novel applications.
- Important components of the GYREOSS package were modified following the latest changes and improvements in the formulation of the boundary value problem based on mixed finite elements. Numerical experiments with the first version of the 3D field solver implemented as a FreeFEM++ and FreeFEM++cs script were carried out in order to study both the accuracy and the efficiency for different combinations of finite elements, linear solvers and methods for mesh optimization. The results of the numerical experiments point to some problems, but at the same time suggest some possibilities for improving the accuracy and increasing the speed of the calculations. A preparation for parallelization of the code is in progress now and will continue during 2012.
- The codes outlined above were used in a series of numerical experiments carried out to study the designs of powerful gyrotrons that are under consideration and/or development at present. The simulations conducted give deeper physical insight into the operation of high-performance gyrotrons of the megawatt class and are benchmarks that demonstrate the improved capabilities and functionality of the upgraded codes. Moreover, these results suggest some further experiments for a more detailed study of the correlation between the beam-quality parameters and efficiency, on the one hand, and the particular design (configuration of the electrodes, tailoring of the magnetic field etc.), on the other. It is expected that the novel and upgraded versions of the simulation packages will contribute to the development of the next generation of powerful gyrotrons for fusion with improved performance.

These results are an adequate basis for continuation of the development of the software packages (most notably ***GYREOSS*** and ***GYROSIM***) on which we are working following the ideas that form our concept for the next generation of simulation tools (physical models and numerical codes) for analysis, CAD and optimization of high performance gyrotrons. The Work Plan for 2012 includes: (i) theoretical work on the formulation of adequate, self-consistent and informative physical models; (ii) selection of efficient numerical methods and algorithms and their implementation in computing modules for the simulation packages developed and maintained by the international team; (iii) conducting numerical experiments for testing and benchmarking of the codes under development and for studying, evaluation and optimization of real constructions of gyrotrons.

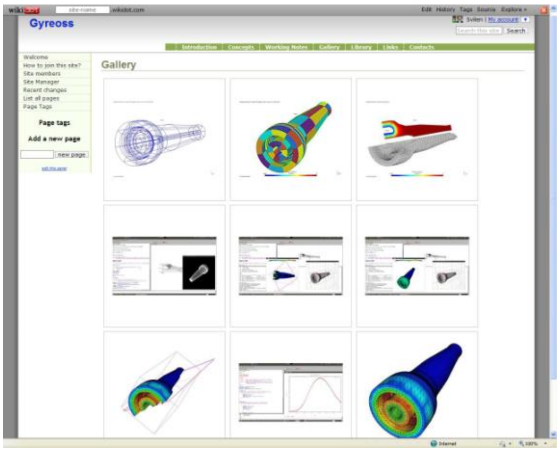

Figure 5. Screenshot of the website of GYREOSS at http://gyreoss.wikidot.com.

As in 2011, the main focus of the work during 2012 will be on the 3D solver of GYREOSS. We plan to continue experimenting with different methods for optimization, partitioning and adaptive refinement of the used tetrahedral meshes, as well as with different combinations of finite elements (including novel mixed and high-order elements) and linear solvers in order to find an appropriate realization which provides both sufficient accuracy and speed of the calculations and allows an efficient parallelization of the PIC algorithms.

More detailed information about the current status of the work on the GYREOSS is available at the project's website [11]. A screenshot is shown in figure 5.

Aknowledgements

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NANOTECHNOLOGY AND NANOMATERIALS

a collaboration between Bulgaria **(**Institute of Electronics BAS**)** and Ukraine **(**National Technical University "KPI")

G. Mladenov, E. Koleva and K. Vutova

As the main result of this three-year collaboration, the **Nanoelectronics** monograph was published consisting of two volumes [1, 2] (Figs.1, 2). It presents a short review of the contemporary status of the methods of fabrication and characterization of nanomaterials and nanodimensional devices.

The first volume is an introduction to the nanoelectronics technologies, such as thin film deposition, structuring of surfaces and thin film structures by ion implantation, ion sputtering and plasma etching, electron and ion lithography, electron transmission and scanning microscopy, as well as other methods of surface and profile testing of solid structures by electron and ion beams and the application of mechanical probes to micro-structuring and characterization of surfaces.

The second volume is devoted to nanostructured materials and to the description of some functional devices. The difference between nanostructured materials and conventional materials arises from dimensional effects of classical and quantum-mechanical nature. The different and rather amazing behavior of the electrical and thermal conductivity and the mechanical strength and in phenomena, such as electron tunneling, spin-state transport, quantum energy levels density, hold high innovation potential and open possibilities for applications based on new principles.

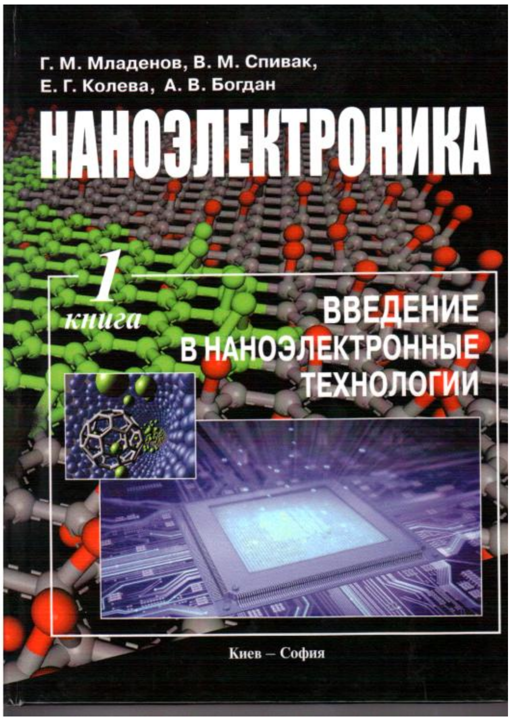

Figure 1. Cover of volume 1 of the monograph: Nanoelectronics. Introduction to Nanoelectronics Technology.

Figure 2. Cover of volume 2 of the monograph: Nanoelectronics. Nano-structured Materials and Functional Devices.

The level of nanotechnology utilization in this century will determine the status of every developed nation in the world. The early nanotechnology products have reached market realization in the order of billions of U.S. dollars, the forecast for the coming years being for a considerable expansion. However, penetrating segments of the market will necessitate investing today in education, relevant scientific research and community knowledge. This understanding has been reached at state level in Ukraine and Bulgaria.

Nanoelectronics is the leading direction in the development of nanotechnology and nanomaterials. The progress in microelectronics and the expansion of the implementing technologies form the foundation on which modern nanotechnology is to be built. The synthesis of advanced information technology and nanoelectronic hardware will be the future basis and a focus of the development of communication systems, information processing and storage devices, units for control and automation of production processes, intelligent applications in various spheres of human activity.

What do we mean by the term nanotechnology? First of all, it involves methods for creating functional elements and the devices and systems assembled using these elements, as well as fabricating nanomaterials with dimensions of the individual structural components comparable to molecular dimensions, namely, from fractions of a nanometer to few tens or, in some cases, up to one – two hundreds of nanometers.

Nanoscience and nanotechnology have to do with research aimed at understanding the processes occurring in nanodevices through visualization and measurements, using computer modeling of the processes, employng control and directed manipulation of individual atoms or molecules and, as a result, introducing nanoscale components, devices and systems in the industrial production.

Due to the relevance of the problems involved, it was the authors' intent for the book to compile and review their own research results, together with presenting some of the most promising developments of leading experts in the field of nanoelectronics. The state-of-the-art is described of the research and application of the most advanced, in our view, materials and technologies in nanoelectronics. The data and analyses given will be useful to both specialists and university students, including PhD students, active in areas related to nano and micro-electronics.

Content and some of the features of the material included

The two-volume monograph is organized in five parts, including introduction and 19 chapters.

The first volume of the monograph is entitled **Book 1. Nanoelectronics: Introduction to Nanoelectronics Technology.**

The introduction provides information on a phenomenon that took place in the late 80's and 90's of the last century, namely, the nanotechnology revolution. What is meant by the terms nanoscience and nanotechnology is described there. The authors point to some new properties of nanoscale structures, including mechanical and electrical, that determined the basic, most promising, fields of nanotechnology applications.

Part 1 "Overview of modern micro-and nanoelectronics," consists of two chapters.

Chapter 1, "The transition from micro-to nanoelectronics" deals with the problems that arise when further microminiaturization in electronics takes place. The principle of scaling when reducing the size of the electronic components and integrated circuits, and the problems in developing new silicon elements for the digital nanoelectronics, in particular, nanodimension silicon transistors and hetero-transistors, are discussed.

Chapter 2 describes *the use of new elements in nanoscale electronics* and is dedicated to the clarification and explanation of the physical effects in nanostructures. The physical interpretation of the ballistic motion of electrons is given, together with ideas concerning the development of such elements and devices, as the one-electron transistor; the new types of electronic and magnetic memories, memristors and memristive systems; hybrid nanodimension semiconductor circuits (such as CMOL); the use of quantum dots in cellular automata.

Part 2 is devoted to **the fundamental technological methods of analysis of surfaces and nanostructures**, and comprises one chapter (*Chapter 3*), describing the methods of analysis of the composition and structure of surfaces, thin films and nanostructures. In this section, a classification is made of electron and ion methods for the analysis of materials. Various electron and ion analytical methods are described that are applied to the study of surfaces, including: X-ray photoelectron (XPS) and Auger electron spectroscopy, secondary ion mass spectroscopy (SIMS), low energy electron diffraction (LEED) and low-energy backscattering ion spectroscopy; spectroscopy utilizing ion-induced optical emission from excited sputtered particles. Methods are also presented for in-depth analysis of thin film structures by fast ions and electrons: analysis using the ion microprobe; Rutherford backscattering of ions and the analysis using nuclear reactions, application of diffraction of high energy electrons etc. Methods and devices for visualization and characterization of nanoobjects, such as transmission electron microscopy, scanning electron microscopy, scanning tunneling and atomic-force microscopy; features of near-field scanning optical microscopy are described as well. Methods for determining the nanoparticles size are briefly mentioned.

Part 3 is an explanation of **the nanoelement deposition and structuring.** This is the largest part of book 1 and comprises six chapters.

Chapter 4 begins with a description of *the technological methods of thin films* deposition. A general description is given of the vacuum-thermal methods of thin film deposition. The physics of materials evaporation is described, on the basis of which methods of controlling the process are presented; the thin film growth by thermal vacuum deposition is also discussed. Further, the physical processes during ion sputtering are enumerated; triode ion-plasma sputtering, a system with direct current, as well as a magnetron system for thin film deposition are described. Attention is paid to the details of high-frequency sputtering systems for deposition of dielectric and metallic thin films. The authors describe a modern system for molecule-beam epitaxy and atomic layer deposition, as well as the Langmuir-Blodgett method for thin film fabrication.

Chapter 5 is devoted to *the ion implantation of fast ions*. The basic physical processes of accelerated ions penetration and channeling and the generation of radiation-induced defects, as well as of their annealing, are explained. Formulae and graphics allowing one to evaluate the sheet resistance of the ion implanted layers are given. The remaining part of the chapter is devoted to the design and principles of operation of the ion implantation equipment and the application and the most efficient use of the ion implantation.

In *Chapter 6,* entitled *ion etching,* the particularities of the methods and systems for reactive ion and plasma etching are described. Data for processes and equipment are complemented by an explanation of the physical features of the image transfer of the microstructures during ion etching.

Chapter 7 presents *the physical basis of electron lithography*. In particular, the nature and usage of microlithography, together with a summary of the penetration and scattering of fast electrons in thin films and bulk samples, are described. The authors provide experimental data on the ranges of electrons penetration in the bulk of the samples, as well as on the absorbed energy distribution of in the sample during electron irradiation.

Chapter 8 contains information about the *equipment and technology of electron and ion lithography*, namely, various types are described of electron and ion microlithography equipment; the processes taking place in nanolithography resists are described as well. Modern techniques are discussed for determining the sensitivity and contrast of electron and ion resists, the dissolution rate dependence on the exposure dose and the resist radiation efficiency. Characteristics are quoted of mono-component and multi-component resists, followed by up-to-date data on the characterization of chemically amplified resists and on non-organic resists used in nanolithography. The authors present an original description of the processes of resists exposure and development in electron and ion lithography, estimate the energy absorbed in resists during electron lithography and the energy deposition processes in the resist during ion lithography; show the role of electronic and nuclear energy loss during ion lithography; and discuss results of computer simulation of electron and ion lithography. A concept is proposed for numerical correction of the exposure of micro-images with predetermined shapes and sizes. At end of the chapter, the capability is demonstrated of regression analysis for the improvement of the lithographic process quality.

Chapter 9, "Lithography using a mechanical probe" contains description of modern probe technologies as applied to the design of nanostructures. An analysis of STM lithography by using electron sensitive resists and a description of the lithography by anodization of metal surfaces are given. Micro-contact lithography in polymer layers using the mechanical probe of an AFM and the contactless probe mode of AFM lithography, as well as manipulation of atoms by STM are illustrated. Data on deep-pen probe lithography and hybrid AFM/STM lithography are discussed as well.

The next part of the monograph was published as **Book 2 Nanoelectronics: Nanostructured materials and Functional Devices**.

Part 1. Materials for nano-electronics. The technology of their fabrication, properties, fields of applications

Chapter 1 is entitled *"Self-organized nanoscale structures"* considers the self-organization processes in semiconductors, such as porous and nanoporous silicon with controllable functional properties, namely: the impact of technological modes of producing porous silicon and the mechanisms of growth of porous and nanoporous silicon.

