INSTITUTE OF ELECTRONICS

ANNUAL REPORT 2007

Editors: N. Guerassimov, Ch. Ghelev

Contents

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.

Scientist 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, the Higher Attestation Commission, specialized scientific boards at the Higher Attestation Commission, 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 studies 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.

SCIENTIFIC COUNCIL*

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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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LABORATORIES

EMISSION ELECTRONICS
HEAD: Assoc. Prof. N. Donkov, Ph.D.

PLASMA PHYSICS AND ENGINEERING
HEAD: Prof. B. Djakov, Dr.Sc.

PHYSICAL PROBLEMS OF ION TECHNOLOGIES
HEAD: Prof. S. Tinchev, Dr.Sc.

PHYSICAL PROBLEMS OF ELECTRON BEAM TECHNOLOGYIES
HEAD: Corresponding Member of BAS G. Mladenov, Dr.Sc.

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HEAD: Assoc. Prof. A. Yanev, Ph.D.

PHYSICAL TECHNOLOGIES - SLIVEN
HEAD: Assoc. Prof. R. Enikov, Ph.D.

LABORATORIES

- **Research Activities**
- **Publications**
- **Patents**
- **Conferences**
- **Ongoing Research Projects**
- **Collaborations**
- **Lecture Courses**
- **Guests**
- **Visits**

LABORATORY

EMISSION ELECTRONICS

HEAD: **Assoc. Prof. N. Donkov, Ph.D.**

TOTAL STAFF: **9**
RESEARCH SCIENTISTS: **5**
M. Mladenov; P. Georgiev; V. Varbanova; Ts. Valchovska; Pl. Petkov.

RESEARCH ACTIVITIES:

1. Ion beam modification

Using detailed calculation with full damage cascades, part of the SRIM 2003 software package, we performed computer simulations of experiments planned to be conducted in the laboratory.

The changes were modelled occurring in layers of Ta_2O_5 prepared by electron-beam evaporation or ion-assisted electron-beam evaporation following irradiation by 400-eV Ar ions, with the purpose of improving the layers' optical characteristics.

An analogous experiment was also modelled, but with a thin oxide film deposited on the Ta_2O_5 layer. Following the oxide film deposition, the surface is bombarded by 400-eV Ar ions, in view of improving the Ta_2O_5 stoichiometry, together with the improvement of its optical characteristics.

The comparison between the two cases modelled demonstrated that in the presence of an oxide layer the desired effect is achieved at lower irradiation doses. One observes penetration of O_2 from the oxide film into the Ta_2O_5 layer, which results in an improvement of the Ta_2O_5 stoichiometry.

At the same time, the number of induced defects is reduced, which reduces the degree of layers' amorphousness and, in turn, the necessity of additional annealing of the structures.

2. Focused ion beams

The inclusion of quadratic field terms in the usual expression for predicting the zero-Q evaporation field for a chemical element yields a fourth-order equation. This has previously been solved numerically to give the enhancement factor β_n by which the solution exceeds that obtained when the quadratic field terms are neglected. Expressing this equation into a suitable dimensionless form yields a much simpler fourth-order equation for β_n that has a straightforward analytical solution. Solutions exist only for values of the coefficient D less than a critical value D^* equal to 27/256, and D can be simply evaluated using the bulk atomic volume and the usual thermodynamic parameters needed to predict the evaporation field. The cases where D is greater than D^*, for one or more values of the escape charge-state n, are strongly correlated with the position of the element in the Periodic Table, and show that the dominant influence is the pattern of ionization-energy values. Tables and formulae are provided for performing such calculations easily. D-values and enhancement factors were tabulated for relevant elements and for n=1 to 4, using thee thermodynamic parameter values previously used in evaporation-field tabulations. In 9 out of 56 cases the escape charge-state predicted by Branson's criterion increased by 1, as compared with predictions based on Müller's formula and

the same thermodynamic data. The enhancement factors predicted lay between 1.03 and 1.47, with average 1.11.

3. Ion beam assisted deposition of thin films and process control

Using an EB evaporation technique, TiO_2 were deposited on Si substrates. During the deposition, certain process parameters were controlled. The layer composition was monitored by XPS. A study of the influence of the partial pressure on the properties of the in-situ mass-spectrometer analysis is under way.

In order to determine the TiO_2 sorption ability to NH_3, quartz crystal microbalance (QCM) with thin TiO_2 layers was investigated. The TiO_2 film was used for the detection of NH_3 gas. The quartz resonators created on AT-cut with frequency of 14 MHz were used to transform the additional mass loading, as a result of sorption, into the frequency shift. The experiments were carried out by measuring the QCM resonance frequency shifts over aqueous solution of NH_3 with different concentrations from 10 ppm to 1000 ppm.

The experimental results obtained indicated that the resonance frequency varied depending on the ammonium concentrations and TiO_2 thickness. It was also found that the process of sorption is reversible.

It could be concluded that a QCM covered with thin TiO_2 layer is sensitive to ammonium vapor at room temperature and has the ability to distinguish between different NH_3 concentrations in the range investigated.

PUBLICATIONS:

1. Georgieva V, Donkov N, Spassov L, Spassov D,
Tantalum pentaoxide-based quarz crystal microbalance for NH_3 detection,
J Optoelectr Adv Mater 2007;9/2:252-255.

ONGOING RESEARCH PROJECTS:

Financed by the Bulgarian Academy of Science:
Ion beam- application for investigations and synthesis of new materials.

Financed by the Ukraine Academy of Science and the Bulgarian Academy of Science:
New materials for biomedical investigations.

Financed by BMW - Germany:
Investigation of the cluster emission characteristics of a liquid-metal ion source and their improvement with the aim to produce focused ionized cluster beams. Numerical simulation of the cluster emission process and of the nonlinear effects in the interaction with matter.

COLLABORATIONS:

1. Thermionic emission energy transverter for vacuum technology; Model based control,
Institute for Applied Physics, Otto von Guericke University, Magdeburg, Germany.

2. Ion implantation for nano-technology applications,
Research Center Dresden-Rossendorf, Germany and University of Edmonton, Canada.

LABORATORY

PLASMA PHYSICS AND ENGINEERING

HEAD: **Prof. B. E. Djakov, Dr.Sc.**

TOTAL STAFF: **12**
RESEARCH SCIENTISTS: **8**
Prof. L. Zarkova, Dr.Sc.; Assoc. Prof. R. Enikov, Ph.D.; Assoc. Prof. N. Guerassimov, Ph.D.; Assoc. Prof. D. Oliver, Ph.D.; Assoc. Prof. E. Balabanova, Ph.D.; M. Damyanova; E. Vasileva; J. Alexieva.
Ph.D. student: M. Dimitrova.

RESEARCH ACTIVITIES:

1. Fundamental processes in gases at high temperatures

The perfluorinated *n*-alkanes C_mF_{2m+2} (m = 1 to 6) are widely used expensive substances which are not only of technological interest for the semiconductor industry but as powerful greenhouse gases have an important impact on the atmosphere. We present tables with recommended thermophysical data in the temperature range (200 to 1000) K and pressures ≤ 0.1 MPa. Second *pVT*-virial coefficients *B*, viscosities η, and diffusion coefficients *D* are calculated by means of a (*n*-6) Lennard-Jones temperature-dependent potential. The potential parameters, equilibrium distance, and potential well-depth are defined as functions of the temperature *T* by solving an ill-posed problem of minimization of the squared deviations between measured and calculated *B*, η, and *D,* normalized to their experimental error. Tables with potential parameters as well as algorithms for calculation of the potential-dependent properties are given. We also present new tables of the harmonic vibrational frequencies of *n*-C_4F_{10}, *n*-C_5F_{12}, and *n*-C_6F_{14} which are required as input parameters in the course.

2. Investigation and description of nanostructures in inorganic materials

The object of our investigations were inorganic immiscible oxide glass materials. It is known that during the formation of such glasses inhomogeneties (droplets, aggregates etc.) with nano- and microsizes can be obtained. These structures are interesting from both theoretical and applied points of view. Recently, the existence of nanoscaled heterogeneities in the glasses has been recognized as a universal characteristic on which basis a large number of glass peculiarities can be explained.

The nanostructures of some TeO_2 glasses were investigated. Two and three component oxide systems were considered: TeO_2-GeO_2, TeO_2-B_2O_3, TeO_2-B_2O_3-SiO_2, TeO_2-B_2O_3-TiO_2.

The study of the evolution of immiscibility nanostructures is based on the TEM data coupled with micrograph computer treatment for quantitative estimation of the structural evolution observed. The parameters calculated are the immiscibility droplet perimeter, area and circularity. The development of the immiscibility nanostructures strongly depends on the composition and the method of synthesis. It is shown that in many binary and ternary TeO_2-based

glasses there exist appropriate compositions with uniformly distributed heterogeneities. These structures make the glasses convenient matrices for composite materials formation.

3. Monitoring and control of jets produced by arc plasma torches

A. In recent years, we extended our chromaticity based diagnostic technique to produce a means for monitoring plasma jet geometrical properties, such as angle of propagation and cross-sectional radius. A new sensor is now proposed for monitoring such characteristics based on a simple processing algorithm for the signals from four photo diodes.

In addition, a 3D image reconstruction algorithm is proposed and tested on arc plasma jets with deviation from the axial symmetry and with filamentary structure. The new technique is based on 3-recourse dynamical imaging by means of a fast CCD camera followed by "line by line" Gabor expansion of the digitized images. The Gabor components are then used to recover the optical emission in three dimensions.

B. Our current research on arc plasma torches was extended toward the automatic control of plasma technological processes: A new method was proposed for on-line compensation of operational enthalpy drifts in the issuing plasma from arc torches with known or unknown *a priori* volt-ampere characteristic.

4. Energy distribution functions of charged particles in oxygen containing plasma

In a number of technologically important applications, gas pressures (100 - 1000 Pa) are required that are higher than those where the classical Langmuir probe is applicable. In view of improving the probe technique, a procedure is proposed which allows one to determine correctly the plasma parameters by measuring the probe current second derivative at intermediate pressures while accounting for the distortion effects.

In order to obtain the electron energy distribution function (EEDF) by using the extended Druyevestein formula, one has to measure the second derivative of the probe current electron component. To obtain experimentally the second derivative we used the technique of the probe-current second-harmonic. The influence of the instrumental function on the signal was also accounted for, together with the distortion arising due to its finite width.

The procedure proposed was applied to and tested under various experimental conditions. The first case involved a discharge tube with sectioned coaxial cathodes and a common mesh anode ensuring a homogeneous and stable plasma column along the tube length with the purpose of studying oxygen and argon plasma in stream afterglow under Maxwell charged-particles energy distribution. The experiments proved the applicability of the procedure proposed to intermediate gas pressures. E.g., in pure oxygen we observed the presence in the EEDF of a structure typical for the existence of negative ions.

Ar-O plasma used to deposit superconducting films by means of YBCO cathode sputtering was studied using a Langmuir probe and the plasma parameters were determined under various conditions using the procedure proposed. The absence was proved of negative oxygen ions, even in the case of the negative glow of a 30%Ar+70%O_2 mixture. The results obtained yield information that can be used to optimize the conditions of producing high-quality superconducting YBCO films.

PUBLICATIONS:

1. Hohm U, Zarkova L, Stefanov B B,
   Perfluorinated n-alkanes C_mF_{2m+2} (m < 7): second pVT-Virial coefficients, viscosities, and diffusion coefficients calculated by means of an (n-6) Lennard-Jones temperature-dependent potential,
   J Chem Eng Data, 2007;52/5:1539-44.
2. Kashchieva E, Dimitriev Y, Ilieva D, Balabanova E,
   Peculiarities of nanoscale immiscibility design in GeO_2-TeO_2 glasses,
   Nanoscience & Nanotechnology, ed E. Balabanova, I. Dragieva (Heron Press Ltd, Sofia, Bulgaria) 2007;7:156-9.
3. Popov Tsv K, Stöckel J, Dejarnac R, Dimitrova M, Ivanova P, Naydenova Tsv,
   Advanced probe measurements of electron energy distribution functions in CASTOR Tokamak plasma
   J Phys: Conf Ser 2007;63:012002.
4. Djakov B E, Oliver D H, Vasileva E, Enikov R,
   Three dimensional optical imaging of plasma jets,
   Proc XIVth Workshop on Plasma Technology (2007 Ilmenau, Germany) pp 21–7.
5. Djakov B E, Shpanin L M, Spencer J W, Jones G R,
   Propulsion of a plasma ring in a rotary arc device at atmospheric pressure,
   J Theor Appl Mechanics 2007;37/1:35–43.
6. Guerassimov N, Ghelev Ch (Eds),
   Institute of Electronics Annual Report 2006:1-129.
   Institute of Electronics, Sofia, Bulgaria, 2007.
7. Guerassimov N, Ghelev Ch, Martev I, Petrov P I (Eds),
   Abstract book of the 15th International Summer School on Vacuum, Electron and Ion Technologies, 126 pages, 2007, Sozopol, Bulgaria.

SEMINAR OF THE INSTITUTE:

M. Dimitrova, Charged particles energy distribution functions in oxygen containing plasma, 09.05.2007.

Prof. U. Hohm, Thermophysical properties of low density pure gases and their binary mixtures determined by a temperature dependent potential – results from the collaboration between the Institute of Electronics, BAS, Sofia, and the Institute of Physical and Theoretical Chemistry, TU Braunschweig, Germany, 30.05.2007.

COLLABORATIONS:

Investigation on the intermolecular potentials by means of Lennard-Jones temperature dependent potential,
Institut für Physikalische und Theoretische Chemie der TU Braunschweig, Hans-Sommer-Strasse 10, D-38106 Braunschweig, Germany.

Diagnostics of thermal plasma jets used for processing of materials,
Institute of Plasma Physics, Academy of Sciences of Czech Republic, Za Slovankou 2, 182000 Prague, Czech Republic.

LECTURE COURSES:

Plasma Diagnostics, Gas Discharge Plasma Sources, Plasma Technologies,
University of Sofia, Sofia, Bulgaria.
Elementary Applied Physics, Introductory Mathematics, Stellar Astronomy and Cosmology,
American University in Bulgaria, Blagoevgrad, Bulgaria.

LABORATORY VISITS:

L. Zarkova, University of Braunschweig, Germany, 01.09 – 01.12.2007.

M. Damyanova, University of Braunschweig, Germany, 01.11 – 01.12.2007.

B. Djakov, Ilmenau Technical University, Germany, 20.06 – 02.07.2007.

GUESTS:

Prof. U. Hohm, Institut für Physikalische und Theoretische Chemie der TU Braunschweig, Hans-Sommer-Strasse 10, D-38106 Braunschweig, Germany, 27.05 - 02.06.2007.

LABORATORY

PHYSICAL PROBLEMS OF ION TECHNOLOGIES

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

TOTAL STAFF: **6**
RESEARCH SCIENTIST: **5**
Assoc. Prof. J. Kourtev, Ph.D.; P. Nikolova; Y. Dyulgerska; R. Kozhuharova; H. Basheva.

RESEARCH ACTIVITIES:

1. Mechanism of operation of Josephson junctions made from HT_c materials by ion modification

In the situation of missing tunnel junctions from HT_c materials ion modifed HT_c Josephson junctions are a real alternative. After our first successful fabrication of YBCO Josephson junctions and SQUIDs by oxygen ion implantation a number of leading laboratories realized and studied its potential for easy production and high density integration. In this technology, an implantation mask with a submicrometer slit made by electron beam lithography is used to create a nanometer scale barrier in an HT_c bridge. In our first experiment, repeated later by others, oxygen ions were used. Other kinds of ions were also successfully used: argon, neon and hydrogen. Moreover, after the recent discovery of superconductivity in MgB_2 this technology was applied also to create excellent Josephson junctions from this new material.

After the initial skepticism, now it is well accepted that these junctions are of the superconductor- normal - superconductor (SNS) type. This is the reason why they operate as Josephson junctions in spite of the barrier being some hundreds nanometers long. However, many people still doubt that this is a manufacturable technology and that it is possible to achieve the high yield necessary for fabrication of great number of identical junctions.

In our work, existing attempts to fabricate Josephson junctions from HT_c materials by ion modifcation were summarized.

A computer simulation with these experimental data for every case was made to calculate the critical temperature depth profiles. The experimental results are consistent with our calculation and Josephson behaviour is observed in the temperature range predicted.

We summarized experimental attempts to fabricate ion beam modified Josephson junctions from HT_c materials. The results from our simulations are presented in publication [1]. Most of the data presented are for junctions made from oxide 123-superconductors. However, the recently successfully fabricated ion beam implanted Josephson junctions from MgB_2. The calculation of T_c was made using the dependence between dT_c/dU (U is the dose) and nonionizing energy loss (NIEL). The NIEL was obtained by the well-known Monte-Carlo program TRIM. The annealing effects were simulated.

From [1], it is evident that in the cases of modification with oxygen, neon and argon the experimentally found doses for Josephson behaviour are similar (some 10^{13} ions/cm^2). Only in the case of using hydrogen ions, which cause much smaller atomic displacement, is this dose higher (10^{15}–10^{16} ions/cm^2). This is good evidence that the junction properties are defined by the modified base material

properties and not by some damaged weak part of the HT_c material. Therefore, these junctions can be fabricated reproducibly.

2. Amorphous hydrogenated carbon coatings for thermal solar collectors

Amorphous hydrogenated carbon (a-C:H), a semiconductor, is an interesting absorber material whose bandgap, refraction index, adhesion, hardness and durability can be tailored. Layers of a-C:H are used as antireflection coatings for solar cells. Films of a-C:H containing transition metals are a promising material for the fabrication of selective solar absorbers. We investigated a simple process where the selective solar absorbers are made of pure a-C:H without metal inclusions. This is achieved by varying the bias voltage during the PECVD deposition. In such a way a five-sublayer system with graded optical properties was fabricated. In our previous work we reported our investigations of a matched to the solar spectrum a-C:H absorber layer deposited on glass. For thermal solar collectors, however, it is important to use substrates with high thermal conductivity like copper (Cu) and aluminum (Al).

Thin films of amorphous hydrogenated carbon were deposited in a DC plasma CVD reactor. Benzene vapors diluted by argon were chosen as a processed hydrocarbon. Rough Al substrates were used for the experiments. However glass substrates were needed for the UV-VIS transmittance measurements and Si wafers were used for the IR transmittance measurements. Aluminum was chosen as a substrate material because of earlier experience, relatively low cost, good adhesion of a-C:H to it, its high reflectivity in the IR range of wavelengths and its high thermal conductivity. Ten-minute Ar ion sputtering at 2 kV provided for an additional cleaning of the surface. The samples were prepared at five different DC voltages (0.5 kV, 1 kV, 1.5 kV, 2 kV and 2.5 kV) with 6 min deposition time of each layer and one graded layer which consisted of the same five layers with a 30 min total deposition time. The voltage decreased from bottom (film-substrate interface) to top (air-film interface). The voltage variation from 2.5 kV to 0.5 kV changes the optical bandgap of an a-C:H material from 1.2 eV to 2.1 eV, thus covering almost the whole solar spectrum.

A double-beam spectrophotometer type Shimadzu UV-190 with integrating sphere was used for the measurement of the layer hemispherical reflectance on Al substrates and transmittance and reflectance on glass substrates in the solar spectrum wavelength range. A FTIR Shimadzu Prestige 21 spectrophotometer operating in the infrared wavelength range from 1.25 μm to 28.5 μm was used for the measurements of the transmittance of the a-C:H sublayers and of the multilayer system as a whole.

The ideal behavior of solar absorber surfaces is that of high absorption ($\alpha(\lambda) \approx 1$), i.e. $R(\lambda) \approx 0$ in the 250÷2500 nm wavelength range, where almost all solar radiation is concentrated. As the average value of R for Al is 0.62, an Al substrate covered with a graded a-C:H thin film has average value of R=0.078. The reflectance of the graded film is lower than the reflectance of all single layers.

Our a-C:H/Al tandem actually acts as a heat mirror. Since an Al substrate has very good reflectance we have to prepare coating which is transparent for infrared radiation. With decreasing the voltage of film deposition, the film transmittance increases, the graded layer having the highest transmittance.