Chapter 2 "*Nanostructured silicon and composites*" describes the chemical processes during the formation of nanoporous silicon; the structure and chemical composition of the layers; the gettering and passivation properties; the electro-physical and optical properties of porous and nanoporous silicon; as well as the methods to control the porosity of porous silicon. Details are discussed of the photoluminescent and optical properties and the impact of modes of formation on the properties of nanostructured silicon, together with the characteristics of the gettering process. Considering photovoltaic cells based on porous silicon, an advanced technique is presented of determining the formation of porous silicon on the textured surface of the photovoltaic cells and an analysis is conducted on the prospects of applying the nanoporous silicon technology in the important development of high-efficiency silicon photovoltaic cells. Original data are given on developing and exploring a technology for production of nanostructured nanocrystalline silicon photovoltaic components, as well as on the properties of photovoltaic films based on nanocrystalline silicon. The chapter concludes with a description of silicon composite materials and an assessment of the influence of rare earth elements on the properties of nanocrystalline Si films.

Chapter 3 "Carbon nanostructured materials (fullerenes, carbon nanotubes, graphene) contains a description of the methods of preparation and the properties of fullerenes. The processes are explained of thermal decomposition of graphite and catalytic decomposition of hydrocarbons, the basic idea of the symmetry of fullerenes is given, and data on the physical properties and reactivity of fullerenes are summarized. The prospects are discussed of the chemistry of fullerenes as the concept of intercalation in fullerites. The authors quote data on the conductivity and the structure of the fullerite films and explain the effect of oxygen on their conductivity. The polymerization of fullerenes and the prospects of practical use of fullerenes and fullerite are discussed. The authors then describe the carbon nanoparticles and nanotubes and, in particular, the structure and the basic properties of single-wall and multi-wall carbon nanotubes, capillary effects, electrical resistivity, emission properties, magnetic susceptibility in carbon nanotubes and their practical use.

Chapter 3 includes also a discussion on *diamond-like carbon films*. These films are usually fabricated by means of high-frequency and microwave plasma chemical deposition. The authors present original studies of the physical properties of films thus formed by Raman scattering and by measuring the films' optical properties and electrical parameters. Finally, *graphene*, its fabrication and the prospects for its applications are considered.

Part 5 „**Functional nanoelectronic devices"** comprises 7 chapters.

Chapter 4, "Photonics on nanoscale structures", summarizes information on the classification of photonic crystals, the theory of photonic band gaps, the ways of producing photonic crystals, functional devices based on photonic crystals, and combinations of photonic crystals and optical fibers with Bragg gratings. The application of photonic crystals in integrated optics is discussed.

Chapter 5 "Sensory Systems" describes the following devices: sensors based on optical waveguides with photonic-crystal structure; sensors based on carbon nanotubes, including carbon nanotubes used to measure force; sensors for measuring pH; gas sensors based on carbon nanotubes; flexible hydrogen sensors; sensors for determining virus concentration; as well as applications of carbon nanotubes as biosensors for breast cancer detection in blood cells; biosensors for hydrogen peroxide-based compounds detection on carbon nanotubes and DNA; biosensor systems using thin nanocrystalline silicon magnetic films; sensors based on surface plasma resonance (SPR). A description is given of the "electronic nose" and "electronic tongue" types of multi-sensor electronic systems.

In *Chapter 6, "Molecular electronics"*, the basics are given of molecular microelectronics, molecular conductors, intermolecular charge transfer, molecular superconductors, piezoelectric and pyro-electric properties; organic molecular magnets. The technologies are described for production of molecular materials for optoelectronics, organic photo-chromatic materials, organic light-emitting diodes, functional devices of molecular electronics, polymer transistors.

Chapter 7 "Bioelectronics" presents the information properties of DNA; the wave features of the genome; phantom memory; genetic structures of both the source and destination of the holographic media; wave maps of DNA replication and its immediate environment. The study presented of DNA nanomechanical robots and computing devices reflects the main trends in the development of devices using the genetic material; further, DNA nanoinformatics is described.

Chapter 8 "Crioelectronics" provides essential theoretical knowledge – Ginzburg-Landau explanation of the superconductivity, critical magnetic field and superconductors of the second kind, Abrikosov's vortexes and Josephson's effect. Information on q-bits and quantum informatics is also given.

Chapter 9, "Magnetoelectronics and spintronics", contains data on nanocomposite materials utilizing magnetic nanoparticles based on ferromagnetic FeCo embedded in a dielectric matrix and possessing unique physical properties: giant magnetoresistance, magnetorefractive effect, good magneto-optical properties, high absorption coefficient in the radio frequency and microwave ranges, as well as a wide interval of electrical resistance variation. A permanent magnet device is discussed aiming to create a storage medium with ultra-high-density of magnetic recording. The device can be shielded from the effects of microwave radiation interference.

In *Chapter 10,* "*Nanoelectro-mechanical systems",* the technology and examples are considered of practical realization of devices based on micro-electromechanical systems (MEMS). The devices and the technology of their production, namely, nanopillow-blocks; mechanical relays on carbon nanotubes; nanoactuators; nanodrive gears; nanomotors; carbon nanotubes for nanorobotics, are shortly described. The possibilities of applying carbon nanotubes to the development of sensors, actuators, frequency selective devices and electric signal filters are presented as well.

If one attempts to generalize the main trends in and approaches to the nanotechnologies, these can be formulated as:

1. The materials acquire new properties and may found new applications if a relevant nanostructure could be prepared. This is due to the characteristic length corresponding to each of the materials' properties. For example, the electrical resistance of the material is the result of the flux of electrons in the conduction band and their scattering off the vibrating atoms and the impurities of the material. These acts are characterized by a scattering length, termed as a mean-free-path. When the length of the device becomes comparable to any of the characteristic lengths, most of which are in the nanoscale region, the physics and chemistry of the phenomenon change.

2. The driving force behind the nanotechnologies is the search for nanomaterials whose structure and properties differ from those of bulk materials (as is the case for a large number of materials), and the development and design of devices from nanodimension components.

3. Nanoelectronics, as a natural consequence of microelectronics, is an advanced field of development of new nanotechnologies, design and applications of new nanodimension devices and successful utilization of various nanomaterials.

4. Progress in the nanotechnologies is of crucial importance for the development of a strong and prosperous economy. The nanotechnologies products are not localized in a single national economy sector, but are rather important factors in the improvement of the quality, functionality and competitiveness of the

manufacturing processes in many industrial branches.

5. The complex nature of nano-technology and nanoelectronics require that the research teams active in this field should be composed of experts in different scientific areas. Due to their impact on a wide range of branches of human life, education in nanotechnology and nanoelectronics should be included in many relevant student educational profiles.

Figure 3. G. Mladenov’s Certificate of Honor awarded by the Ministry of Science, the National Academy of Education, the National Chamber of Commerce and the Organizers of the International Books Exhibition.

Figure 4. E. Koleva’s Certificate of Honor awarded by the Ministry of Science, the National Academy of Education, the National Chamber of Commerce and the Organizers of the International Books Exhibition

6. The problems of the development and wide application of nanomaterials and nanodevices will be solved individually for each area of research and/or for each application. It is expected that equipment related to nanoelectronics and information technologies, energy efficiency, including energy conversion efficiency, biotechnologies with impact on quality of life and ecology compatible technologies, including resource and energy saving nanotechnologies, will develop faster than other branches.

The books were presented at the International Exhibition of Education Services in Ukraine and the authors were awarded the Honor Certificates shown in figure 3 and figure 4.

During the work on the contract, 13 other papers were published by the joint Bulgarian-Ukrainian research team. In ref. [3], the results were reported of the research on linear and non-linear behavior of electron resists during electron beam nanolithography. Ref. [5] presented results on the design and testing of integral bio-sensor systems utilizing nanocrystalline silicon. In [6-13], the state-of-the-art and the trends for the future development of micro- and nanodimensional components making use of electron spin transport, electronic and magnetic memories and integrated circuits were discussed. Papers

[14] and [15] were devoted to the renewable energy sources, especially solar energy conversion, and clean fuels and the trends to their utilization.

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COHERENT POPULATION TRAPPING RESONANCES FOR MAGNETOOPTICAL SENSOR DIAGNOSTICS

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1. Introduction

The growing interest in coherent-population-trapping (CPT) resonances, prepared and detected under different conditions, is stimulated by their numerous applications in high-resolution spectroscopy, quantum information storage and processing, metrology and atomic clocks, magnetometry, lasing without inversion, laser cooling, ultraslow group velocity propagation of light, etc. [1,2].

High-contrast sodium D_1 line CPT resonances were reported in [3] for the case of Hanle configuration for atoms confined inside a glass cell and irradiated by a broadband multimode dye laser light. Under these experimental conditions, a narrow structure (of the order of 1 mG) in the CPT resonance superimposed on a broader profile was observed [4,5].

Narrow structures in the CPT resonance profile were observed by using monomode excitation in different experimental configurations [6,7]. A repeated interaction model for the diffusion-induced Ramsey narrowing was developed in a series of works [8 and references therein] where the diffusion-induced Ramsey narrowing is presented as a general phenomenon, in which diffusion of coherence in-and-out of the interaction region induces spectral narrowing of the associated resonance lineshape. The model was applied to investigation of electromagnetically induced transparency (EIT) in Rb vapour contained in a buffered by noble gas cell and excited by bi-chromatic laser light (three-level Λ-system). There, a sharp central peak on a broad pedestal was measured experimentally and analyzed theoretically. The broad pedestal is associated with the single pass interaction time and is power-broadened. The sharp central peak is the central Ramsey fringe, which adds coherently for all Ramsey sequences. The width of the central peak is determined by atomic collisions, magnetic field gradients, collisions with the cell walls, etc. Its width changes with the laser beam diameter. At a low laser power, small beam diameter and low buffer gas pressure, the sharp central peak is not Lorentzian in shape and is insensitive to the power broadening. At a high laser intensity, the central peak loses contrast, and is Lorentzian in shape and power-broadened.

A narrow structure in the CPT resonance was registered by monomode single-beam excitation as well [7]. The investigation of the resonance, prepared in Hanle effect configuration in an evacuated glass cell containing Rb vapour at room temperature, showed that the resonance has a complex shape - a narrow (few mG) structure superimposed on a broader one (about 100 mG). The width of the narrow structure is much smaller than that determined by the atom's flight across the laser beam. The narrow resonance is with a Lorentzian shape, it is not radiation broadened and its amplitude increases with the laser power. The results of the investigation of the fluorescence angular distribution are in agreement with the assumption that the narrow structure is a result of atom interaction with Rayleigh scattered light [9]. This result is interesting in view of indicating the vacuum cleanness of the cells and building magnetooptical sensors.

A detailed study of CPT resonance shape in sodium atoms excited by multimode laser light in spectral interval of several GHzs is presented in [10]. The experiment was performed in Hanle effect configuration in a geometry providing a significant orientation of the atomic angular momentum. A new theoretical model was developed concerning the CPT resonance preparation by a large number of laser modes in a spectral interval covering the absorption profile of the D_1 line of Na. Potential applications were discussed of the CPT resonances for diagnostics of glass cell coating quality and for studying the atomic momentum orientation of alkali atoms released by the light-induced atom desorption (LIAD) phenomenon in coated cells.

2. Experimental setup and results

The experimental setup adopted is sketched in figure1.

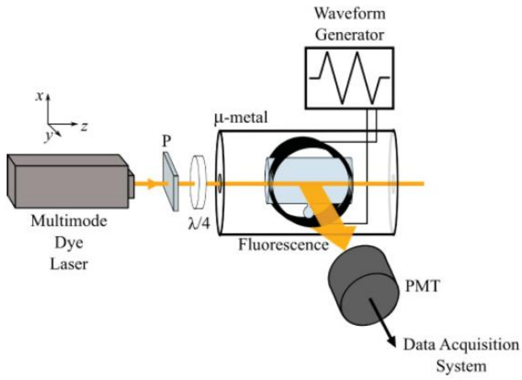

Figure 1. Experimental setup. P-polarizer, PMT-photomultiplier tube.

The sodium atomic vapor is contained in an evacuated glass cell (length L = 5 cm, diameter $2R$ = 2.2 cm) and irradiated by the multimode laser light of a dye laser emitting in a spectral interval of about 5 GHz with mode spacing 50 MHz. The broadband excitation is effective in preventing hyperfine optical pumping through simultaneous excitation of both hyperfine ground levels; moreover, the multimode excitation reduces the power broadening of the CPT resonance because the total laser power is spread into many modes.

A diagram of the D_1 line hyperfine structure levels, magnetic sublevels, and absorption transitions is shown in figure 2.

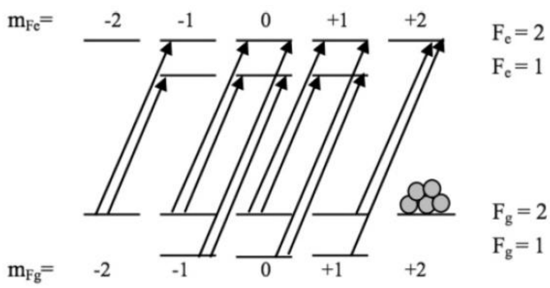

Figure 2. CPT effect with σ^+- polarized light on the Na D_1 line in Hanle configuration.

The CPT resonance-profile dependence on the light intensity was the key point of our experimental study. The total power of the resonant light was varied in the range of 50 to 300 mW, which corresponds to a variation of a single laser mode mean intensity from 1.8 to 10.8 mW/cm^2. The average mode intensity is given here because it is a reasonable approximation of the actual intensity distribution among resonant modes (35 out of about 100 cavity modes).

The CPT resonance registered in fluorescence and prepared by the multimode broadband excitation of the D_1 line of Na has the typical composite shape shown in figure 3: a narrow dip (NR) (indicated by the ellipse in the figure), about 1 mG wide, superimposed on top of a much broader resonance (BR) whose width is about 0.6 G.