It is obvious that our further investigations should be aimed at increasing the transparency in the near infrared. The absorbers fabricated for thermal solar collectors manifest very low reflectance in the optical range, but their

near IR transparency should be increased in order to improve the optical selectivity.

3. A method for controlling the cluster size distribution

Supported nanoclusters in the range of a few nanometers have attracted increasing interest in catalysis, in sensor production as well as in optoelectronics and for different medical applications because of their unique chemical, optical, magnetic and electric properties. In many cases however, their application is determined by the size monodispersity and time stability. Recently, a variety of different physical and chemical methods for cluster deposition, as well as their combinations, have been developed. Monodispersed nanoclusters can be produced relatively easily via a chemical route, but the nanoclusters obtained are encapsulated by organic shells hindering their application when "naked" clusters have to be used. With respect to the physical methods, the main problem is the prevention of cluster coalescence and the resulting time evolution of their sizes and dispersity. For solving this problem, different techniques have been proposed e.g. by "pinning" of preliminary formed high energy clusters into the substrate or by deposition using low energy mass-selected ion or cluster beams on substrates with preliminary generated surface defects. The latter methods, however, require very sophisticated and expensive setups, which significantly limits their industrial application.

We proposed a method for depositing stable nanoclusters with narrow size distribution using a magnetron with a continuous control on the ion assistance. Employing this method, isolated and stable (more than one year) silver nanoclusters with mean sizes of 5-6 nm and dispersities down to 5 % were deposited on amorphous carbon (a-C) substrates.

PUBLICATIONS:

1. Tinchev S S,
   Mechanism of operation of Josephson junctions made from HT_c materials by ion modification,
   Physica C 2007;460-462:1477-78.
2. Tinchev S S,
   Comment on "High-T_c superconducting quantum interference devices made by ion irradiation",
   Appl Phys Lett 2007;90:136101.
3. Tinchev S, Dyulgerska Y, Nikolova P**,** Alexandrova S, Valcheva E,
   J Optoelectr Adv Mater 2007;9/2:386–9.

CONFERENCES:

1. S. Tinchev, P. Nikolova, S. Balabanov, N. Georgiev,
   Amorphous hydrogenated carbon coatings for thermal solar collectors,
   Fifteen International Summer School VEIT 2007, Sozopol, Bulgaria.

ONGOING RESEARCH PROJECTS:

Financed by the National Science Fund

E-04-01 a-C:H selective absorbers for thermal solar collectors.
F-1304 Investigation of coherent effects in micro- and nanostructures of high temperatures superconductors.
VU-TH –964 Assisted microwave processes in the nanocomposite materials forming.
EE-103 Research system of the materials and solar elements investigation in the UV-VIS region.

Financed by the FP6

ESA SURE AO 20006-002 Space application reliability of diamond-like carbon films.

LABORATORY

PHYSICAL PROBLEMS OF ELECTRON BEAM TECHNOLOGIES

HEAD: **Prof. G. Mladenov, Dr.Sc.**, **Corresponding Member of BAS**

TOTAL STAFF: **17**
RESEARCH SCIENTISTS: **14**

Assoc. Prof. K. Vutova, Dr.Sc.; Assoc. Prof. P. Petrov, Ph.D.; Assoc.Prof. V. Vassileva, PhD; Assoc. Prof. S. Sabchevski, Ph.D.; E. Koleva, Ph.D.; Y. Gueorgiev, Ph.D.; M. Beshkova , Ph.D.; M. Petkov, Ph.D.; Ch. Georgiev; M. Kardjiev; T. Nikolov; E. Georgieva; S. Velinova; D. Mollov.

1. Electron and ion beam lithography

The main steps of the algorithms developed for computer simulation of the processes during electron and ion lithography were discussed. Peculiarities and benefits of our computer software package utilizing Monte-Carlo techniques were demonstrated. The calculation results on the adsorbed energy distributions and the profiles developed in the resist layer in the region of microstructure images with critical dimensions of less than 250nm were compared with the experimental data and with the results of other computer simulations. The comparison shows good agreement for the process conditions investigated, meaning that we achieved adequate simulation of the micro-structuring technology for nano-structures by electron and ion lithography exposure and development. The model and the computer code could, therefore, be applied for predicting and optimizing the micro-fabrication of nano-structures with critical dimensions of less than 250 nm.

2. Evaluation of intense electron beam quality

The electron beam emittance is chosen as a suitable parameter for standardization of the electron optical technology systems. The evaluation of this parameter is a condition for achieving good quality, repeatability and reproducible performance of electron beam welds. This parameter forms the basis for transferring a concrete technology from one machine to another which will minimize the experimental test volume as well as will extend the capability of the expert systems to choose the process regimes of specific welds. The methods for intense beam emittance evaluation were analyzed. A new method for emittance estimation based on the use of a measuring slit in a non-movable plate, and another method using the changes of the beam focusing current during the beam profiles measurement were developed. The methods are modification of a method proposed earlier by us for emittance determination utilizing three beam profile measurements along the beam axis.

As a practical implementation of the measuring devices we developed two beam-analyzing devices: (i) with one line slit and (ii) with seven radial slits. The modulation plates with these slits are situated at the input of a Faraday cup.

3. Electron beam melting and refining of metals in vacuum

The factors controlling the behavior of the alloy component or impurity concentrations during electron beam melting and refining (EBMR) of Ti were studied. New data on heat and mass transfer were obtained through computer simulation. For oxygen concentration

minimization during EBMR, a statistical analysis is applied to the experimental data and computer simulation results. Thermodynamic analysis was also performed.

The optimal Ti EBMR can be implemented at low temperatures (2370 K) and refining time of 4.7 minutes.

4. Electron beam welding

Statistical regression models were developed of the electron beam weld geometry parameters depending on the process conditions for construction steel type 45 and for stainless steel at deep penetration. Other models for stainless steel, Ti and Al, at thin plate welding were also developed. All models discussed can be used to predict the weld process in view of development of automated control systems.

The specifics of electron beam welding in the case of utilizing additional material in the welding pool and the methodology of choosing the welding wire diameter were clarified.

The structures and mechanical properties of electron beam welds of construction and tool steels and the measured thermal distributions during the electron beam welding were studied.

An approach to the technological regime choice in the case of welding permaloy thin plates was developed. The welding regimes of such components were optimized for the purposes of fabricating an optical magnetometer developed in the institute.

5. Thin film deposition

High temperature superconducting thin films (YBCO) were deposited on substrates from $LaAlO_3$ using magnetron sputtering. Thermal baking of the structures in oxygen ambient increases the superconducting critical current density and the critical temperature. After baking, the crystallites dimension changes (from 35 nm to 50 nm) as evaluated by X-ray diffraction.

A new system of electron beam evaporation using an electron gun with a plasma cathode was applied for oxide thin film deposition in reactive atmosphere. Thin films of TiO_2 were deposited to demonstrate the capabilities of the new system. Data were accumulated on the evaporation rate of Ti, the deposition rate of TiO_2 and the role of substrate temperature.

6. Computer simulation of powerful gyrotrons for fusion research

The numerical analysis and comparison of the known software for computer simulation of gyrotrons were completed. A concept was proposed for the development of a new generation of computer programs based on 3-D physical models.

Numerical experiments for studying coaxial gyrotrons with MW power were performed and new data characterizing the electron beam quality and the efficiency of models and programs used were obtained.

New basic program modules for calculation of a static electromagnetic field were developed. These modules are for PIC simulation of new generation.

An analysis of the methods for frequency control of the gyrotron radiation was also performed. A new class of intelligent resonators utilizing a piezo-ceramics materialwas proposed.

PUBLICATIONS:

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   J Mater Processing Technol 2007;184/1-3:305-11.
2. Vutova K, Mladenov G, Tanaka T, Kawabata K, Rangelow I,
   Electron and ion beam lithography simulation for sub-quarter-micron patterns,
   Nano Trends: A Journal of Nanotechnology and its Applications 2007;2/1:32-47.
3. Beshkova M, Grigorov K G, Zakhariev Z, Abrashev M, Massi M, Yakimova R,
   Sublimation Epitaxy of AlN layers grown by different conditions on 4H-SiC substrates,
   J Optoelectr Adv Mater 2007;9/1:213-6.
4. Sabchevski S, Zhelyazkov I, Thumm M, Illy S, Piosczyk B, Tran T-M, Hogge J-Ph, Pagonakis J Gr,
   Recent evolution of the simulation tools for computer aided design of electron-optical systems for powerful gyrotrons,
   Computer Modelling in Engineering and Science 2007;20/3:203-20.
5. Sabchevski S, Saito T, Idehara T, Nakano T, Tatematsu Y
   Simulation of mode interaction in the gyrotron FU CW I
   Int J Infrared and Millimeter Waves, 2007;28:1079-93.
6. Sabchevski S, Idehara T,
   Resonant cavities for frequency tunable gyrotrons,
   Int J Infrared and Millimeter Waves 2007;20:1-22.
7. Mladenov G, Koleva E,
   Evaluation and some applications of the electron beam emittance,
   Proc 7th Int Conf on Beam Technol 2007 (Halle, Germany) pp 85-92.
8. Koleva E, Vassileva V, Mladenov G,
   Simulation of thermal and mass transfer of reactive metals,
   Proc Int Conf Liquid Metal Processing and Casting – LMPC'2007, (Nancy, France) pp 219-25.
9. Sabchevski S, Zhelyazkov I,
   Modelling and simulation of new generation of powerful gyrotrons for fusion research,
   J Phys: Conf Series 2007;63:012003.
10. Koleva E, Mladenov G,
    Modeling of electron beam welding of steel 45,
    Proc 15th Int Symp Electrical Apparatus and Technol SIELA'2007 (Plovdiv, Bulgaria), Publisher CEEC – Bulgaria, pp 67-76.
11. Jankova Y, Petrov P,
    Modeling of electron beam welding process for reconstitution of Charpy specimens,
    Proc MTF 2007 Conf (Sozopol, Bulgaria) pp 221-7.
12. Petrov P, Jankova Y,
    Reconstitution of Cv test specimens by electron beam welding: process parameters selection,
    Proc 12th National Conf Thermal and Nuclear Energetics 2007;1:175-82.