From the width of the NR it is possible to calculate the Larmor frequency $\omega_L = 2\pi \times \mu_B g_F B = 2\pi \times 700$ Hz (μ_B is the Bohr magneton and g_F is the Lande factor) with $\mu_B g_F$ = 0.7kHz/mG for the Na ground state and the relaxation time τ = 2.2x10^{-4}s. For this relaxation time at T=375 K, atoms with an average thermal velocity

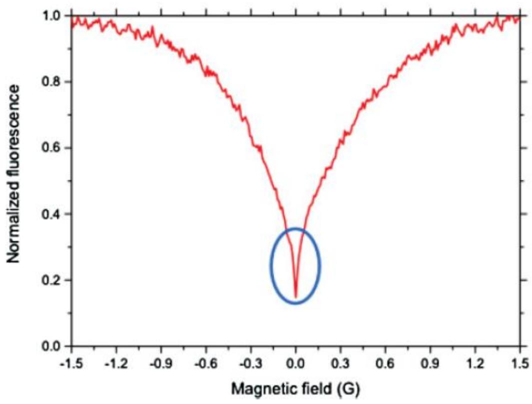

Figure 3. Profile of the resonance shape induced by multimode excitation by 9mW/cm^2 at T=375 K. The narrow peak is indicated by the blue ellipse.

$v = \sqrt{8kT/(\pi M)} \approx 600$ m/s have a mean-free path of about 13 cm. Because this distance is significantly longer than the laser beam radius (r=0.3 cm) and is longer even than the dimensions of the cell (R=1.1 cm), the observation of the narrow dip in the fluorescence implies on one hand that not every wall collision leads to de-orientation of the atom angular momentum and, on the other, that not all atoms re-entering the laser beam have an isotropic momentum distribution because some of them remain in the $m_{Fg} = F_g = +2$ state after several collisions against the wall.

For atoms not undergoing depolarizing collisions with the glass cell walls, de-orientation is caused by the magnetic field. A significant de-orientation is detected with a magnetic field such that $\omega_L \tau = 1$. This condition determines the NR width.

The probability P for an atom to re-enter the laser beam after a collision against the wall is

$$P = 2r/(\pi R), \tag{1}$$

where r and R are the beam and the cell radii, respectively.

For our experimental parameters (r = 0.3 cm and R = 1.1 cm) P = 0.17, which means that, on average, an atom returns into the laser beam after 6 collisions against the walls. The mean distance traveled by an atom between two subsequent collisions is

$$\ell = 2RL/(R+L) = 1.8 \text{ cm}. \tag{2}$$

Then, the distance covered by an atom before re-entering the laser beam is

$$l = 6\,\ell = 10.8 \text{ cm}. \tag{3}$$

The time necessary for an atom-wall interaction during a collision is of the order of 10^{-8} s and is neglected.

Hence, there is a direct correlation between the experimentally observed NR width and the time spent by an atom to re-enter the interaction volume. This correlation justifies the following assumption based on the theoretical model described in the next section: even in the absence of anti-relaxation coatings, several atom-wall collisions could take place without atomic spin randomization.

3. Theoretical model

In order to describe this phenomenon, we developed a theoretical model based on numerical solutions of density matrix equations, which takes into account the peculiarity of CPT induced by broadband multimode laser light in the so-called Hanle configuration [10].

The dynamics of the atomic ensemble in external electric and magnetic fields is described by the well-known density matrix equation:

$$i\hbar\left(\frac{\partial}{\partial t}+\mathbf{v}\frac{\partial}{\partial \mathbf{r}}+\hat{\Gamma}\right)\hat{\rho}=\left[H_0,\hat{\rho}\right]+\left[V_B+V,\hat{\rho}\right]. \tag{4}$$

Here, $\hat{\Gamma}$ is the atomic relaxation operator, involving the spontaneous decay of excited states; H_0 is the free-atom Hamiltonian; V_B is the interaction potential of an atom with the magnetic field **B**. The interaction of the atom with the electrical field of the laser light **E** is considered in the dipole approximation $V = -\mathbf{d}.\mathbf{E}$, where **d** is the atomic dipole moment. The light induces optical transitions between ground-state levels $g = |F_g, M_g\rangle$ and excited-state levels $e = |F_e, M_e\rangle$, where M is the full angular momentum projection on the quantization axis.

The spontaneous relaxation is described by

$$\hat{\Gamma}\rho(F_g, M_g|F_g', M_g')$$
$$= -\delta_{F_g, F_g'} \frac{\Gamma}{d^2} \sum_{\sigma, F_e, M_e, M_e'} \langle F_g, M_g|d_\sigma|F_e, M_e\rangle \quad (5)$$
$$\times \langle F_e, M_e'|d_{-\sigma}|F_g, M_g'\rangle \rho(F_e, M_e|F_e, M_e').$$

Theoretical simulation to test the experimental data is then performed by solving density matrix equations along the atom trajectories inside the cell. After each atom-wall collision, the new direction and velocity of the atomic motion are calculated by the Monte Carlo method and then the angular momentum relaxation is calculated.

We assumed that the probability of angular momentum relaxation after each collision with the cell walls is less than one: $\varepsilon < 1$. In consequence, atoms take more than one collision against the wall in order to reach complete randomization of their angular momentum. We will demonstrate in the next section that, in the simulation, it is possible to take into account only the atom trajectories for which 10/ε collisions take place to properly describe the experimental results.

Finally, for simulation purposes, the intensity profile of the laser beam is assumed to have a spatial Gaussian distribution; namely,

$$I(x) = I_0 \exp(-x^2/r^2). \qquad (6)$$

4. Comparison between experimental and theoretical profiles

Numerical calculations of the resonance profiles were performed for different values of light intensity and were compared with the experimental results.

Before approaching the actual numerical simulation, a proper choice of the ε value has to be made and justified. Figure 4(a) shows the experimental results for the BR at a laser intensity per mode of I = 9.0 mW/cm^2. Numerical simulations with ε = 0.1 and ε = 1 are also shown. It is evident that the theoretical BR line shape is independent of the particular choice of ε. Hence, orientation-preserving atom collisions against the cell walls affect neither the formation nor, more importantly, the width of the broad resonance profile.

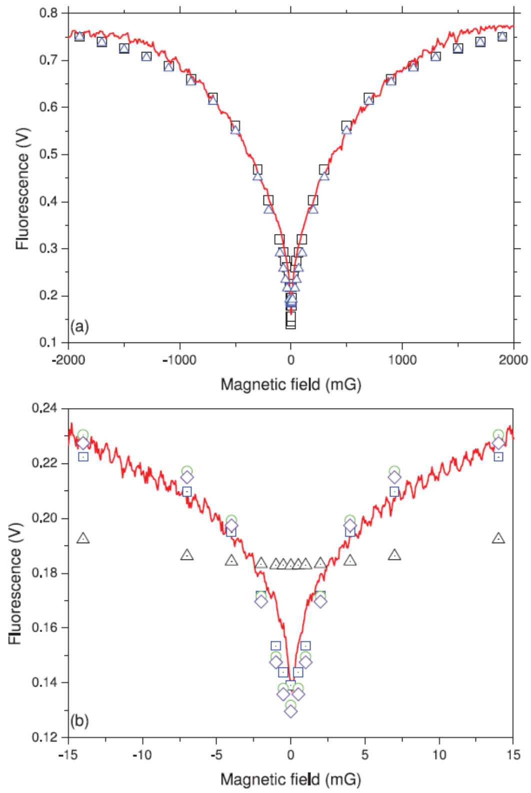

Figure 4. (a) BR profile and (b) NR profile (red line) as a function of the magnetic field with the simulated profiles for I = 9.0 mW/cm^2 and
ε = 1 black triangles
ε = 0.1 blue squares
ε = 0.01 green circles, and
ε = 0.001 violet diamonds.
The fluorescence is measured in the detection system units of volts (V).

In figure 4(b), the experimental results for the NR peak obtained under the same conditions are shown. The NR shape is fit with four different values of the "collision parameter" ε. Unlike the BR, the narrow resonance line shape exhibits a strong dependence on the probability to have an atom-wall collision without atom-orientation randomization.

If every atom-wall collision leads to a complete randomization of the atomic polarization (ε = 1), no narrow resonance should be observed at the center of the broader profile, as shown by triangles in figure 4(b). A satisfactory agreement with the experimental data is achieved for ε = 0.1, as shown by squares in figure 4(b). This means that, on average, after 10 spin-preserving collisions, the atoms re-enter the laser beam and are again available for CPT resonance formation. On the other hand, a further increase in the number of atomic collisions with the cell walls that preserve the atomic momentum orientation (i.e., ε < 0.1) does not result in an additional narrowing of the NR. Note that, just after 10 collisions, the atoms re-enter the laser beam and again interact with the light. Thus, the assumption of ε = 0.1 is the right choice for our experimental conditions and, thus, this value was used in the simulations.

At all laser powers from 50 to 300 mW, the agreement between experiment and theory is very good. It is evident that the width increase with power is very pronounced for the BR but, on the contrary, the experimental NR exhibits only extremely small broadening with the light intensity.

This result offers the opportunity to implement a simple technique for studying atom-wall collisions: it is possible to estimate the mean number of spin-preserving collisions of atoms in a cell once the experimental parameters have been properly chosen to fit the system characteristics. However, in order to study systems with a greater spin-preserving capability, the laser-beam dimension has to be suitably reduced to increase the total number of collisions experienced by an atom before re-entering the interaction volume.

This approach might be a useful tool to test, for example, the cell coating quality and also to study the polarization of atoms released from the coated cell walls by the light-induced atomic desorption (LIAD) effect.

To gain physical insight into the significant difference in the power broadening exhibited by the two resonances (BR and NR), we suggested the following phenomenological explanation: the BR width Δ_{BR} shows a linear behavior as the resonant light intensity per mode (I) is increased under our experimental conditions (figure 5); therefore, it is reasonably described by

$$\Delta_{BR} = \Delta^0_{BR} + aI\ . \qquad (7)$$

In this equation $\Delta^0{}_{BR}$ is related to the transit-time broadening contribution, while a is the power broadening coefficient and actually depends on the excited atomic transition. In figure 5, the experimental widths of the broad resonance fit by equation (7) are shown.

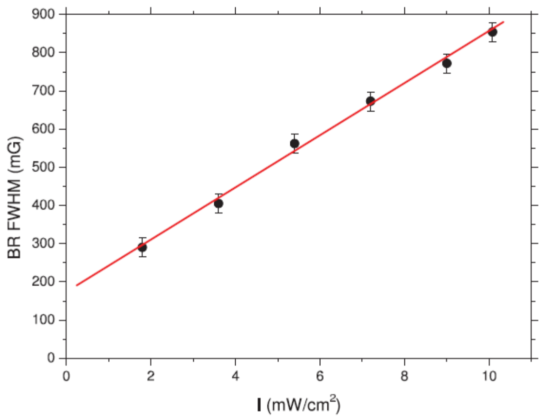

Figure 5. BR width as a function of the laser intensity per mode. The line is the fit according to equation (7).

The analysis of the experimental data using equation (7) suggests that the residual broadening for BR at I=0 is $\Delta^0{}_{BR}$ = 174 mG, which is consistent with the time-of-flight broadening for single crossings of the laser beam, as assumed before. The linear coefficient was measured to be a =67.57 mG(mW/cm^2)$^{-1}$. Similarly, the width of the narrow resonance NR exhibits a linear dependence on the laser intensity, as shown in figure 6.

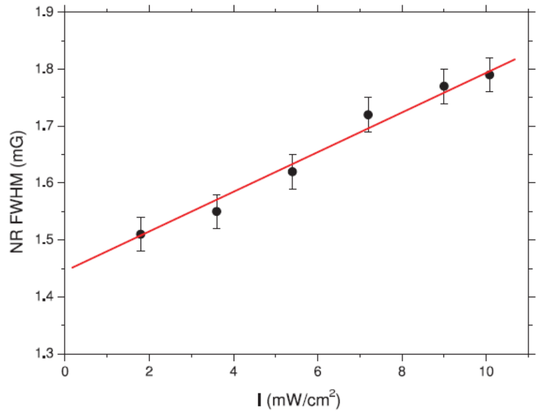

Figure 6. NR width as a function of the laser intensity per mode. The line is the fit according to equation (9).

Therefore, it can also be described by a linear equation that takes into account the aforementioned effect of the time spent by the atoms to re-enter the laser beam. The simplest assumption satisfying these requirements is

$$\tilde{\Delta}_{NR} = \Delta^0_{NR} + 67.57\frac{r^2}{R^2}W\,, \qquad (8)$$

where Δ_{NR} is related to the atomic orientation relaxation caused by collision with the cell walls and the ratio r^2/R^2 characterizes the average fraction of time spent by atoms in the laser beam [11]. In our case, the cell radius R is more suitably substituted by the mean distance traveled by an atom before re-entering the laser beam, l [equation (3)]: thus, the atom's motion in and out of the interaction volume results in a lower rate of power broadening for the NR. Therefore, equation (8) is properly rewritten as

$$\Delta_{NR} = \Delta^0_{NR} + 67.57\frac{r^2}{l^2}W\,, \qquad (9)$$

and was used to fit the data shown in figure 6 with good agreement.

By inserting this experimental value into equation (9), it is possible to estimate parameters for the NR. The residual broadening is Δ^0_{BR} = 1.44 mG and the slope of the fit line shown in figure 6 is 0.035 mG(mW/cm^2)$^{-1}$, which is nearly 2000 times less than the one for the BR, as expected after the observation of the negligible power broadening affecting the narrow resonance.

Finally, by using these experimentally measured parameters for the NR, one can estimate the value of the mean path traveled by an atom before re-entering the light beam l_{expt} and compare it with the chosen ε value as a consistency check. l_{expt} then is 13.2 cm, which is in good agreement with ε = 0.1 used in the simulations described above. Hence, the number of atom collisions against the cell walls with atomic orientation preservation can also be estimated by the power broadening analysis of both resonances, suggesting another, different, approach suitable for coating analysis and diagnostics.

5. Conclusions

The CPT resonance in Hanle configuration was studied in Na atoms by multimode excitation, which effectively inhibits the hyperfine optical pumping and results in efficient magneto-optical resonance preparation. Moreover, the resonance power broadening is reduced because the total laser power is spread over a large number of modes.

For Na atoms contained in evacuated glass cells, a narrow resonance superimposed on a broader one was observed. The broader resonance is related to atoms that make a single crossing of the laser beam and suffer significant power broadening. The narrow resonance is more than two orders of magnitude narrower than the broader resonance and has a power broadening rate lower by about three orders of magnitude.

A theoretical model was developed to describe the CPT resonance preparation by broadband multimode laser light. A core assumption is that not all atom-cell wall collisions result in de-orientation of the atomic angular momentum. The theoretical analysis showed that atoms interacting with the laser beam and not re-entering it or re-entering with randomized spin orientations are responsible for the broader resonance formation, and that the narrow resonance is due to the contribution of atoms, which cross the laser beam, collide on average 10 times with the cell walls without orientation randomization, and then re-enter the laser beam.

The small width and the low rate of the power broadening of the narrow resonance were related to the time spent by atoms to return into the laser beam without randomization of their orientation.

By using experimental and theoretical results, the value of the mean path travelled by atom before re-entering the laser beam can be estimated not only from the width of the narrow resonance, but also from the power broadening rates of both resonances. This simple approach, however, is applicable only under the condition of negligible hyperfine optical pumping, which in our case is realized by multimode excitation of atoms.

The investigations performed showed that, based on the power dependence of the CPT resonance width, a simple methodology can be developed for testing coated cell parameters and for studying the orientation of atoms desorbed from cell coatings.

Acknowledgements

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EC 7TH FRAMEWORK PROGRAM "RESEARCH INFRASTRUCTURES FOR ATMOSPHERIC RESEARCH"

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Project EARLINET-ASOS

The project EARLINET-ASOS (European Aerosol Research Lidar Network - Advanced Sustainable Observation System, http://www.earlinet.org/) is an integrated activity implemented as a coordination action within the EC Sixth Framework Program (EC FP6: “Structuring the European Research Area Specific Program - Research Infrastructures Action” - Contract Number 025991). EARLINET-ASOS is a 5-year project started on 1 March 2006.

It started on the basis of EARLINET [1], and covered 20 lidar stations distributed across Europe. The main objective of the project was to improve the infrastructure of the European research lidar network, resulting in a better spatial and temporal coverage of the observations, continuous quality control for the complete observation system, and fast availability of standardized data products.

The single lidar station in Bulgaria is positioned in Sofia, in the Laser Radar Laboratory of the Institute of Electronics of Bulgarian Academy of Sciences (IE-BAS). The Institute is located in the urban area of the capital Sofia (42^{o}39’14”North, 23^{o}23’14”East), at about 550 m above sea level (ASL). Sofia lidar station has two functional lidars. The first one is based on a CuBr-vapor laser, and the other one, on a Nd:YAG laser.

The types of lidar measurements performed in Sofia in the framework of EARLINET-ASOS project were as follows:

- Regular lidar measurements within the objective to establish a common database from measurements of profiles of the atmospheric aerosol backscatter coefficient. Measurements are performed twice weekly, every Monday at noon when the sun is in zenith and in the evening during sunset, and every Thursday at sunset. A specialized EARLINET database collects the results from the longtime monitoring of atmospheric aerosols by regular lidar measurements. It contains a valuable information for the atmospheric processes over Europe [2] and gives an opportunity for further improvement and validation of atmospheric models and retrieving algorithms applied to climatologic investigations.
- Observation of special phenomena, such as unusually high concentrations of aerosols in the troposphere. Their appearance may be due to transportation of a dust from Sahara over the Mediterranean Sea to Europe, volcanic eruptions, formation of smoke layers as a result of forest or industrial fires, intense photochemical smog, etc. This type of lidar observations were carried out upon notification by the program coordinator for upcoming dust events above the territory of Europe. The notification was based on satellite observations and weather forecasts.
- Measurements in the framework of cooperation with satellite missions with the objective of a detailed comparison of ground-based and spaceborne lidar data sets over Europe. These measurements are related to the *Quid pro Quo* (QPQ) validation measurements of the project Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations CALIPSO (http://calipsovalidation.hamptonu. edu/ QPQ_plan062206.htm). CALIPSO is a

free-flying lidar in space and provides data on atmospheric clouds and aerosols needed for climate studies. Ground located EARLINET stations were deemed to be an optimal tool for validating CALIPSO lidar data and providing the necessary information to fully exploit the information from that mission.

Each lidar measurement lasts 1-4 hours. The data-processing applies 30 min time integration interval, so that each lidar measurement yields about 2 to 8 data files of an atmospheric parameter measured – backscatter or extinction coefficient profile. Sofia-lidar group has collected data from more than 430 lidar measurements that correspond to about 880 data-files uploaded on the common EARLINET database.

Additional information from dust forecast maps and backward air mass trajectories calculations

The aerosol lidar cannot determine exactly the type of detected aerosols in the atmosphere without additional information provided by the conventional meteorological systems of measurements. In the analyses of our lidar measurements, we used as additional information the weather-forecast maps and maps of dust load and concentration in the atmosphere for the Euro-Mediterranean zone. Such maps are issued by the Atmospheric Modelling and Weather Forecasting Group of NTUA, Greece, and the Forecast System of Barcelona Supercomputing Centre, Spain, and are accessible via Internet [3]. These maps give an image of the wind direction and speed, position of cloud fields and magnitude of dust load in the atmosphere above North Africa and Europe. They visualize the predictions concerning the dispersion of Saharan dust storm outbreaks over the Mediterranean Sea to Europe.

Another source of information about the origin of the aerosol layers detected by the lidar is offered by the HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory)[4] model. It represents a complete system for computing simple air parcel trajectories to complex dispersion and deposition simulations. The model can be run interactively on the web through the READY system on the site of the Air Resource Laboratory of NOAA (National Oceanic and Atmospheric Administration), USA. The calculations of the backward air mass trajectories yield a plot of the road that the air mass has traversed for a chosen time period before arriving at the lidar observations location.

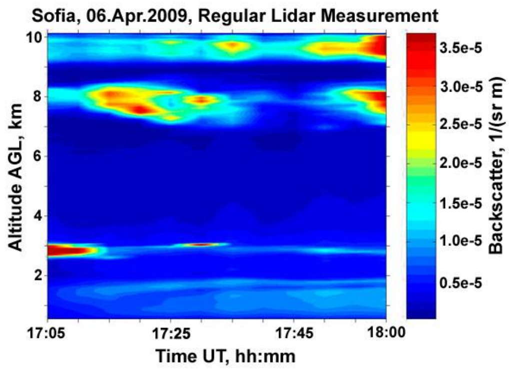
Aerosol lidar with CuBr vapor laser

The Aerosol lidar with CuBr-vapor laser is described briefly below [5].

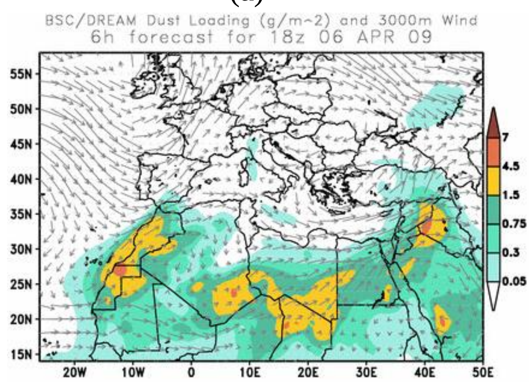
The CuBr-laser generates high-repetition pulses at a frequency of 13.5 kHz, duration of 10 ns and wavelengths 510.6 nm and 578.2 nm. The laser beam is directed vertically upward, parallel to the axis of the receiving telescope, forming a lidar base of 24 cm between the axes. A Cassegrain type telescope with 20-cm aperture and 1 m focal length receives the laser radiation backscattered from the atmosphere. A registration in photon-counting mode is applied. The photon-pulses are stored in a photon counting board LD-P 03-01 built in a computer. This board allows registration of the backscattered lidar signal with respect to the altitude with spatial resolution of 30 m, in 1024 samples and averaging time of 60 s. The sounding height is from 900 m to 10-12 km at nighttime. The maximum height is limited by the laser pulse repetition rate because of the laser pulse scattered from a higher altitude overlapping with the next one, from a lower height. In daytime conditions the sounding height decreases to about 4-5 km, due to intensive sky illumination reducing the signal-to-noise ratio (SNR).The lidar profiles integrated over an accumulation time of 1 min are additionally averaged by summation of data from 30 profiles. Thus, the measurement time for each profile amounts to 30 min. The stored data are subsequently processed by Fernald's algorithm, using a program in MATLAB environment developed in the LRL-IE.

Three-chanel lidar with Nd:YAG laser

The Nd:YAG lidar system of the LRL-IE is a 3-channel combined aerosol-Raman lidar [6]. The laser provides output pulse energies of up to 1 J at 1064 nm and up to 120 mJ at 532 nm, at a repetition rate of 2-5 Hz, with pulse duration of 15 ns FWHM. The pulse power is of up to 70 MW at 1064 nm and up to 10 MW at 532 nm. The corresponding values of the averaged power for the two wavelengths are of up to 2 W and 0.25 W, respectively. The output beam divergence is 2.5 mrad (total angle). These performance characteristics of the laser allow one to carry out nighttime and daytime lidar measurements. The optical part of the receiver contains a Cassegrainian telescope (35 cm aperture; 2 m focal length) and a 3-channel spectrum-analyzing module based on dichroic beam-splitters, narrowband interference filters (1-3 nm FWHM), edge-pass filters, and neutral density filters. The electronic part of the lidar receiving system consists of three compact photo-electronic modules. Each module comprises a photon detector (a photomultiplier or an avalanche photodiode), a 10-MHz/14-bit ADC, a high-voltage power supply, and controlling electronics. The aerosol lidar channels operate in an analog mode with 15 m range resolution. The receiving modules are connected to a computer by high-speed USB ports. The acquisition system is controlled by specialized software providing accumulation, storage, and processing of the lidar data. It allows for evaluating and plotting profiles of range-corrected lidar signals, the aerosol backscattering coefficient, and the estimation error.



(a)



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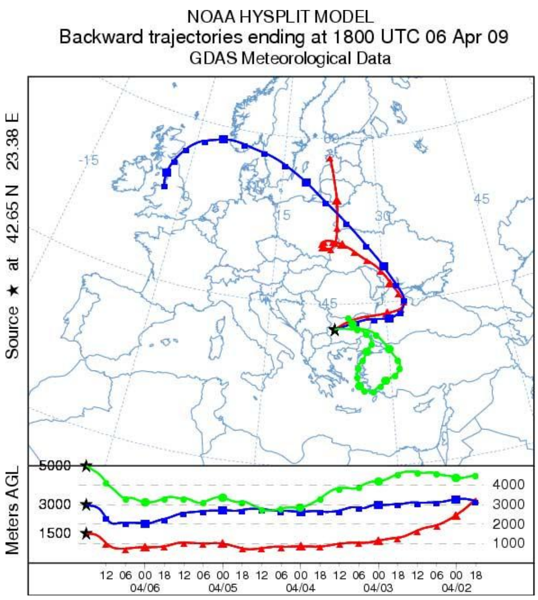


(c)

Figure 1. One-hour evolution diagram of the aerosol backscattering coefficient retrieved by lidar measurements on 6 April 2009 (a), BSC-DREAM Saharan dust forecast map (b) and backward air mass trajectories plots calculated using HYSPLYT model (c).

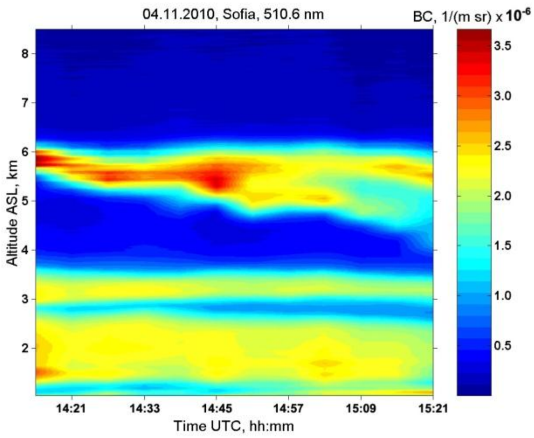
Lidar measurements – results and discussions

Regular lidar atmospheric measurements (lidar measurements below are presented in [7])

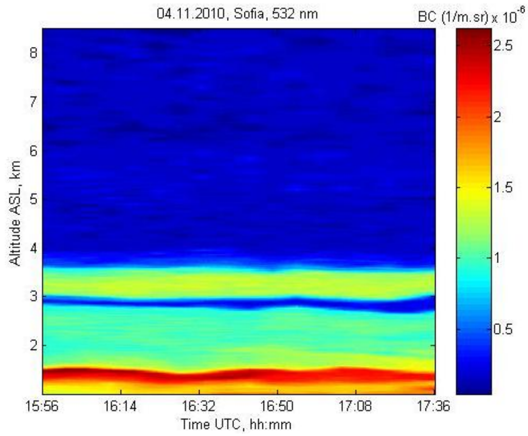
The results of lidar measurements carried out by Sofia lidar station on 6 April 2009 are presented in figure 1. The color map (figure 1a) represents the one-hour evolution of the retrieved aerosol backscattering coefficient based on lidar profiles with 5 min time averaging in the period 17:00-18:00 UTC. The multi-layered aerosol structure observed is explained as follows. The lower layer between 500 m to 1.5-2 km height represents the aerosol existing permanently in the planetary boundary layer (PBL) of the atmosphere due to human activity (anthropogenic aerosol) and the convection processes. The layer at 3 km altitude is determined to be a residual aerosol layer due to the decomposition of the PBL in the evening. The origin of the two higher aerosol layers is determined by analyzing the meteorological situation given by the corresponding BSC-DREAM dust load forecast map (figure 1b). It shows that Sofia remains away from the Saharan dust flow. The backward trajectories indicate a transport of an air mass arriving from North Europe above Sofia (figure 1c) at the time of lidar measurement. We conclude that the two aerosol layers, at 8 km and 9.5 km height, represent cirrus clouds.