ONGOING RESEARCH PROJECTS:

Financed by the National Science Fund

BIn-2 Electron beam melting and refining of refractory metals and alloys.
BIn-3 Power electron beam equipment for melting and refining of metals and alloys in vacuum.
F-1505/05 Electron beam welding of metals with various properties.
MUF-1508/05 Synthesis and modification of YBCO films for IR sensors.
F-1514 Physical characteristics and mechanical properties of multilayer nanostructures of complex nitrides of transition metals.
VUI 307 Integrated information medium for modeling and control of the process of electron beam melting and refining of metals.
C 102/06 High-technology sub-micron electron beam lithography.

Financed by the National Innovation Fund

Electron-beam and orbital electric arc welding under multifunctional microprocessor control.

COLLABORATIONS:

Projects from programs of EU, NATO and other International organizations

Contract No 801505 (FU6) in the framework of the Euratom Key Action Controlled Thermo-Nuclear Fusion,
Numerical investigations of selected problems associated with the development of powerful gyrotrons for fusion research.

Indo-Bulgarian Inter-governmental Cooperation - The Bhabha Atomic Research Centre, Mumbai, India, and The Nuclear Fuel Complex, Hyderabad, India,
High power electron beam equipment for EBMR. Characterization of intense electron beams.

Research Programme of Association EURATOM-INRNE, Sofia (Task P3),
Development of numerical codes to describe the behavior of high power gyrotrons.

Projects of collaborations of IE BAS and other foreign institutions

Department of Electronics and Photonic Systems Engineering, Hiroshima Institute of Technology, Japan,
Computer simulation of the processes of electron, ion and X ray irradiation of electron materials.

LECTURE COURSES:

Electron Beam Technologies,
European school for advanced studies: Application of ionizing radiation in material studies, University of Pavia, Italy.

Electron and Ion Technology,
Faculty of Electronics Engineering, Technical University of Sofia, Bulgaria.

Statistics,
University of Chemical Technology and Metallurgy, Sofia, Bulgaria.

LABORATORY FELLOWS VISITS:

G. Mladenov - 7th Int. Conference on Beam Technology, 17-19.04.2007, Halle, Germany.
G. Mladenov – Lectures in University of Pavia, 04-10.05.2007, Pavia, Italy.
S. Sabchevski – University of Fukui, 02.01-02.07.2007, Fukui, Japan.
K.Vutova - 8th International Balkan Workshop on Applied Physics, 04-08.07.2007, Constanta, Romania.
E. Koleva - Conference on Applied Stochastic Models and Data Analysis, 29.05 – 01.06.2007, Chania, Greece.
E. Koleva - Conference on Liquid Metal Processing and Casting (LMPC 2007), 01-06.09.2007, Nansy France.

GUESTS:

1. Dr. Igor Zhirkov, Tomsk Institute of Automation and Radio-electronics, Russia, 11.04-10.06.2007, research fellowship under the INTAS financial support.
2. Dr. E. Kandaswamy, BARC, Bombai, India, 05-09.02.2007, joint investigations.
3.Prof. Bernard F. Lamond, Department of Operation and Decision Systems, Laval University, Quebec City, Canada, 12-18.07.2007, lecture and discussions.

LABORATORY

SUPERCONDUCTIVITY AND CRYOELECTRONICS

HEAD: **Assoc. Prof. T. Nurgaliev, Ph.D.**

TOTAL STAFF: **8**
RESEARCH SCIENTIST: **5**
Assoc. Prof. E. S. Mateev, Ph.D.; S. I. Miteva, Ph.D., L. I. Neshkov; R. V. Todorovska; B. S. Blagoev.

RESEARCH ACTIVITIES:

1. Layered thin film structures of ferromagnetic manganites (FMM) and high temperature superconductors (HTS) for spintronics applications

The injection of spin-oriented charge carriers from ferromagnetic manganites (FMM) to high temperature superconductors (HTS) stimulates a destruction of the paired charge carriers and an increase of the concentration of the normal carriers in HTS, which results in the modification of the electrical parameters of the double-layer FMM/HTS structure. At present, the interest to FMM/HTS oxide structures grows rapidly due to their original physical characteristics and their possible applications in spintronics.

For this reason the microwave properties of ferromagnetic thin films and double–layer structures of ferromagnetic manganites and high temperature superconductors were analyzed. Simple formulas for the estimation of the sensitivity of the HTS thin film surface impedance to changes in the concentration of normal charge carriers in it (which can be induced by the injection of spin-oriented charge carriers from the FMM material to the HTS film) were obtained. It was shown that the relative changes of the microwave surface impedance can exceed by more than a factor of ten the relative change of the normal charge carriers concentration in the film at temperatures which are not very low.

In a practical plan, a scheme for measuring the microwave surface impedance of both surfaces of the thin film FMM/HTS structures was proposed and was used for the microwave characterization of $La_{0.7}Sr_{0.3}MnO_3$/ $YBa_2Cu_3O_7$ structures at 77 K. The scheme allowed the observation of a peak in the dependence of the microwave surface resistance on the external field induction, which is assumed to be due to the ferromagnetic resonance in the FM component of the structure.

The high sensitivity of the impedance to the concentration of the charge carriers can be used as an instrument for the investigation of the physical characteristics of FMM/HTS structures. Such structures can serve as a basis for the elaboration of devices of a new type – devices of microwave spintronics, the characteristics of which are controlled not by the electrical current or the electrical field, but by the spin state of the charge carriers.

2. Properties of the treated substrates and the YBCO films grown on the treated substrates

The preparation of high temperature superconducting (HTS) YBCO thin film devices requires different operations: the deposition of the HTS film on a heated substrate, photolithography, etching and treatment procedures and the new deposition, photolithography and treatment procedures. The treated areas of the substrate are characterized by a lower quality and the YBCO films grown on

such areas can have different quality in comparison with the films grown on high quality substrates.

The problem was investigated on the example of two different YBCO films deposited on new and treated LAO substrates, respectively. The results of the XRD analysis demonstrated a significant difference in the widths of the characteristic XRD peaks of these two substrates and of the YBCO films grown on these substrates. This means that the treatment procedures lead not only to an increase of the roughness of the substrate, but to a modification of the crystalline structure of the substrate top layer neighbouring with the treated surface, and affect negatively the growing conditions of YBCO films.

3. RF magnetron sputtering of $GdMnO_3$ thin films

Multiferroic materials demonstrate magnetic and electrical ordering at the same physical conditions. This allows a manipulation of the magnetic phase with an external electric field and a manipulation of the electric phase with an external magnetic field. The multiferroics are considered as multifunctional materials and are promising for the development of combined multifunctional electronic devices. The ortorohmbical $GdMnO_3$ is one such material.

For this reason, the technological regime for preparing $GdMnO_3$ films was optimized and thin films of such material were grown on $SrTiO_3$(100) and Si(100) substrates by RF magnetron sputtering in collaboration with the Institute of Solid State Physics, BAS. The films grown on $SrTiO_3$ substrates were well textured and were suitable for investigation of their structural, magnetic and electrical characteristics. The results allow us to conclude that the technological regime arrived at, with some small variations, can be used for the growing of manganite films of other compositions as well.

4. Optical oxygen sensors

An investigation of the deposition conditions of YSZ -, and platinum doped YSZ - thin films, and an investigation of the characteristics of these films as oxygen sensors, were completed. As a result, a version of a reliable oxygen sensor functioning at low temperatures and low concentration of oxygen was proposed.

PUBLICATIONS:

1. 1. Nurgaliev T, Štrbík V, Miteva S, Blagoev B, Mateev E, Neshkov L, Beňačka S, Chromik S,
   Electrical characteristics of HTS/manganite double layers,
   Centr Eur J Phys 2007;5:-- (in press).
2. Vlakhov E, Blagoev B, Mateev E, Neshkov L, Nurgaliev T, Lakov L, Toncheva K, Marinov Y, Nenkov K, Radulov I, Piotrovski K, Paszkowicz W, Szewczyk A, Baran M,
   Magnetron sputtering deposition and characterization of $GdMnO_3$ thin films,
   J Optoelectr Adv Mater 2007;9:456-459.
3. Mateev E,
   RF magnetron discharge model based on power balance,
   J Phys: Conf Ser 2007;63:012027.
4. Atanassov V, Mateev E,
   Spatial structures along a surface wave produced plasma column: an experimental study,
   J Phys: Conf Ser 2007;63:012025.
5. Iordanova I, Popova L, Alexandrova P, Beshkov G, Vlakhov E, Mirchev R, Blagoev B,
   X-ray investigation of annealed CeO_2 films prepared by sputtering on Si substrates,
   Thin Solid Films 2007;515:8078-81.

6. Todorovsky D S, Todorovska R V, Milanova M M, Kovacheva D G,
Deposition and characterization of $La_2Ti_2O_7$ thin films via spray pyrolysis process,
Appl Surf Sci 2007;253:4560-5.
7. Dimitrov D, Dushkin C, Petrova N, Todorovska R, Todorovsky D, Anastasova S, Oliver D,
Oxygen detection using junction based on thin films of ittria-stabilized zirconia doped with platinum nanoparticles and pure ittria-stabilized zirconia,
Sensors and Actuators A 2007;137:86–95.
8. Nurgaliev T,
Numerical investigation of the surface impedance of ferromagnetic manganite thin films,
AIP Conf Proc 2007;899:793.
9. Nurgaliev T, Miteva S, Blagoev B, Mateev E, Neshkov L, Strbik V, Benacka S, Chromik S,
HTS/manganite double layer structures,
AIP Conf Proc 2007;899:788.
10. Todorovska R, Dimitrov S, Pavlova P, Todorov G,
Light-enhanced chemical whitening of teeth – new "in-vitro" investigation,
Proc SPIE 2007;6604:66042D-1–D-5.
11. Dimitrov D, Todorovska R, Angelov I, Todorov G,
In-vitro investigation of temperature influence on teeth during light-activated chemical bleaching,
Proc ILLA/LTL'2006 2007:274-9.
12. Blagoev B, Sardela M, Donchev T, Nurgaliev T,
YBCO thin films grown on LAO substrates of different quality,
Nanoscience & Nanotechnology Eds Balabanova E, Dragieva I (Heron Press Ltd, Sofia, Bulgaria) 2007;7:127-9.

CONFERENCES:

1. T. Nurgaliev,
Modeling of the surface impedance of conductive ferromagnetic films on different substrates,
13th Czech and Slovak Conf on Magnetism, Kosice, Slovakia, July 2007.
2. T. Nurgaliev, V. V. Demidov, A. M. Petrzhik, G. A. Ovsyannikov, S. Miteva, B. Blagoev,
Microwave losses in ferromagnetic thin LSMO films,
8th Int Balkan Workshop on Appl Phys, Constanta, Romania, July 2007.
3. B. Blagoev, P. B. Mozhaev, T. Nurgaliev, M. Sardela, T. Donchev,
Quality of YBCO thin films grown on LAO substrates exposed to the film deposition – film removal processes,
15th Int Summer School VEIT 2007, Sozopol, Bulgaria, September 2007.
4. E. Vlakhov, L. Neshkov, T. Nurgaliev, E. Mateev, Y. Marinov, L. Lakov, K. Toncheva,
Magnetron sputtering deposition of $NdBaCo_2O_{5-x}$ thin films,
9th Workshop Nanoscience&Nanotechnology, Sofia, Bulgaria, November 2007.

ONGOING RESEARCH PROJECTS:

Financed by the National Science Fund

F1503/05 Characteristics and application possibilities of sandwiches of HTS and magnetic oxides in spintronics (2005-2008).
VUX05/05 Photoluminescent properties of thin films prepared by incorporation of metal complexes into SiO2–sol-gel matrix (2005-2008).
TN-1316 Nanocomposite materials for the polymer optics (2005-2008).
MUF-08/05 Synthesis, modification and characterization of YBCO films for IR detectors (2005-2007)

Financed by NATO Science for Peace Program

SfP977986 Fabrication and properties of porous electro and photo-catalytic films (continued, 2007-2011).

COLLABORATIONS:
Investigation of electrical and microwave effects due to the interfaces in cuprate/manganite heterostructures,
Institute of Electrical Engineering, Slovak Academy of Sciences, Bratislava, Slovak Republic.

LABORATORY VISITS:

Dr. T. Nurgaliev,
Institute of Electrical Engineering, SAS, Bratislava, Slovak Republic, 07-14 July 2007.

LABORATORY

GAS LASERS AND LASER TECHNOLOGIES

HEAD: **Prof. P. A. Atanasov, Dr.Sc.**

TOTAL STAFF: **14**
RESEARCH SCIENTISTS: **12**
Assoc. Prof. N. N. Nedialkov, Ph.D.; M. E. Koleva, Ph.D.; A. Og. Dikovska, Ph.D.; A. S. Nikolov, Ph.D.; S. D. Donchev, Ph.D., T. R. Stoyanchov; S. E. Imamova; E. L. Pavlov; I. G. Dimitrov; N. E. Stankova; D. R. Milev; Ts .G. Naidenova.

RESEARCH ACTIVITES:

1. Pulsed laser deposition of thin films

1.1. Rare-earth doped active thin films

Thin films were grown on (001) SiO_2, SiO_2/(100) Si or (100) MgO substrates by laser ablation of neodymium-doped potassium gadolinium tungstate (Nd:KGW) single crystal target. The films were deposited at temperatures between room temperature and 750 °C and pressures between 1×10^{-4} Pa and 50 Pa of oxygen ambient. The influence of the deposition conditions on the composition, structure, morphology and electrical properties of the films was investigated. Special attention was paid to the films deposited in vacuum (1×10^{-4} Pa) or at very low oxygen pressures. Under such conditions, the potassium (K), gadolinium (Gd) and oxygen (O) content decreased strongly as the temperature was increased. At room temperature, the films were K and O stoichiometric, in contrast with Gd, which showed twice as high concentration. The films were polycrystalline, with the exception of those deposited at temperatures below 500 °C, which were amorphous. However, all were smooth and dense. The films grown in vacuum and at temperatures between 500 and 700 °C consist mainly of "â-tungsten" - tungsten oxide (W_3O) phase. The films grown on SiO_2/Si possessed the best surface quality with nano-size relief. The resistivity measurements as a function of the temperature showed that the films produced in vacuum and at temperatures below 500 °C were highly insulating, whereas at 600 °C they exhibited semiconducting behavior or a metallic one at 700 °C. This behavior can be attributed to the existence of various valence states for tungsten below W^{6+} in the films and to their crystal structure.

Thin Er, Yb co–doped Y_2O_3 films were grown by pulsed laser deposition from a ceramic target. Subsequent ion implantation with 1.1 MeV Er^+ ions at a fluence of 6×10^{14} at/cm^2 at room temperature was performed in order to modify the structure of the as-deposited films. The as-deposited films had a polycrystalline column-like structure. Ion implantation induced defects into the as-deposited films. After annealing at 900 °C for 1 h in oxygen atmosphere, the films recrystallized in a roundly shaped grain-like structure with grain size of about 100 nm. The Er^{3+} photoluminescence response was obtained for all the films by excitation through cross-relaxation of Yb^{3+} ions. The IR emission spectrum, consisting of two narrow peaks at 1415 and 1514 nm, differs from the typical spectra of Er-doped materials. The VIS emission spectrum observed in as-deposited films does not appear after implantation and subsequent 900 °C annealing.

Thin YVO_4 films were deposited on amorphous SiO_2 substrates by pulsed laser deposition (PLD). Ceramic targets of pure and doped (Er and Er, Yb) YVO_4 were

prepared and used for ablation. The influence of the substrate temperature and oxygen pressure applied during the depositions was investigated. Crystalline films were obtained at temperatures higher than 500 °C. The films with the best crystallinity were obtained at 5 Pa oxygen pressure and 700 °C substrate temperature. All the films are transparent in the visible and near infrared region of spectra. The crystalline samples show difference in the refractive indexes Δn ($\Delta n = n_{TE} - n_{TM}$) for the TE and TM polarizations. It was evaluated to be about 0.08.

1.2. Thin semiconductor metal oxide films for gas sensors

Undoped and palladium doped indium tin oxide films were produced by pulsed laser deposition and analyses of their optical, waveguide and structural properties in view of optical sensor applications were performed. The films were deposited at oxygen pressure from 5 to 20 Pa and substrate temperature between 200 and 450 °C. Palladium was used as a dopant since it is critical in improving the sensor's properties. The X-ray diffraction spectra showed that all films are polycrystalline with preferential [111] orientation. The optical transmittance measured in the visible region has maximum values of 85–90% for films grown at oxygen pressure 15 Pa independently of the substrate temperature used. SEM, AFM and optical and investigations revealed that indium tin oxide films with 1 wt.% Pd have higher transmittance and better surface morphology than those with 3 wt.% Pd concentration. ITO films with minimum propagation losses of 2 $dB.cm^{-1}$ were deposited at substrate temperature 200 °C and oxygen pressure 5 Pa, but doped ITO films with minimum propagation losses were obtained at 400 °C and 15 Pa.

Thin zinc oxide (ZnO) films were produced by pulsed laser deposition on periodically structured substrates. The films were grown at substrate temperature of 300 °C and 5 Pa oxygen pressure. The periodically structured substrates were prepared by applying a combination of a modified lithography technique with a typical holographic exposure. After the deposition of the ZnO, the film groove period is preserved whereas the depth decreases (h~100 nm) for a film thickness of about 445 nm. The periodical structure was used for easy coupling of the light into the films to ensure optical detection. Sensitivity of the ZnO sensors to 1000 ppm butane diluted in nitrogen was proven. Response time of about 1 min was evaluated.

A simple sensor element consisting of a side-polished single-mode fiber and a planar metal oxide waveguide was fabricated. The thin ZnO planar waveguide was formed on the polished fiber surface by pulsed laser deposition at optimized processing parameters. A measurement scheme for *in situ* control of the film thickness during the deposition process was developed and used. X-ray diffraction measurements and scanning electron microscopy were used to characterize the structure and the surface morphology of the planar waveguide, respectively. The numerical evaluation of the sensor sensitivity predicts the possibility to detect refractive index changes of less than 10^{-4}. Furthermore, preliminary gas sensor tests were performed by using a mixture of 1.5% butane diluted in N_2 and pure butane. A shift of the spectral position of the resonance points was observed from 3 to 5 s after gas exposure, which corresponds to refractive index changes of 3×10^{-5} and 1.2×10^{-3} for 1.5% butane and for pure butane, respectively.

The optical and the gas sensing properties of thick TiO_2 waveguide films, produced by pulsed laser deposition, were investigated by m-line spectroscopy. The films were deposited on (001) SiO_2 at temperature of 100 °C. The thickness of the films was measured to be in the range from 650 to 1900 nm and the roughness increased from 5 to 14.6 nm. High quality mode spectra, consisted of thin and bright

TE and TM modes, were observed in the films with thickness up to 1200 nm. All the films revealed anisotropic optical properties. Gas sensitivity of the films to CO_2 was examined at room temperature on the basis of the variations of the refractive index. CO_2 concentration of 3×10^4 ppm was detected, which corresponds to a refractive index variation of about 1×10^{-4}.

1.3. Thin films of diluted magnetic semiconductors

Vanadium doped ZnO thin films with potential application in spintronic technology were produced and investigated. Thin films with different concentration of V (2, 3, 5 and 7 at.%) were deposited by using the pulsed laser deposition (PLD) technique. The distribution of vanadium in the films and the variation of its content during laser deposition were determined by Rutherford backscattering spectroscopy (RBS). A comparative study of the structural and electrical properties of 2 at.% V:ZnO films deposited on sapphire substrates with different orientations was also made.