Observation of special phenomena – Saharan dust transport

As an illustration, vertical profiles of the aerosol backscattering coefficient measured by both lidars (with CuBr-vapor laser and Nd:YAG laser) at 510.6 nm and 532 nm on 4 November 2010, during a dust-transport event, are presented in figure 2. The altitude range 1-5 km above sea level (ASL) is only shown in order to zoom the profile part containing the Saharan dust layer. The latter is located in the range 2.8-4 km ASL, just above the



(a)



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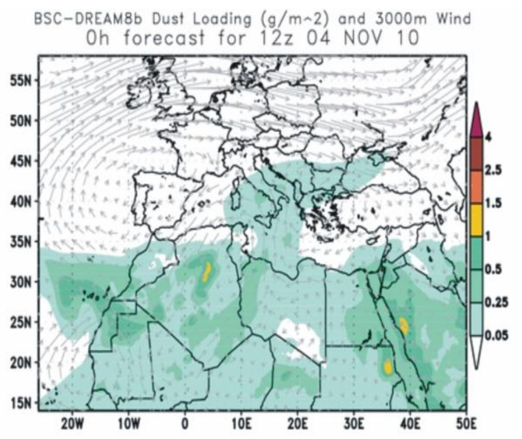


(c)

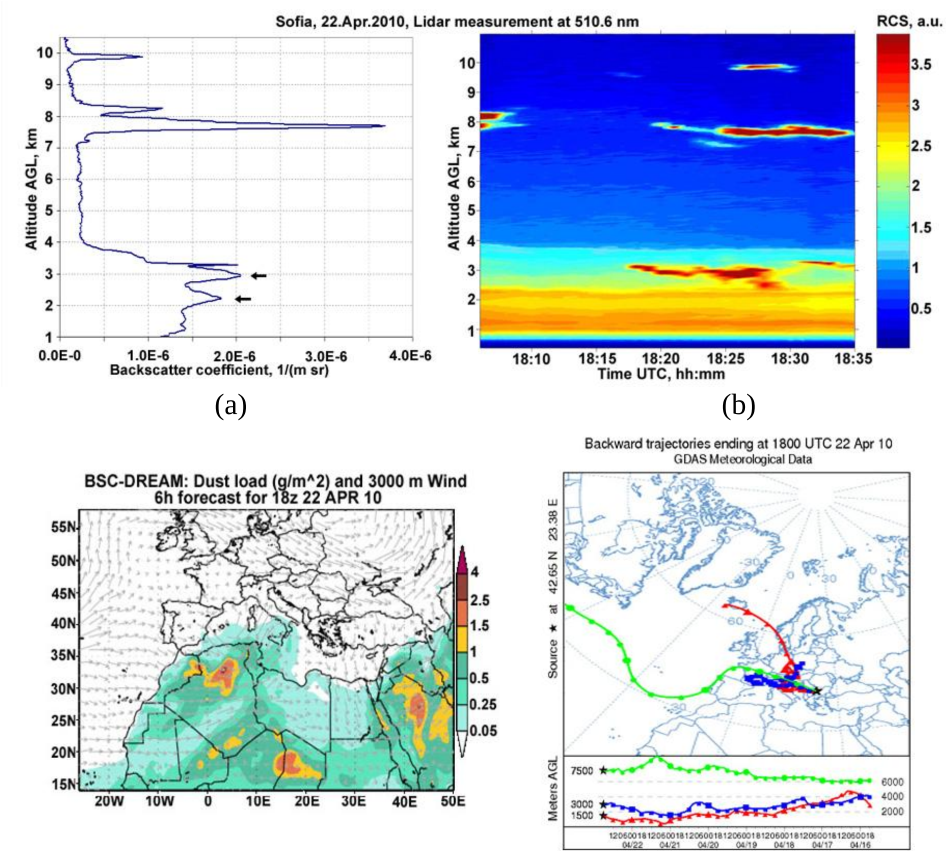
Figure 2. Evolution diagrams of the aerosol backscatter coefficient at 510.6 nm (a) and 532 nm (b) as measured by the CuBr and Nd:YAG lidars, respectively, on 04.11.2010 and BSC-DREAM forecast map of dust loading (c).

PBL, which is typical. The color-coded DREAM dust loading forecast map for the time preceding the measurements is displayed in figure 2a. As one can see, a dust layer with density of about 0.2 g/m^2 has covered the lidar station region, in good correlation with the intense peaks of the dust backscattering coefficient (exceeding 1×10^{-6} m^{-1}sr^{-1} at 532 nm), observed in figure 2a.

As is evident in figure 2a and 2b, the Saharan dust layer is well expressed, intense, and relatively stable in terms of height and thickness. Nevertheless, one can perceive a specific internal structure of th density distribution evolving over time. The aerosol layer at 5-6 km ASL, observed by the upward-looking CuBr lidar (figure 2a), is absent in the other diagram (figure 2b) because the Nd:YAG lidar is operated at a slope angle of 58 degrees with respect to the zenith, thus receiving signals from different spatial domains.

Observation of special phenomena – detection of volcanic ashes

The eruption of Eyjafjallajokull volcano in Island on 14 April 2010 offered the opportunity for lidar stations participating in the European Lidar Network to demonstrate the effectiveness of the lidar sensing for 4-dimensional characterization of the volcanic ash transport. The lidar monitoring of Eyjafjallajokull plumes spreading above Sofia lidar station started on 18 April 2010 and ended on 25 May 2010 (Grigorov et al., 2011).



(a) (b)

(c) (d)

Figure 3. Results of lidar measurements on 22.04.2010: (a) averaged vertical profile of the retrieved aerosol backscattering coefficient; (b) time evolution of range-corrected lidar signal (RCS); (c) BSC-DREAM forecast map of Saharan dust load in the atmosphere; (d) backward HYSPLIT air mass trajectories. The two peaks marked with arrows in figure 3a are volcanic ash layers over Sofia.

The results of lidar measurements performed on 22 April 2010 by using the CuBr lidar at the wavelength of 510.6 nm are given in figure 3, showing presence of volcanic ash layer positioned at ~2.2 and 3 km altitudes AGL. The low limit observed of the layer frequently remains mixed with the PBL, at about 2-2.5 km altitude AGL.

The lidar observations are presented in two formats: as a single averaged vertical profile of the retrieved backscattering coefficient (figure 3a), and as a map of the time evolution of the range-corrected lidar signal (RCS) (figure 3b). The corresponding BSC-DREAM forecast map and the calculated HYSPLIT backward trajectories, proving the origin of the detected aerosols, are presented in figures 3c and 3d, respectively.

Concerning the backscattering coefficient, two peaks appear just at the top of the PBL, indicating the presence of aerosol layers at about 2.2 and 3 km altitude AGL. As it can be seen in Fig.3b, these two layers do not disappear during the whole period of measurement. The forecast map of BSC-DREAM concerning the Sahara dust transport (figure 3c) shows an atmosphere free of desert dust over the Balkans at that time. In addition, the HYSPLIT backward trajectories (see figure 3d), corresponding to altitudes of 1.5 km and 3 km AGL, cross the volcano site and/or European countries with volcanic ash atmospheric contamination. Thus, the conclusion can be drawn that the two aerosol layers detected are due to the volcanic ash transport. The aerosol layers appearing at heights of about 8 km AGL are identified as cirrus clouds.

Measurements in the framework of cooperation with a satellite missions

Atmospheric profiling by a network of ground-based lidar stations is an optimal approach for validation of results obtained by space-borne lidars, providing supporting data to fully exploit the

(a)

(b)

(c)

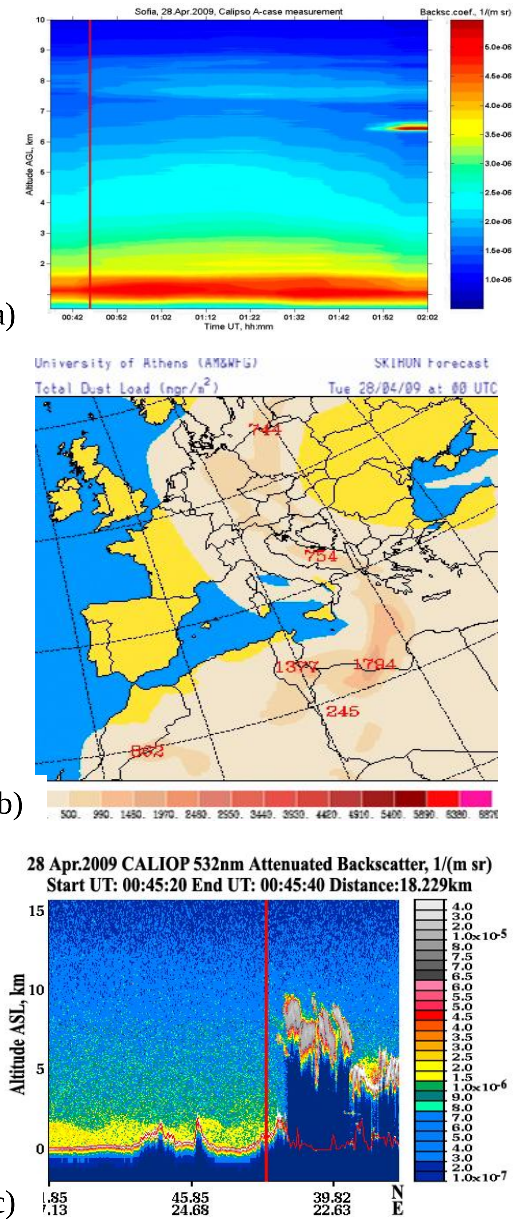


Figure 4. Aerosol backscatter coefficient profiles measured over Sofia lidar station on 28 Apr 2009 (a), Saharan dust forecast maps provided by Atmospheric Modelling and Weather Forecasting Group of NTUA, Greece (b) and map of attenuated Backscatter coefficient measured by the Calipso lidar CALIOP (c). The vertical red line marks the time of nearest overpass of the satellite over the Sofia lidar station. The overpass time interval is given in the caption of plots (c). The distance between the satellite ground-track and the lidar is also presented. Time evolution of the profiles shows the changes of the aerosol load in the atmosphere over the lidar.

information from satellite lidar missions. Such a mission is the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO). The Cloud-Aerosol LIdar with Orthogonal Polarization (CALIOP), mounted on the CALIPSO satellite, is a Nd:YAG-laser-based lidar specially designed for aerosol and cloud monitoring. The several years of correlative ground-based lidar measurements, performed by the EARLINET stations as synchronized with CALIPSO overpasses, have contributed to the specialized database and illustrated the lidar network potential to provide a sustainable ground-based support for space-borne lidar missions [8].

Figure 4 shows the results of lidar measurement in cooperation with CALIPSO satellite missions carried out on 28 April 2009. High aerosol load in the atmosphere up to altitude of ~4.5 km AGL was observed (figure 4a), due to the transport of Saharan dust over the Mediterranean Sea (figure 4b). A map of the attenuated atmospheric backscatter coefficient as measured by the CALIPSO satellite lidar (CALIOP) is presented on figure 4c. The vertical red lines mark the time and the position of the nearest overpass of the satellite above Sofia lidar station. The overpass time interval is of the order of 0.2 sec, as noted in the caption of figure 4c. The distance between the satellite ground-track and the lidar is also presented. Using this map, we compared qualitatively the backscatter profiles measured by the two lidars. Flying to the south-west above Sofia, the CALIOP lidar observed thick aerosol layers (clouds) at about 6-8 km AGL, shown on figure 4c to right of the vertical red line. A similar aerosol layer was registered by the ground-based lidar (figure 4a) at 01:50 h UTC at altitude ~7 km AGL one hour after the CALIPSO overfly. Briefly, the two atmospheric aerosol backscatter coefficient diagrams showed similar limits of the values measured by the instruments and corresponding stratification of aerosol layers.

ACTRIS Project

ACTRIS (**A**erosols, **C**louds, and **T**race Gases **R**esearch **I**nfra **S**tructure Network – Grant Agreement No 262254) is an European Project aiming at integrating European ground-based stations equipped with advanced atmospheric probing instrumentation for aerosols, clouds, and short-lived gas-phase species (http://www.actris.net/). ACTRIS will play the essential role of assisting in the accumulation of new knowledge, as well as in devising policies on climate changes, air quality, and long-range transport of pollutants.

ACTRIS is a European project funded within the EC 7th Framework Program under “Research Infrastructures for Atmospheric Research”. ACTRIS started on 1st April 2011 for a period of four years.

ACTRIS is building the next generation of the ground-based component of the EU observation system by integrating three existing research infrastructures, namely, EUSAAR, EARLINET, CLOUDNET, and a new trace-gas network component into a single coordinated framework.

Main objectives of ACTRIS

■ To provide long-term observational data and to substantially increase the number of high-quality data relevant to climate and air quality research on an regional scale produced with standardized or comparable procedures throughout the network;
■ To provide a coordinated framework to support transnational access to European advanced infrastructures for atmospheric research, strengthening high-quality collaboration in and outside the EU and access to high-quality information and services for the user communities (research, environmental protection agencies, etc);

■ To develop new integration tools to fully exploit the use of multiple atmospheric techniques at groundbased stations, in particular for the calibration/ validation/integration of satellite sensors and improvement of the parameterizations used in global and regional scale climate and air quality models. ACTRIS aims at providing time series of climate and air quality related variables not directly measured, which are presently not available through existing data centers;

■ To enhance training of new scientists and new users – in particular students, young scientists, and scientists from Eastern European and non-EU developing countries in the field of atmospheric observation;

■ To promote the development of new technologies for atmospheric observation of aerosols, clouds and trace gases through close partnership with EU companies. ACTRIS aims at contributing to more than four new operating standards for atmospheric monitoring by the end of the project.