2. Interaction of ultrashort pulsed laser radiation with matter

Ultrashort laser micromachining of metals was investigated, both from the point of view of the basic physical processes, and the technological implications. The process of hole drilling of Ni with ≈300 fs SHG ($\lambda = 527$ nm) Nd-glass and Al samples with 100 fs Ti:sapphire ($\lambda = 800$ nm) laser pulses, respectively, was experimentally addressed by using time-gated optical emission spectroscopy of the ablated material and SEM analysis of the targets. The ablation process was also analyzed by classical and molecular dynamics (MD) simulations, by using a Morse potential to describe the interaction between the atoms, and taking into account the electron heat diffusion contribution. The dependence of the ablation depth on the laser fluence, as measured by SEM analysis, is in good agreement with the numerical simulations and is also well correlated with the optical emission yield of the expanding plume.

Experimental characterization and theoretical analysis of ultrashort laser ablation of a nickel target were performed to highlight the general and particular features of femtosecond (fs) laser ablation of metals. The study was carried out by using visible (527 nm) laser pulses of ≈300 fs duration. The vacuum expansion dynamics of the ablated species was investigated by using fast photography and optical emission spectroscopy, while the fs laser pulse–metal interaction was studied theoretically by means of molecular dynamics simulations. Special attention was given to the study of the dependence of ablation depth on the laser fluence, which was carried out by comparing the SEM analysis of micro-holes drilled into the nickel samples with the predictions of the theoretical model. The main outcomes of our investigation, which are very satisfactorily reproduced and accounted for by the theoretical model, are (i) the nonlinear dependence of the ablation yield on the laser fluence, and its reliance on electron heat diffusion in the process of redistribution of the absorbed energy, (ii) the splitting of the material blow-off into two main classes of species, atoms and nanoparticles characterized by different expansion dynamics, and (iii) the different degrees of heating induced by the laser pulse at different depths into the material, which causes the simultaneous occurrence of various ablation mechanisms, eventually leading to atoms and nanoparticles ejection.

3. Nanotechnologies

3.1. Nanostructuring

Nanohole fabrication on a silicon surface by femtosecond laser pulse irradiation mediated by gold nanoparticles was demonstrated. Gold spheres with diameters of 40, 80 or 200 nm were placed

on the silicon substrate surface by spin-coating. Laser pulses with duration of 150 fs and wavelength of 820 nm were used to irradiate the Si substrate. The aser fluences applied were in the range of 140–300 mJ/cm^2, i.e. below or near the ablation threshold fluence of the bulk silicon substrate without gold particles. The morphological changes of the laser-irradiated areas were investigated by scanning electron microscope (SEM) and atomic force microscope (AFM). Their dependence on the particle diameter, shape and laser fluence was investigated. The ablated surface morphologies were found to depend strongly on the polarization and the energy of the laser pulse. Nanoholes with diameters of about 150 nm and depths in the range of 30 nm were produced in the case of 200 nm diameter particles at fluences below the threshold for Si without Au particles. At a fixed laser fluence, the diameter and depth of the holes increase with the particle sizes. The optical field enhancement factor on the Si surface is calculated using an FDTD simulation code. A maximal value of about 26 is obtained for 200 nm Au particles. A comparison between the theoretical results for the electromagnetic field enhancement factor achieved and the experimental results was made in order to explain the physics of the nanomachining process.

Nanohole fabrication using near-electromagnetic field enhancement in vicinity of gold particles was demonstrated. Spherical gold particles with diameters of 40, 80 or 200 nm were deposited on substrate surfaces and irradiated by a 100 fs laser pulse at wavelength of 800 nm. The enhanced near field results in substrate surface modification and nanohole formation under the particle. The laser fluence applied ranged from values bellow the ablation threshold of the substrate material without particles to the values slightly above it in order to estimate its influence on the properties of the produced structures. The morphological changes on the surface of soda lime glass, Si, and Au, and the parameters of the nanostructures produced were analyzed by scanning electron microscope (SEM) and atomic force microscope (AFM). The distribution of the near-electric field was analyzed by a FDTD simulation code. The structures produced were found to depend strongly on the properties of the substrate and the laser parameters. In the case of metal and semiconductor substrate, the electric field is localized in the vicinity of the contact point. In the case of glass substrates, the electric field is spread in an area larger than the particle size. The enhancement factor is about an order of magnitude lower than in the case of using a silicon substrate. The results indicate that this method is capable of producing precise nanostructuring of a variety of materials.

Experimental and theoretical studies on the properties of the electromagnetic field in the near-field zone of gold nanoparticles excited by an 800 nm ultrashort laser pulse were carried out. The near-field properties were studied for the cases of a single isolated particle and a 2D nanoparticle array case. Particles were deposited on different substrates: metal (Au), semiconductor (Si) and dielectric (SiO_2). The calculations based on the finite difference time domain (FDTD) simulation technique predict that the field in the vicinity of the particles is enhanced as the magnitude of the field intensity depends on the substrate material and the interparticle distance for 2D array. For closely arrayed nanoparticles on a gold substrate, the maximal field intensity is more than twice as low as that of a single particle. With the increase of the distance between 200 nm diameter gold particles, the value of the field intensity increases up to a distance of about 800 nm. The theoretical prediction of the field enhancement on the substrate was confirmed experimentally. The irradiation of the nanoparticles deposited on the three different substrates with a single laser pulse of a Ti:sapphire laser results in a

nanohole formation. Discussion on the observed properties is presented.

3.2. Generation of nanoparticles

The dependence of the process of nanoparticle generation by ultrashort laser ablation of solid matter in vacuum on the laser wavelength was investigated both experimentally and theoretically. The study was carried out for a Ni target by using laser pulses of ≈300 fs duration at two different laser wavelengths: in the visible ($\lambda = 527$ nm) and ultraviolet ($\lambda = 263$ nm). The size distribution of the nanoparticles, which is quite broad in the case of visible light, becomes significantly narrower and shifts slightly towards the smaller sizes for ultraviolet light. Molecular dynamics simulations confirmed the dependence of the process on the laser wavelength by showing that the laser photon energy affects the material relaxation and, thus, the nanoparticle generation process. This, in turn, indicates that the photon energy can be used as an effective parameter to control the nanoparticle size distribution in femtosecond laser ablation of solid matter.

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Proc SPIE 2007;6604:660415.

ONGOING RESEARCH PROJECTS:

Financed by the National Science Fund

F–1512/05 Production and investigation of thin films for optical gas sensors.

MUF–02/05 Active planar waveguides.

MUF–07/05 Formation and evolution of nanoparticles produced during laser ablation by ultrashort lase pulses.

COLLABORATIONS:

Couches transparentes minces, produites par deposition laser d'impulsion pour des applications optiques et microelectroniques,
Institut des Nanosciences de Paris, Université Paris VI, CNRS, Paris, France.

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

Pulsed laser deposition of planar waveguides,
Institute of Physics, Czech Academy of Sciences, Prague, Czech Republic.

Interaction of intense laser radiation with matter and laser technologies
Institute of Fluid-Flow Machines, Polish Academy of Sciences, Gdansk, Poland.

LECTURE COURSES:

P. A. Atanasov, Laser deposition and structuring of thin films, PhD course, 20 hours.

GUESTS:

Prof. Dr. I. Mihailescu, Institute of Lasers, Plasma and Radiation Physics, Romanian Academy of Sciences, Bucharest, Romania, 1 week, work on the common project Pulsed laser deposition of thin oxide films.

Dr. C. Ristoscu, Institute of Lasers, Plasma and Radiation Physics, Romanian Academy of Sciences, Bucharest, Romania, 1 week, work on the common project Pulsed laser deposition of thin oxide films

Mr. F. Sima, Institute of Lasers, Plasma and Radiation Physics, Romanian Academy of Sciences, Bucharest, Romania, 1 week, work on the common project Pulsed laser deposition of thin oxide films.

Dr. G. Socol, Institute of Lasers, Plasma and Radiation Physics, Romanian Academy of Sciences, Bucharest, Romania, 1 week, work on the common project Pulsed laser deposition of thin oxide films.

Dr. Lionel Presmane, Universite "Paul Sabatier", Toulouse, France, 1 week.

LABORATORY VISITS:

P .A. Atanasov, CNRS, Universités Paris VI et Paris VII, Paris, France.

M .E. Koleva, CNRS, Universités Paris VI et Paris VII, Paris, France.

N.N. Nedialkov, Keio University, Yokohama, Japan.

T .R. Stoyanchov, Institute of Physics, Czech Academy of Sciences, Prague, Czech Republic.

N .E. Stankova, Institute of Lasers, Plasma and Radiation Physics, Romanian Academy of Sciences, Bucharest, Romania.

N .E. Stankova, Radiation Physics Laboratory, Physics Department, University of Salento, Lecce, Italy.

D. R. Milev, Institute of Fluid-Flow Machines, Polish Academy of Sciences, Gdansk, Poland.

LABORATORY

CONDENSED MATTER LASERS

HEAD: **Assoc. Prof. G. Todorov, Ph.D.**

TOTAL STAFF: 13
RESEARCH SCIENTISTS: 12

Prof. M. N. Nenchev, Dr.Sc.; Assoc. Prof. L. A. Avramov, Ph.D.; D. G. Slavov, Ph.D.; E. G. Borisova, Ph.D.; A. T. Daskalova-Shivarova, Ph.D.; A. I. Gisbrecht; L. P. Petrov; N. J. Momchilov; Z. S. Jordanova; D. S. Petkov; D. I. Hristov; I. G. Kocev.
Ph.D. student: I. Bliznakova.

RESEARCH ACTIVITIES:

1. Tunable lasers and amplification

An improved approach for generation of a tunable sub-nanosecond pulse (0.1-0.4 ns) (theory, experimental check), based on a single pulsation ("spike") separation from the transient oscillations in a dye laser with active mirror (AMIR) was developed. Pumping by 20-50 ns pulses from Q-switched Nd:YAG laser is considered. The separation takes plate in a two spectrally selective channels cavity of original designed, where the quenched generation forced by the AMIR at one of the wavelength stops the initially started spiking generation at the other wavelength after the first spike development. The AMIR quickly starts the quenching generation at a precisely controlled moment and with necessary intensity thus assuring the separation desired. An advantage is high reproducibility of the separation for high (~ 250 %) pump power fluctuations combined with tuning in a large range (~ 20 nm). To obtain such operation, we form ~1 ns leading front pump pulse by electro-optical temporal cutting of the input pump pulse and use an optical delay line. This increases also a few times the power in the separated spike (to be ~100 kW). Our approach widens the combinations of lasers for effective applications of the spike separation technique (dye lasers excited by Q-switched solid-state or Cu-vapor lasers).