The work of ACTRIS is organized in networking activities, transnational access and service activities, and joint research activities. The data provision structure in ACTRIS involves four networking activities (NAs) covering the activities of each research infrastructure of the Consortium (EUSAAR, EARLINET, CLOUDNET, and a new trace-gas network). Two NAs define the main interest of observations and researches for EARLINET-community:

WP2: Remote sensing of vertical aerosol distribution;

WP20: Lidar and sunphotometer – Improved instruments, integrated observation strategies and algorithms for the retrieval of advanced aerosol microphysical products.

ACTRIS partners

The ACTRIS Consortium is formed by 28 contractors, including 13 third parties (JRUs), representing 19 countries across Europe. The Bulgarian contractor in ACTRIS is the Institute for Nuclear Research and Nuclear Energy at the Bulgarian Academy of Sciences (Dr. Ivo Kalapov). Because partners were grouped into a single contractor for most countries, the true ACTRIS Consortium involves also 18 initial associated partner institutes, which contribute to and at the same time benefit from the activities undertaken within the project. The Institute of Electronics at the Bulgarian Academy of Science, with the Laser-Radar Laboratory led by Prof. D. Stoyanov, is presented in the contract in the initial list of 18 associated partners actively participating in the project.

EARLINET will continue to build a quantitative comprehensive statistical database of the horizontal, vertical, and temporal distribution of aerosols on a continental scale. The goal is to provide aerosol data with unbiased sampling for important selected processes and air-mass history, together with comprehensive analyses of these data. The objectives will be reached by operating a network of presently 18 stations distributed across most of Europe using advanced quantitative laser remote sensing to directly measure the vertical distribution of aerosols, supported by a suite of more conventional observations. Special care is taken to assure the data quality, including inter-comparisons at instrument and evaluation levels. A major part of the measurements is performed according to a fixed schedule to provide an unbiased statistically significant data set. Additional measurements are performed to specifically address important processes that are localized either in space or time. Back-trajectories derived from operational weather prediction models are used to characterize the history of the air parcels observed, accounting explicitly for the vertical distribution.

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NEW MATERIALS FOR APPLICATION IN ELECTRONICS BASED ON BIOGENIC FERROXIDES

Project DID 02/38 financed by the Bulgarian National Science Fund

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The morphological and physical properties were investigated of biogenic iron oxides/hydroxides obtained from laboratory cultured *Leptothrix* bacterial strain. To mimic the natural conditions of development of the targeted group iron oxidized bacteria (FeOB), in the experiments we used the equipment for cultivation of iron bacteria in the Faculty of Biology of University of Sofia. Although numerous studies have been carried out on material gathered at different natural sites and on chemical or physical modifications of this material, little has been done on these bacteria selective culturing under laboratory conditions. In our experiments, we used several different nutrition media aiming at collecting detailed information about their influence on the end iron containing bio-products. The studies on neutrophilic FeOB showed the appearance of bacteries of the *Leptothrix* group and identified a number of morphologically distinct species from different study sites, including water iron seeps, hydrothermal vents, groundwater and rhizosphere of wetland plants.

The bactery subproducts were thoroughly examined via Raman micro-spectroscopy, SEM and XRD. The Raman spectra were obtained using a LabRAM HR visible single spectrometer equipped by a microscope and a Peltier-cooled CCD detector. The 633 nm He-Ne laser line was used for excitation. We used different acquisition times, because of a strong luminescence signal at some of the chosen spots for investigation and also because of the different surface roughness.

The Raman measurements were performed at room temperature and atmospheric pressure. The structural identification was confirmed by XRD patterns.

Table 1. All culture media used with the corresponding iron bio-products detected via Raman spectroscopy.

Sample's number/Culture media	Iron oxides/hydroxides detected (via Raman scattering)	Type of magnetism	Luminescence (at 687 nm Raman line)	Source of Fe^{2+}
1/Adler (Fehrenbach)	lepidocrocite (γ-FeO(OH)) magnetite (Fe_3O_4)	antiferro-magnetic ferrimagnetic	strong	$(NH_4)_2Fe(SO_4)_4.6H_2O$
2/Isolation media.(Fehrenbach)	lepidocrocite (γ-FeO(OH))	antiferro-magnetic	strong	iron cuttings, $FeCO_3$ and $FeCl_2$
3/Lieske (Roux)	Goethite (α-FeO(OH))	antiferro-magnetic	strong	iron cuttings, $FeSO_4.7H_2O$ $FeCO_3$ and $FeCl_2$

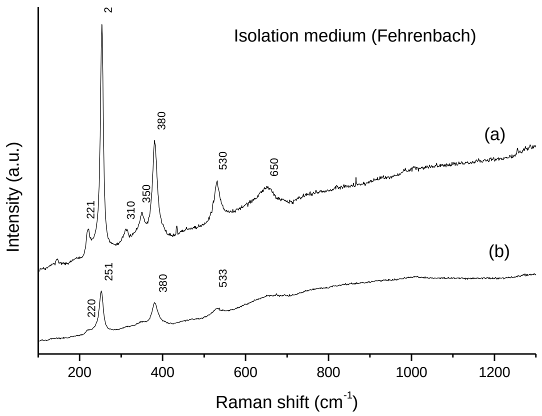

Figure 1. Sample 2 - Raman spectra and corresponding microscopic photographs, with the focus of the laser beam at x=0 and y=0. Best coincidence with literature data, for peak positions: (a) and (b) lepidocrocite (γ-FeO(OH)).

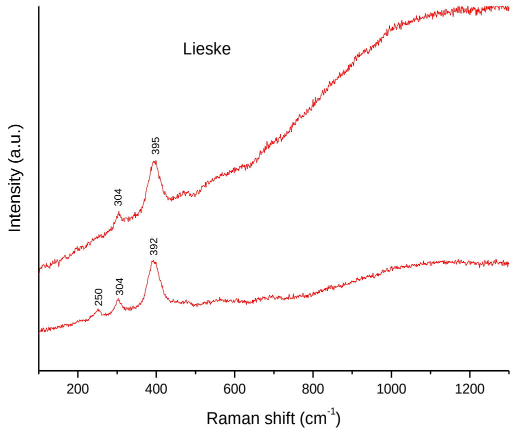

Figure 2. Raman spectra and corresponding microscopic photographs, with the focus of the laser beam at x=0 and y=0. Best coincidence with literature data, for peak positions goethite (α-FeO(OH)), for both spectra.

In Table 1 one can find all culture media used with the corresponding iron bio-products detected via Raman spectroscopy. No Raman signal was detected using a focused laser beam incident on naked glass (slides), thus proving the lack of interference from it.

Well-defined subproducts were exhibited b sample 2 – lepidocrocite and sample 3 – goethite (see fig.1 and 2).

The synthesis of Lepidocrocite ($\gamma - FeOOH$) is not a widely practiced process. Indeed, most of the reaction mechanisms and pathways are poorly understood. The oxy-hydroxide structures are very complex, not only because of the fact that most of the time they appear as a mixture in nature, but also because of their highly dynamic surface state when immersed in aqueous solutions. Consequently, it is relevant from a research point-of-view to evaluate reliably which phase is more likely to act as a sorbent for contaminants.

Specific studies have been carried out on the effect of ferrous ions on solid iron oxyhydroxide surfaces which, in the case of lepidocrocite, may lead to the formation of either magnetite or goethite [1]. Indeed, it is often found present in mixed phases instead of in pure structures. Small changes in conditions, such as pH, agitation and temperature, may lead to significant variability in the resulting product's composition and structure. It was found that a surface complexation/reducing agent is one of the major mechanisms through which such surfaces are so reactive, specifically FeIIIOFeIIOH0. This was observed for sample No 1 (see Table 1).

The initial stage of this investigation ended with determining and implementing laboratory conditions for cultivation FeOB. The bio-subproducts have well structured inorganic substances which are ready for application. The physical studies revealed a luminescence effect for bio-subproducts at 687 nm.

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PREPARATION OF THICK FERRITE COATINGS BY DEPOSITION IN A MAGNETIC FIELD

Project DO-02-99/2008 financed by the Bulgarian National Science Fund

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The increasing use of microwave frequencies for telecommunications has stimulated the expansion of civil applications in the mm-waves range. Nonreciprocal devices, such as circulators, are indispensable parts of highly efficient microwave modules for telecommunication systems. Among the several types of ferrites, the hexaferrites are the only materials suitable for mm-wave applications. The anisotropic crystalline structure of $BaFe_{12}O_{19}$ results in a high saturation magnetization and a high magentocrystalline anisotropy. The ferromagnetic resonance of BaHF occurs at around 50 GHz, which makes it suitable for mm-wave applications; magnetically oriented thick films are expected to possess optimal properties in this respect.

The main objective of this project is to obtain knowledge on the preparation of magnetically oriented thick films. We intend to study the deposition of the BaHF particles in the presence of a magnetic field. The idea is to exploit the magnetism of the BaHF particles and the driving force of an applied magnetic field for controlled deposition of the particles. One of the goals of the project is optimizing the deposition process parameters, from the synthesis of nanosized $BaFe_{12}O_{19}$ parameters, through their stabilization in an aqueous solution, to their orientation by applying an external magnetic field

To achieve the main objective of the project, the following research tasks were performed:

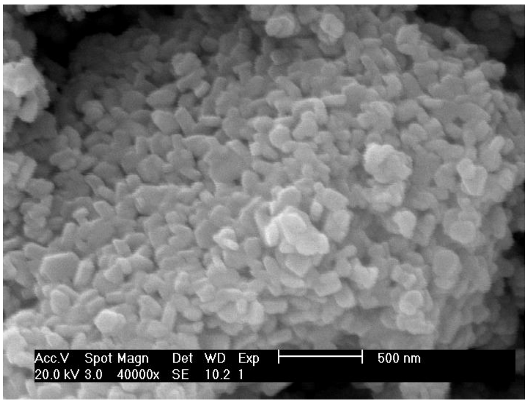
1. Synthesis of monodomain $BaFe_{12}O_{19}$ (BaHF) and Al-substituted $BaFe_{12}O_{19}$ ($BaAlFe_{11}O_{19}$, Al-BaHF) particles with high degree of homogeneity with respect to their size and shape;
2. Investigation of the structural and magnetic characteristics of the hexaferrites synthesized;
3. Simulation of the magnetic field distribution within the magnetic field source;
4. Design of a setup for film deposition in a magnetic field;
5. Preparation of thick oriented magnetic films of $BaFe_{12}O_{19}$ in the presence of an external magnetic field. Optimization of the deposition parameters;
6. Investigation of the structural and magnetic characteristics of the thick films obtained.

Some of the results of the project implementation are briefly presented below.

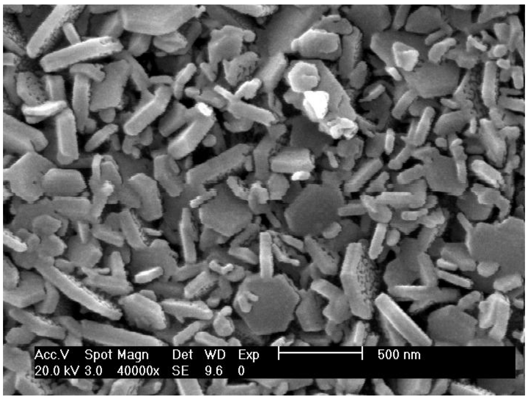
The original methodologies based on the single and double microemulsion techniques were extended to the synthesis of nanosized monodomain hexaferrite particles ($BaFe_{12}O_{19}$ and Al-substituted $BaFe_{12}O_{19}$), characterized by a high degree of homogeneity of the particles with respect to their shape and size. One of the advantages of the microemulsion thechnique is the preparation of very uniform particles (< 10% variability). This is due to the fact that each water droplet acts as a nano-reactor in the nanoparticles formation. and the growth of each nanoparticle formed is limited by the water droplet size. The research work included selecting the microemulsion system composition and determining the ratio of the components in view of preparing a stable microemulsion system with a specific water droplets radius. A microemulsion system was chosen consisting of cetyltrimethylammonium bromide (CTAB) as a surfactant, 1-butanol as an auxiliary surfactant, n-hexanol as an organic phase, and an aqueous phase containing metal cations (Ba^{2+}, Al^{3+}, Fe^{3+}) or a precipitating agent (NaOH).

The surfactant (CTAB) has the property of allowing OH^- to pass freely through the water droplets wall in both directions. On this basis, we developed a novel microemulsion technology, namely, the so-called "single microemulsion", in order to synthesize nanosized monodomain hexaferrite particles. This technology makes use of one microemulsion system only, whose aqueous phase contains metal cations. The co-precipitation is achieved by adding a solution with high concentration of NaOH. The amount of this solution is such as not to disturb the microemulsion system stability, while provoking the full co-precipitation of the metal cations. One of the advantages of the methodology developed by us is its low cost. We optimized the parameters of producing nanosized monodomain $BaFe_{12}O_{19}$ particles with high degree of homogeneity with respect to their size and shape. Further, we studied the effect of the synthesis temperature on the structural and magnetic properties of the nanosized $BaFe_{12}O_{19}$ powders synthesized.

Figure 1 presents SEM images of the samples prepared. We found that one can vary in a controlled way the particles size by varying the synthesis temperature, while at the same time preserving the homogeneity of the powder sample. For example, the BaHF produced at 900 °C by single emulsion has an average particles size of 110 nm, while that prepared at 950 °C, 250 nm. We should note that the particles produced at the lower temperature have irregular shapes, between spherical and hexagonal, which indicates that the process of formation of the hexagonal platelet shape characteristic for this material



a)



b)

Figure 1. SEM images of BaHF powders synthesized by single microemulsion and annealed at 900°C (a) and 950°C (b).

has not been completed; this also explains these particles' small size; in contrast, the particles formed at the higher temperature exhibit the typical hexagonal shape. Using TEM, we were able to observe the step of growth along the *c* axis of the particle, together with the crystal lattice parameter, namely, 2,34 nm.

The synthesized samples' magnetic characteristics are presented in Table 1.

The data obtained demonstrated that the samples prepared by single microemulsion possess better magnetic characteristics that those produced by double microemulsion. This is a confirmation of the importance of fabricating nanosized powders of particles that are homogeneous with respect to the size and shape. The above results will be summarized in a scientific paper, which is in the process of preparation.

Table 1. Magnetic properties of $BaFe_{12}O_{19}$ obtained by single (I) and double (II) microemulsion.

Sample	M_s, (emu/g)	M_r, (emu/g)	M_r/M_s	H_c, (kOe)	K_1 (10^5), (J/m^3)
I, 900	65.12	31.33	0.48	4.34	3.09
I, 950	58.35	27.45	0.47	4.55	2.97
II, 900	59.69	29.05	0.49	3.97	2.96
II, 950	50.22	23.89	0.47	2.89	2.39

An original technology (sonochemical synthesis) was developed for the preparation of nanosized $BaFe_{12}O_{19}$ particles with average size of 25 nm (figure 2).

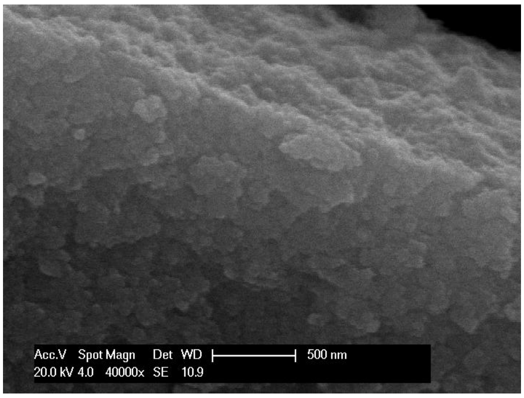


Figure 2 SEM image of BaHF powders obtained by sonochemical synthesis.

As further implementation of the project tasks, we designed and built an experimental setup for thick films deposition in an external magnetic field. We followed the variation in the deposition process parameters, namely, the $BaFe_{12}O_{19}$ concentration in the suspension, the time for film deposition, the time and temperature of drying, and the temperature of the high-temperature film treatment.

Figure 3 presents the results of the structural studies of the thick $BaFe_{12}O_{19}$ films deposited on an Al_2O_3 substrate and heat-treated at 1050 ºC for five hours. The films produced are built of particles oriented along the *c*-axis perpendicularly to the substrate with a degree of orientation 60 %.

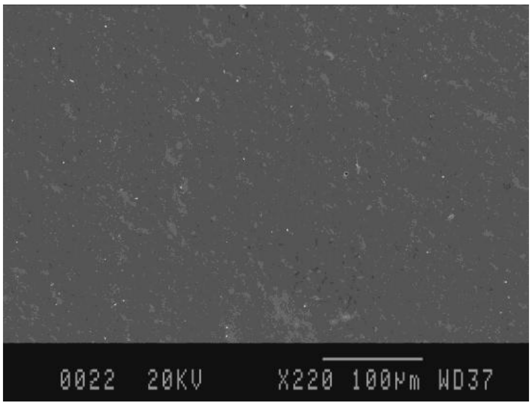


Figure 3. SEM image of the surface of a thick $BaFe_{12}O_{19}$ film deposited on an Al_2O_3 substrate.

Figure 4 presents the hysteresis curves of a barium hexaferrite film. The coercive field has a value of H_c = 420 Oe when the field is applied in a direction perpendicular to the substrate plane, and a value of H_c = 180 Oe in the case of the field being applied parallel to the substrate plane. The magnetization exhibits anisotropic behavior: the M_r/M_s reaches the value of

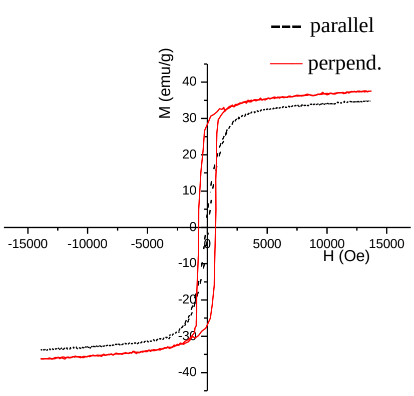


Figure 4. Hysteresis curves of a thick $BaFe_{12}O_{19}$ film taken with a magnetic field applied perpendicularly and parallel to the film plane.

0.75 in the former case, and of 0.15 in the latter one.

The thick oriented $BaFe_{12}O_{19}$ films show the anisotropic magnetic behavior typical for oriented monodomain particles. Their structural and magnetic properties make them suitable for applications in microwave components and devices operating in the mm-range.

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ORIENTED BARIUM HEXAFERRITE FILMS ($BaFe_{12}O_{19}$) FOR MICROWAVE COMPONENTS

Contract DO 02-343/2008 financed by the Bulgarian National Science Fund

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Nanosized hard magnetic material – monodomain $BaFe_{12}O_{19}$

The implementation of the project tasks during the year reported had to do with the preparation of nanosized $BaFe_{12}O_{19}$ powders by hydrothermal synthesis following a technology developed jointly with a research team at the Jozef Stefan Institute, Ljubljana, Slovenia. The powders are characterized by particles size of 10-20 nm, which is smaller than the critical size of monodomain particles (460 nm). The results of the SEM analysis are given in figure1.

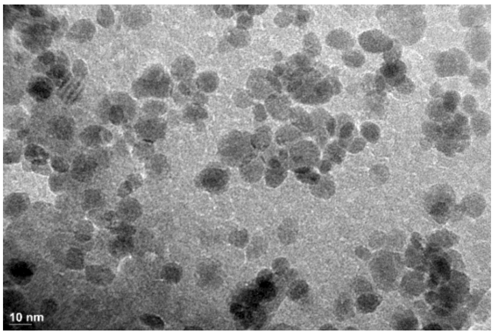

Figure 1. SEM analysis $BaFe_{12}O_{19}$.

During the synthesis, the nanosized particles are wrapped in a polymer shell. This prevents the agglomeration process and is a prerequisite for preparing a monodipersed fluid to be used for producing oriented magnetic structures through deposition and drying in a magnetic field.

For this purpose, we used the experimental setup of permanent magnets (figure 2), which was designed and implemented during stage 1 of the project.

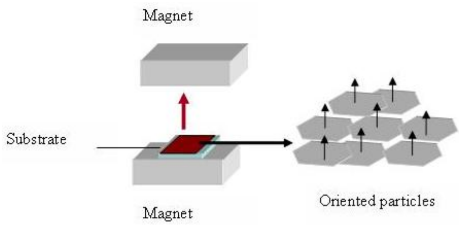

Figure 2. Schematic representation of the sample orienting process.

Figure 3 presents XRD patterns of samples oriented in a magnetic field and annealed at various temperatures.

Besides the peaks characteristic for the $BaFe_{12}O_{19}$ structure, one can see peaks arising from the substrate (Al_2O_3).

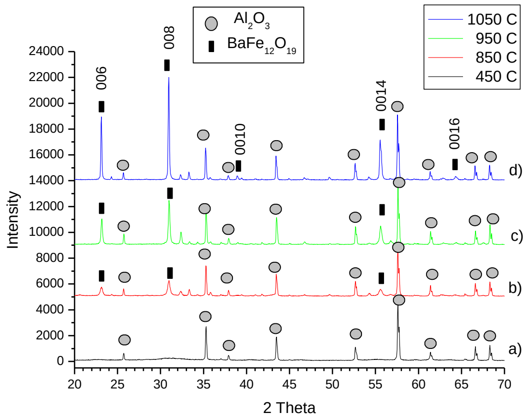

Figure 3. XRD analysis of samples oriented in a magnetic field and annealed at various temperatures.

The analyses reveal a high strength of the (*00l*) peaks for the oriented structures appearing at annealing temperatures exceeding 850 ºC.

Figure 4(a,b) presents SEM images showing the microstructure of two samples – one oriented in a magnetic field, and one, oriented and annealed.

During the annealing, the particles begin growing, but no transition from a mono- to a polydomain state is seen, since the particles diameter is below one micron (i.e., their size is not sufficient for the appearance of a domain structure). The surface of the annealed sample (figure 4b) shows that the organic phase has been removed and the particles have begun growing (sintering process).

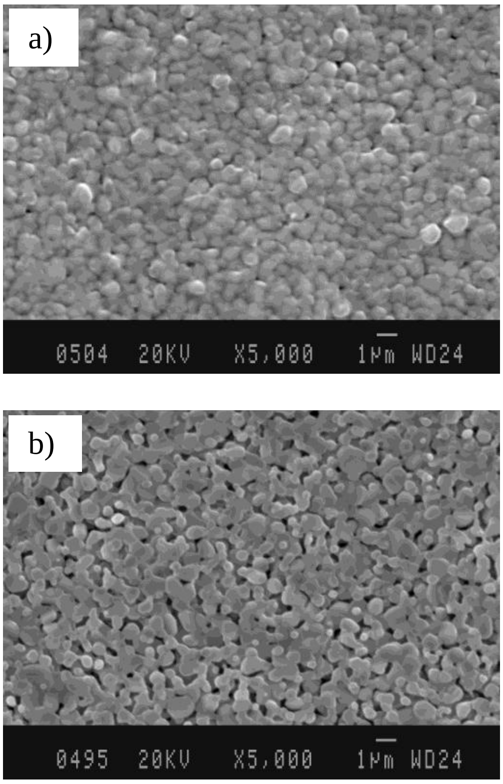

Figure 4. SEM image of the surface morphology of an oriented a) $BaFe_{12}O_{19}$ sample and b) a $BaFe_{12}O_{19}$ sample sintered at 1050 ºC.

Magnetic properties of oriented $BaFe_{12}O_{19}$ structures

The magnetic properties of the oriented structures were determined by applying a magnetic field perpendicular (figure 5a) and parallel (figure 5b) to the substrate plane. The hysteresis curves were taken for different annealing temperatures and a magnetic field applied of 10 kOe.

A sample oriented in a magnetic field contains particles in a stable monodomain state. The annealing process changes the sample's magnetic properties. During annealing, the particles start growing and undergo a transition to a polydomain state.

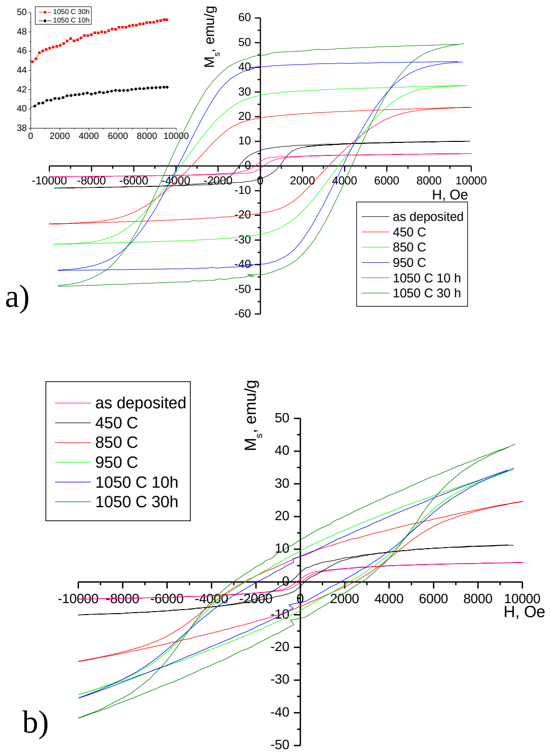

Figure 5. Hysteresis curves of oriented $BaFe_{12}O_{19}$ structures with magnetic field applied perpendicular a) and parallel b) to the substrate plane.

The coercive field changes depending on the domain structure, the particles shape and the crystalline anisotropy.

By varying the annealing temperature, one can vary both the coercive field H_c and the M_r/M_s ratio. The results are presented in Table 1.

Table 1. Variation of the coercive field H_c and the M_r/M_s ratio by varying the annealing temperature.

Annealing temperature (°C)	M_s (emu g^{-1}) (10 kOe)	H_c (Oe)	M_r/M_s (SQR)
As deposited	4.98	183	0.33
450	9.98	913	0.62
850	24.03	3238	0.81
950	32.53	3700	0.87
1050	42.14	3935	0.96

Summary of the results obtained

Oriented magnetic structures of $BaFe_{12}O_{19}$ particles were produced and studied by using a technique not requiring complex and expensive equipment. These structures exhibit high density and homogeneity at a thickness of about 1 μm. The key element in their orientation in a magnetic field is the use of a stable ferrofluid suspension of nanosized $BaFe_{12}O_{19}$ particles produced by applying the hydrthermal synthesis technique.

The oriented structure are characterized by good magnetic properties and a high squareness of the hysteresis cycle (SQR=0,96). This makes them suitable for applications as narrow-band microwave absorbers and circulators at frequencies near 50 GHz, since their ferromagnetic resonance occurs in this range of the electromagnetic spectrum.