2. Magneto-optical (MO) and magneto-galvanic (MG) resonances

2.1. Nonlinear coherent spectroscopy in alkali vapours

Numerical simulations based on the density matrix formalism which take into account the high rank polarization moments (HRPM) influence and the velocity distribution of the atoms were used to calculate the shape of the nonlinear magnetic resonances.

The model analysis shows that the different components of the octupole moment couple the hexadecapole and the quadrupole components, which results in the observation of complex resonance dependencies in the polarized fluorescence and absorption. The numerical results for the transition $F_f = 1 \rightarrow F_\varphi = 2$ show that the hexadecapole components influence the observable quadrupole PM and the main contribution is due to the octupol component (ξ^3_0). High rank PM is narrower by a factor of k and is very sensitive to stray magnetic fields. By using a polarization- or frequency discrimination in the detection of the spontaneous emission or absorption, one could obtain resonances with ultra narrow width.

Experimental verification of the numerical results obtained for the transition $F_f = 1 \rightarrow F_\varphi = 2$ of ^{87}Rb were carried out in the Laser Systems Laboratory of IE. The parameters calculated of the magneto-optical resonances (width, shape and amplitude) measured in dependence of the laser field amplitude and the additional magnetic fields qualitatively agree with the experimentally obtained ones.

The results of this investigation are interesting for high resolution spectroscopy, magnetometry and metrology applications

2.2. Magnetic resonances in alkali atoms in different cells

We have continued the intra-institutional cooperation with the Laser Systems laboratory in order to develop applications in magnetometry. Our efforts were focused on improving the magnetometers performance by alkali cell optimization. Miniaturization of the magnetometer sensor is closely related to the miniaturization of the cell itself but without compromising the CPT resonance parameters. In the beginning we were mainly concentrated on studying comparatively the phenomenon parameters in nano-meter (400-1000 nm) and micro-meter (12 um) thick cells with Cs and Rb, respectively. CPT resonances were obtained in different conditions and were compared with those obtained in an ordinary cell. The CPT resonance parameters were studied in a 2.5 mm miniaturized Rb cell for parameters' comparison, and evaluation of possibilities for additional miniaturization of the sensor to an optimal level.

The work related to measurement of the parameters of an alternating magnetic field with CPT magnetometer was finalized. The potential of this approach for alternating field measurement was estimated both experimentally and in accordance with published simplified theoretical models.

The new results were presented to national and international conferences (three papers) and one publication in a specialized journal.

2.3. Magneto-optical and magneto-galvanic resonances in a glow discharge

New investigations on magneto-galvanic resonances in gas discharge were performed under a bilateral contract between IE-BAS and V. A. Fock Institute of Physics, St. Petersburg State University on the topic "Coherent spectroscopy of gases and low temperature plasma"

The comparative investigations of the MO resonances on the $2p^5 3s$ Ne levels in the positive column as well as in hollow cathode discharges showed that the excitation transfer processes significantly influence the signals:

For the $1s_4$ level the model describing the transformation of the hidden alignment into orientation is in good agreement with the experimental results. Among all possible mechanisms of coherence formation on the metastable level $1s_5$ the cascade transfer mechanism of the alignment from higher levels and/or optical depopulation are significant. The anomalous magnetic resonance dependence of the absorbed from the level $1s_3$ level (J=0) at the lines 616.3 nm and 626.6 nm could be explained generally by means of the influence of the coherence destruction on the discharge current i.e., the magneto-galvanic effect.

The investigation of magneto-galvanic signals in hollow cathode lamps (HCL) was extended, using new laser transitions and different lamps. Both *self-aligned* and *non-aligned* atomic ensembles are distinguished in the conductivity of a hollow cathode discharge. This difference may be designated as a *coherent conductivity*. The latter does not imply a fixed in sign conductivity and depends on the degree of self-alignment. The

measured MG signal represents an integral characteristic of the above coherent conductivity. The selective galvanic contribution of the optical transition NeI $1s_5$-$2p_9$ is checked by using selective light perturbation in an opto-galvanic scheme. The different shape of the MG resonances, measured in commercial HCL with different cathode materials, indicates the essential role of the Penning processes in the formation of the galvanic response on the coherence destruction by a magnetic field. In support of this supposition are the correlations between the MG and the LIG amplitudes on the one hand and the current-voltage curve behaviour on the other.

3. Laser medical and bio-medical research and applications

3.1. Fluorescence endoscopy of the gastrointestinal tract

During the second year of the project VU-L-.01/05 "Optical biopsy of dysplasia and tumors in the upper part of the gastrointestinal tract" spectral diagnostic procedures were developed and tested for endoscopic detection of tumors and dysplasia of the upper and lower part of the gastrointestinal tract. The procedure developed was applied for initial detection and evaluation of dysplasia and neoplasia in the lower part of the gastrointestinal tract, namely for colon cancer. Comparison with inflammatory mucosa exogenous fluorescence was made to evaluate the contrast obtained between abnormalities in the gastrointestinal mucosal layer.

In the current project ALA-mediated fluorescence lesions' detection is under investigation. We used a common video-endoscopic system (Olimpus Inc.), with additionally attached light source based on high-power light-emitting diode chip with maximum at 405 nm, FWHM = 20 nm, 25 mW, which was applied for fluorescence excitation. This light source replaced the white light illumination of the endoscope used. 2-D signals of the mucosa fluorescence were received from the video-channel of the endoscope. Through its instrumental channel, an optical fiber was applied to return information about fluorescence and reflectance spectra of the lesions and normal tissues to a microspectrometer USB 4000 (Ocean Optics Inc.). A computer was used to control the spectrometric system and to store and display the data measured.

Clinically, the 5-ALA ("ALASENS", NIOPIK, Russia) is administered per os six to eight hours (depending on the anatomic target) before measurements at a dose of 20mg/kg weight, according to the clinical experience accumulated in gastrointestinal diagnostic applications of 5-ALA/PpIX fluorescence.

All fluorescence diagnoses of the upper and lower part of the gastrointestinal tract, namely, esophagus, stomach, and colon, were made in 2007 during endoscopic examinations of patients in the Gastro-Enterology Department of "Queen Jovanna" University Hospital. Standard histology was used as "gold" standard for comparison with the results obtained from spectral measurements and video-visualisations.

A comparison of the fluorescence signals detected from inflammatory areas and esophageal carcinoma scanned in the edges and in the centre of the lesions was also made. In this case, the hemoglobin re-absorption in the inflammation area is very strongly pronounced and a weak fluorescence signal in the region 630-704 nm is observed, related to accumulation of 5-ALA/PpIX in the normal but inflammatory mucosal tissue. The contrast between the fluorescent signals at 635 nm between tumor regions and inflammations observed in all patients, where such comparison was possible, usually is higher than three. In such way we could be sure in general that using this detection approach one could distinguish inflammation from tumor site, and

moreover, could distinguish inflammatory areas from normal mucosa.

The effect of distortion of the autofluorescence signal, related to strong hemoglobin absorption, is clearly observable only in abnormal tissues. This feature could therefore be used as additional diagnostic tool to the fluorescent peaks observed at 650 and 704 nm from accumulated protoporphyrin IX, which could improve the diagnostic accuracy of tissue type evaluation.

The normal mucosa accumulation of protoporphyrin IX with significant fluorescent response in the region 650-704 nm was not observed in all patients investigated. The optimization of the dose of 5-ALA, in accordance to Chissov and co-authors' work, allowed us to achieve clear accumulation of the exogenous fluorophore in the abnormal esophageal tissues only. In several cases of inflammation detected during the observation, a weak fluorescence related to delta-ALA/PpIX was observed. In spite of the good contrast observed in the fluorescence signal at 635 nm between tumor and inflammation (>3 times), we still have not investigated a statistically significant number of inflammatory regions to have possibility for general conclusions.

Our results reveal very good sensitivity and specificity of the exogenous fluorescence diagnosis of esophageal neoplasia. However, the cost effectiveness of spectroscopic screening needs to be further assessed in prospective studies. But beyond all doubts, the search for new, more sensitive tools for diagnostics of esophageal dysplasia and neoplasia could potentially make fluorescence surveillance a cost effective procedure applicable to the clinical practice.

3.2. Spectral properties of tissues – basis for development of new methods for diagnostics and therapy of skin cancer

In the framework of the recent project MU-F-03/05 "Development of apparatus and methods for optical biopsy of human skin" spectral diagnostic methods were developed and tested for early differentiation of malignant melanoma vs. normal skin, benign melanin-pigmented cutaneous lesions as well as for non-melanin pigmented cutaneous lesions. The methods of laser-, light-induced fluorescence and reflectance spectroscopy were applied.

In recent years, there has been growing interest in the practical use of laser-induced autofluorescence (LIAF) and reflectance spectroscopy (RS) to differentiate diseased from normal surrounding tissue – the so called optical biopsy method. These forms of optical diagnoses are preferable to the removal of several square millimeters of tissue surface - common in traditional biopsies – followed by delay of several hours to several days while samples are sent for clinical analysis. The goal of our work is investigation of cutaneous benign and malignant lesions by the methods of LIAFS and RS. A nitrogen laser at 337 nm was applied for the needs of autofluorescence excitation. A broad-spectrum halogen lamp (from 400 to 900 nm) was used for diffuse reflectance measurements. An associated microspectrometer detected in vivo the fluorescence and reflectance signals from human skin. The main spectral features of benign lesions – compound nevus, dysplastic nevi, heamangioma and basal cell papilloma and malignant lesions – pigmented, amelanotic and secondary malignant melanoma, as well as basal cell carcinoma were revealed and possible origins were indicated. The influence of the main skin pigments on the spectra detected was evaluated and differentiation algorithms were developed based on lesions spectral properties.

Evaluation of the general spectral parameters and optimization of the light sources were made. The influence of measurement geometry and skin peculiarities – phototype, anatomic area, pigmentation types of the pathologies is

was valuated and included in the algorithms developed.