References

[1] Kolev S, Lisjak D and Drofenik M 2011 Preparation and characterisation of magnetically ordered columnar structures of barium ferrite particles *J. Exper. Nanosci.* **6**/4 362-37

[2] Kolev S, Lisjak D, Ovtar S, Gyrgyek S and Drofenik M 2011 Thermal treatment influence on the magnetic properties and degree of orientation of $BaFe_{12}O_{19}$ films *J. Supercond. Novel Magn.* pp 1-6 DOI: 0.1007/s10948-011-1273-7

[3] Koutzarova T, Kolev S, Nedkov I, Krezhov K, Kovacheva D, Blagoev B, Ghelev C, Henrist C, Cloots R and Zaleski A 2011 Magnetic properties of nanosized $Ba_2Mg_2Fe_{12}O_{22}$ powders obtained by auto-combustion *J. Supercond. Novel Magn.* 2011 pp 1-5 DOI: 10.1007/s10948-011-1232-3

European Union

DEVELOPMENT OF INTERDISCIPLINARY THINKING AND TRAINING OF YOUNG SCIENTISTS WORKING IN THE FIELD OF LIGHT-MATTER INTERACTIONS

Република България

Contract # BG051PO001.3.3.04/54/2009

Project is funded under the frames of Operative Programme "Human Resources Development" of the European Social Fund

General directorate "Structural funds and international educational programmes" of the Ministry of education, youth and science of Republic of Bulgaria

ESF Bulgaria
European Social Fund

Operation scheme BG051PO001-3.3.04 "Support of PhD students, post-doctors and young scientists' development"
Priority axis 3 "Improving the quality of education and training in correspondence with the labour market needs for building a knowledge-based economy"

Terms: 2009-2011
Young scientists involved: 29 persons
Web-site: http://www.ie-bas.dir.bg/YoungSci/

Consortium: Institute of Electronics (IE-BAS) – Basic organization,
Institute of Astronomy (IA-BAS), Optella Ltd. - partners

Project management team
Assoc. Prof. Dr. Ekaterina Borisova - Project Coordinator
Irina Bliznakova – Technical Assistant
Yordanka Dragomanova – ACcountant

Partners' advisory committee
Assoc. Prof. Dr. Sanka Gateva - IE-BAS
Assoc. Prof. Dr. Anna Dikovska – IE-BAS
Assoc. Prof. Dr. Tanyu Bonev - IA-BAS
Assoc. Prof. Dr. Radoslav Zamanov - IA-BAS
Prof. Dr.Sci. Latchezar Avramov – Optella Ltd

Main project goals

Support of young scientists and PhD students from the Institute of Electronics and the Institute of Astronomy in the frameworks of a partnership developed between these organizations for enhancing and broadening their professional skills and knowledge. In the framework of the project activities, institutional fostering of the management and administration's work with young specialists is foreseen. This project provides a large number of opportunities for young professionals from the basic organization and partners to enhance their qualification in the field of photonics, including numerical and statistical methods and modeling of processes and systems, enhancing adaptability and flexibility through their professional training in technology transfer of scientific knowledge to innovation and development environment and production. The project supports mobility by providing short-term scholarships to young scientists and graduate students for research in hybrid applied science fields in foreign R&D organizations and access to unique research equipment as well. Improvement of the institutional capacity of the IE-BAS and IA-BAS through capacity building of young professionals in these organizations with access to additional training and trans-national cooperation schemes is foreseen.

Increased investment in the capacity and training of young scientists and graduate students from IE-BAS and partners is also foreseen under the project, together with the development of a long-term strategy for exchange and cooperation with innovative companies in view of increasing the opportunities of applying their scientific output.

Major activities in 2011

1) Individual support for participation of young researchers in specialized scientific conferences and seminars, as well as for in meetings intended for establishing international contacts and training – two persons were supported for participation in international conferences and schools outside the country and two persons were supported for short-term training visits in foreign specialized research laboratories;

2) Annual subscription is ensured to several scientific journals with possibility for access for all scientists from both research organizations partners in the current project, as follows:

1) Physics Today,
2) Applied Optics,
3) JOSA A,
4) JOSA B,
5) Optics Letters,
6) Optics InfoBase – online database of Optical Society of America (OSA).

3) Courses and seminars were held with the participation of leading specialists in the field of data and image processing, transfer of knowledge and technologies in innovations, patent rights and IP protection; ethical issues; research management; photometry and astronomic observations; laser spectroscopy and applications; biomedical photonics; as well as individual interdisciplinary research and applications – more than 200 hours of lectures in several lectures courses;

4) Organization and implementation of the specialized Seminar on Statistical Methods for Experimental Data Analysis, on 15.02.2011, with four invited lecturers;

5) Organization and implementation of Young Scientists Summer School on image processing and data analysis of physical measurements in the field of ecology, medicine and nanotechnologies, in the period of 24-29.06.2011, Bansko, with eight invited lecturers;

6) Short-term individual trainings of several young researchers by the high-tech company-partner in the project, with presentation of examples and application possibilities for “good practices” for transfer of knowledge from science to innovative practice;

7) Permanent activities for informing young researchers for all project initiatives, lectures’ presentations, information about other initiatives related to the young scientists’ activities from BAS and Ministry of Education, Youth and Science, by e-mail circular letters and printed announcements;

8) Project management – meetings of the project management team and partners’ advisory committee, accounting, documents support, carrying out of administrative procedures needed for project implementation. Implementation of work meetings for monitoring and evaluation of the performance and preparation of project activities foreseen in the project, as well as for the results obtained.

SCIENTIFIC EVENTS

- **Seventeenth International Summer School on Vacuum, Electron and Ion Technologies (VEIT 2011)**
- **Nineteenth International Conference on Advanced Laser Technologies**

  (ALT 2011)

SEVENTEENTH INTERNATIONAL SUMMER SCHOOL ON VACUUM, ELECTRON AND ION TECHNOLOGIES (VEIT)

19-23 September 2011, Sunny Beach, Bulgaria

The International Summer School on Vacuum, Electron and Ion Technologies (VEIT) has been organized biennially since 1977, when the VEIT Summer School series was launched by the Institute of Electronics, Bulgarian Academy of Sciences. The aim was to act as a forum for the exchange and dissemination of knowledge and ideas on the latest developments in electron-, ion- and plasma-assisted technologies. The organizers of the 2011 edition of the event were the Institute of Electronics, Bulgarian Academy of Sciences, Sofia, Bulgaria, and the Department of Applied Physics, Eindhoven University of Technology, Eindhoven, The Netherlands.

The Seventeenth edition of VEIT was held in the Black Sea resort of Sunny Beach, Bulgaria on 19–23 September 2011. It was attended by 96 participants from 18 countries: Belgium, Brazil, Bulgaria, Czech Republic, Denmark, France, Germany, Greece, The Netherlands, Romania, Russia, Serbia, Sweden, Switzerland, Turkey, Ukraine, UK and the USA.

Following the tradition of publishing the VEIT Proceedings, a selection of papers presented at the event was published in a special issue of *Journal of Physics: Conference Series* (2012, vol. 356), under the originality and quality criteria of acceptance by the journal, including peer reviewing.

The school comprised thirteen plenary and three poster sessions. At the plenary sessions, 21 invited talks of general interest were presented by renowned international experts in the field, together with thirteen progress reports by young scientists. In total, 60 contributed papers were presented during the poster sessions. There were several scientific highlights, covering the fundamentals of interaction of fast particles with solids, and challenging practical applications. These ranged from novel techniques for creating hard coatings, optical/protective layers and biocompatible materials, to nanosized structures produced by evaporation, sputtering or external irradiation. The latest results were presented on ion-beam synthesis and modification in both low-energy (deposition and film growth) and high-energy (sputtering, implantation) regimes, the processing of solid materials aimed at surface patterning, and the creation of nanophase systems for electronic or tribological/wear resistant applications.

Despite the busy scientific program, the atmosphere was relaxed and informal. The early afternoons of most conference days were free to stimulate both scientific and social interaction between participants, which often took place on the beach. The social program included a welcome party, an official dinner, and an outing to historical landmarks in the ancient town of Nessebar.

VEIT 2011 owes its success to many people. The International Advisory Committee shaped the scientific program and ensured high-quality plenary presentations by careful selection of the invited speakers. The Local Committee bore the brunt of the organization, both at the conference site and in dealing with correspondence, abstracts, and manuscripts for the proceedings. We are grateful to our sponsor, the Department of Applied Physics, Eindhoven University of Technology, Eindhoven, The Netherlands, for its generosity that enabled us to support the attendance of students, and provided support with mailing, printing, renting the conference site, etc. We would also like to thank all authors for their valuable contributions to the proceedings and to the school, and all reviewers for their hard and tedious, but very important, work.

The next conference in the series will be held in September 2013.

M. Dimitrova and M.C.M. van de Sanden,
Chairs of the School

Website of the event: http://www.veit.dir.bg

INTERNATIONAL ADVIZORY COMMITTEE

G. Dinescu	National Institute for Laser, Plasma and Radiation Physics, Magurele, Bucharest, Romania
A. Ehiasarian	Sheffield Hallam University, Sheffield, UK
N. Guerassimov	Bulgarian Academy of Sciences, Sofia, Bulgaria
D. Mataras	University of Patras, Patras, Greece
W. Möller	Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany
I. Petrov	University of Illinois, Urbana, IL, USA
Z. Petrovic	Institute of Physics, Belgrade, Serbia
B. Rauschenbach	IOM and Leipzig University, Leipzig, Germany
M.C.M. (Richard) van de Sanden	Eindhoven University of Technology, Eindhoven, The Netherlands
M. Ürgen	Istanbul Technical University, Istanbul, Turkey

LOCAL ORGANIZING COMMITTEE

▪	**Angelov Ch.**
▪	**Damjanova M.**
▪	**Dimitrova M. (Chair)**
▪	**Ghelev Ch.**
▪	**Petrov P.**

MAIN SCIENTIFIC TOPICS

▪	Ion-assisted film growth and sputter deposition of thin films
▪	Ion beam and laser processing of surfaces and thin films
▪	Coatings for advanced applications in electronics, magnetism, superconductivity, optics, mechanics
▪	Surface and thin film analysis
▪	Plasma diagnostics and plasma assisted processing
▪	Modeling and computer simulation

NINETEENTH INTERNATIONAL CONFERENCE ON ADVANCED LASER TECHNOLOGIES – ALT'2011

03-08 September, 2011, Golden Gands resort, Bulgaria

The Nineteenth International Conference on Advanced Laser Technologies (ALT'2011) was held in Golden Sands resort, Bulgaria, from third to eighth of September 2011. The Institute of Electronics, Bulgarian Academy of Sciences, was the national host and organizer of this event; thus, for the first time Bulgaria hosted this prestigious international conference in the field of laser technologies and applications. Our co-organizers were the A.M. Prohorov General Physics Institute of the Russian Academy of Sciences, the International Laser Center of Moscow State University, and the Center for Laser Technologies and Material Sciences of the Russian Federation.

The ALT'2011 Organizing Committee included a Chair – Assoc. Prof. Dr. Ekaterina Borisova (BG), Secretary – Irina Bliznakova (BG) and Organizing Committee members: Assoc. Prof. Dr. Anna Dikovska (BG), Dr. Albena Daskalova (BG), Rangel Rangelov (BG), and Natalia Khakamova (RU).

The ALT Conference series, held annually since 1993, are focused on the recent achievements and advances in laser technology and laser applications in various areas. This series of conferences were founded by the General Physics Institute of the RAS. The previous conferences were organized in Russia, the Czech Republic, Germany, Greece, France, Italy, Romania, Switzerland, the United Kingdom, China, Hungary, Finland, Turkey and The Netherlands. Leading scientists and researchers from all over the world are invited to attend the Conference and make presentations reviewing the latest results in their field of interest.

The conference had place in one of the largest hotels of the Golden Sands resort – the Melia Grand Hermitage Hotel. In the list of the invited lecturers we had the pleasure to see some of the leading world specialists in the field of laser technologies and applications, heads of university departments, research institutes and centers from all over the world.

We had 150 participants - researchers from 23 different countries – Austria, Bulgaria, China, Czech Republic, Denmark, Finland, France, Germany, Hungary, Ireland, Italy, Japan, Poland, Romania, Russia, Sweden, Switzerland, Taiwan, The Netherlands, Turkey, UK, Ukraine, and USA.

The key topics of the conference were:

- Biophotonics
- Laser spectroscopy
- Laser-matter interactions
- Laser applications in material sciences
- Laser systems and new laser materials
- Ultrashort laser technologies and applications
- Lasers in cultural heritage
- Laser remote sensing and ecology
- Micro-/nanophotonic devices
- Active optical sensing and metrology
- Optoacoustics

We had the pleasure to find support from:

- National Center on Biomedical Photonics, IE-BAS, Bulgaria
- Russian Foundation of Fundamental Research, Russia Federation
- LaserQuantum, UK
- OceanOptics, The Netherlands
- HORIBA JobinYvon, France
- ASTEL, Bulgaria

The funds received from sponsoring organizations and exhibitors on the ALT'11 conference were used for printing materials, organizing expenses, as well as for three prizes – first, second and third place for "The best report of a young scientist".

The conference program included two parallel sessions from 4 to 8 September 2011, with 9 plenary lectures, 40 invited lectures, 40 oral reports, as well as poster session with 59 reports presented on 6 September 2011.

Special issues will be published in 2012 in several well-recognized international journals with the reports and lectures presented on the conference having been peer-reviewed, as follows:

1) Quantum Electronics ,
2) Journal of Biophotonics,
3) Journal on Biomedical Optics,
4) Journal of Innovative Optical Health Sciences.

Two meetings were held of the International Programme Committee. During the second one, general conclusions were drawn about the current issue of the event and the young scientists were selected to be awarded "The best report of a young scientist" awards, as follows:

1) First award - Maria Khokhlova „Dynamic measurements of RBC elastic properties by means of an optical trapping technique", Russia;
2) Second award - Nina Kalyagina, "Diffuse-reflectance spectroscopic and imaging diagnostic methods for urinary bladder", Russia;
3) Third award - Armin Hochreiner, "Photoacoustic imaging using adaptive interferometer with a photorefractive crystal", Austria.

The ALT'2011 edition was the largest ever from the point of view of the number of participants. The local organizers had also the pleasure to be informed by the international program committee that this the ALT conference has attracted the largest number of young scientists ever for all the history of this conference from its establishment to the present, as well as the largest number of oral presentations in the conference program.

The Local Organizing Committee would like to express its gratitude to the members of the ALT International Program Committee for their support, as well as to all our sponsors and exhibitors, who made this event possible. Special gratitude is extended as well to the editorial boards of the journals where special issues with the ALT'2011 scientific reports will be published.

Website of the event:
http://www.ie-bas.dir.bg/ALT11/