Special studies of different types of malignant melanoma lesions (primary, secondary, amelanotic lesions) were also carried out during this year. Algorithms for differentiation of these pathologies from morphologically and dermatoscopically near lesion kinds were proposed.

Colorimetric analysis of reflectance data was performed in view of increasing the diagnostic accuracy. The results obyained were presented in the book chapter "Chromatic Monitoring of Complex Conditions", ed. G. Jones, A. Deakin, J. Spencer, (UK: Taylor and Francis - CRC Press, 2008), with co-authors Assoc. Prof. P. Pavlova of the Technical University, Plovdiv Branch and Assoc. Prof. P. Troyanova of the National Oncological Center, Sofia.

Animal models of skin were investigated spectroscopically in view of developing an optical model of the human skin applicable to further development of tumor modeling and drug penetration investigations. Chromophores were evaluated from piglet, chicken and murine skin. The experiments were performed in collaboration with the National Technical University of Athens – group of Prof. Al. Serafetinides.

A new system was developed for fluorescent diagnostics and photodynamic therapy for non-melanoma skin tumors. The exogenous photosensitizer applied was 5-ALA/PpIX for detection and treatment of base-cell carcinoma pathologies that are the most common cutaneous tumor type (about 70% of the new cases each year). The equipment is introduced in Integrative Medicine Medical Center.

3.3. Photodynamic inactivation of pathogenic bacteria using long-wavelength photo-sensitizers

As a prolongation of the collaboration with the Institute of Organic Chemistry, BAS, an investigation of photodynamic inactivation (PDI) of pathogenic microorganisms was realized this year. Newly synthesized phthalocyanines were applied for study of cellular uptake and their efficiency as PDI agents. The efficacy of the cationic, anionic, and non-charged unsubstituted Zn(II)- and Al(III)-phthalocyanines was evaluated on representative strains of broad classes of pathogens - two gram-positive strains of *Staphylococcus aureus*, one sensitive and one methycillin-resistant, one gram-negative, *Pseudomonas aeruginosa* and one fungus, *Candida albicans*. The survival of the bacterial strains was studied, depending on the fluence rate of the applied light, the cell density of the bacterial suspension and the drug uptake from the bacteria cells. Both *S. aureus* strains studied were susceptible to the photodynamic treatment. Significant bacterial inactivation was also observed for the methycillin-resistant *S. aureus* after photosensitization with anionic phthalocyanine. In the case of gram-positive bacterial strains, the effect was negligible after cationic and non-charged compounds. Water-soluble cationic compounds were found to be more appropriate for PDI goals, especially for the less sensitive to the inactivation *P. aeruginosa*. Our results are encouraging for the potential future application of cationic phthalocyanine for PDI treatment of bacterial caused infections in humans. Based on these results, new collaborations were established in the end of 2007with Indian and Romanian colleagues, funded by the Bulgarian Ministry of Education and Sciences, for investigation of PDI effect on periodontal bacteria strains and clinical microbial contaminants respectively.

3.4. Ultra-fast laser mass spectroscopy of biological molecules

Mass spectrometry is a powerful tool for the analysis of molecular species on a solid surface. It has also been proven as the most useful method for performing physicochemical studies of laser-induced photo-decomposition of molecules of

biological origin. Since it is well known that the main components of tooth and bone samples are collagen fibers and hydroxyapatite we expected to observe their dissociation products in the measured mass spectra of the ablated biological samples. In collaboration with colleagues from the Vienna University of Technology, we performed a series of studies on the ultra-short laser ablation of hard biological tissue while varying several parameters,such as pulse duration, laser wavelength, and laser fluence. In our approach, we combined ultrashort laser ablation with time-of-flight mass spectroscopy (TOF-MS). Our work demonstrated the sensitivity of TOF-MS for identification of the biomolecular species present in laser-ablated material from hard tissues. Femtosecond laser ablation of hard tissue (tooth and bone) at λ=800 nm altered the chemical composition of the ablated tissue and yielded the highest number of characteristic ions. Comparison was performed between the mass spectra from biological samples obtained under laser ablation and those obtained under bombardment with 9 keV Xe^+ ions. Mass fragments up to m/z≈290 mass units (unique to the peptide chain) appearing in the laser ablation mass spectra at 800 nm of a tooth sample point to the possibility of successful ablation of molecular moiety with suppressed fragmentation. In ns and in SIMS mass spectra the detection of higher mass fragments is much lower. The results obtained on our tooth sample are especially interesting for dental surgery applications. The results obtained show that ultrashort pulses can be used as a minimally invasive technique to ablate hard dental tissue with minimal thermal damage to the surrounding tissues. By studying the process of laser tissue interaction we hope to be able to make qualitative improvements to different type of medical applications of lasers.

Our preliminary results also confirm earlier reports showing that it is possible to process hard dental tissue with high efficiency and we are accordingly planning further reproducibility studies.

3.5. Haemoglobin photodissociation

The experimental study of changes in saturation of arterial blood caused by laser-induced photodissociation of oxyhemoglobin is based on registration of the variations of its value on the background of natural saturation oscillations. Specialized highly sensitive multi channel pulse oximeter - spectrophotometer for control of the local tissue oxygen saturation was developed. Due to the original method of data processing, the accuracy of the measurements is 3-4 times higher compared to similar traditional systems. As a result, registration of small changes in the arterial blood saturation was achieved with accuracy higher than 0.5 %. A novel method of direct control of local tissue oxygen concentration based on laser-induced photodissociation of HbO_2 was proposed. It is shown that the local concentration of free oxygen in tissue under laser irradiation significantly increases at higher body temperature. The efficiency of releasing bonded oxygen from haemoglobin increases with increasing the local tissue temperature and at a temperature around 42 ^{0}C reaches saturation of about 2,2 %. Thus, laser-induced photodissociation of oxyhemoglobin may serve as a unique method in laser therapy for optically increasing the local concentration of free molecular oxygen in tissue, which significantly enhances the cell metabolism

Different biomedical applications of this method were discussed for treatment of a wide variety of diseases including burns, bedsores, ulcers, necrosis and anaerobic infections.

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Proc 7th Int Conf Solid-state Chemistry and Modern Mico- and Nano-technologies, (2007 Kislovodsk, Russia) pp 3-5.
26. Kowalski K, Vaseva K, Gateva S, Głódź M, Petrov L, Szonert J,
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29. Bliznakova I, Borisova E, Troyanova P, Momchilov N, Avramov L,
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Proc SPIE 2007;6604:6604.
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Fluorescence spectroscopy of gastrointestinal tumors using δ-ALA,
Proc SPIE 2007;6604:6604-2H.
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35. Borisova E, Uzunov Tz, Valkanov S, Avramov L,
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36. Borisova E, Uzunov Tz, Vladimirov B, Avramov L,
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37. Borisova E, Bliznakova I, Troyanova P, Avramov L,
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40. Borisova E, Troyanova P, Avramov L,
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42. Asimov M M, Gisbrecht A I, Mamilov S A, Plaksiy Yu S,
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43. Todorova P T, Deneva M A, Nenchev M N,
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Proc Int Conf Electronics (2007 Bulgaria) book 3 pp 191-6.

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Int Workshop on Coherent and Nonlinear Optics and Int Workshop on Laser Appl and Technol – ICONO/LAT 2007, May 2007, Minsk, Belarus.
2. E. Borisova, L. Avramov,
Int Workshop on Laser Appl in Life Sci - LALS'2007, June 2007, Moscow, Russia.
3. E. Borisova,
European Conf of Biomedical Optics – ECBO'2007, June 2007, Munich, Germany.
4. L. Avramov,
Symp Modern Spectroscopy Methods in Studying Structure and Function of Biopolymers in Biology and Medicine, July 2007, Dubna, Russia.
5. E. Borisova, L. Avramov, A. Daskalova,
8th Int Balkan Workshop on Appl Phys, July 2007, Constanta, Romania.
6. A. Daskalova,
15th Int Summer School VEIT'07, September 2007, Sozopol, Bulgaria.
7. L. Avramov,
Int School on Nuclear Phys Methods and Accelerators in Biology and Medicine, July 2007, Prague, Czech Republic.
8. I. Bliznakova, D. Slavov,
Int School and Conf Optics and Optical Mater - ISCOM'2007, Sept 2007, Belgrade, Serbia.
9. E. Borisova,
Saratov Fall Meeting - SFM'07, 9th Int School for Young Scientists and Students on Optics, Laser Physics & Biophysics, September 2007, Saratov, Russia.
10. E. Borisova,
Workshop on Cancer Research 2007, November 2007, Brighton, UK.

11. D. Slavov,
    Young Optician School – YOS, May 2007, Armenia.
12. A. Gisbrecht,
    5th Int Symp Actual Problems in Biophysical Medicine, May 2007, Kiev, Ukraine.

ONGOING RESEARCH PROJECTS:

Financed by the National Science Fund

1. **Contract № 1305** Development of new methods for creation of lasers with non-traditional generation characteristics.
2. **Contract № M-UF-03/05** Development of apparatus and methodology of optical biopsy of human skin.
3. C**ontract № SRP-101/07** Preparation of project proposal for FP7 of EU: Development of a laser system laser ablation of biological tissue with smart feedback.
4. **Contract № V-UL-01/05** Optical biopsy of dysplasia and tumours in upper part of gastrointestinal tract.
5. **Contract № F-1203/02** Emergent structures and collective behaviors in extended and distributed chaotic systems.
6. **Contract № M-1422/04** Enlargement and elaboration of the possibilities for application of the optical biopsy and its approval in the diagnostics of malignant skin tumors.
7. **Contract № UF-12/02** Development of original quantum-electronic methods and devices for application in ecology and optical communications.
8. **Contract № 1404/04** Coherent effects in nano-layers in gas phase.

Financed by the International Atomic Energy Agency

1. **Contract №. CRP F-12016** Ion beam modification of polymer surfaces.

Financed by ministries, departments, and companies

1. Project for preparation of a joint proposal for participation in FP7 framework programme financed by the Austrian Science and Research Liaison Offices Ljubljana and Sofia (ASO) Biomedical photonics, collaboration start up: Establishment of multilateral research network cooperation between scientific organizations in Austria, Bulgaria and Romania.
2. Contract financed by the National Innovation Fund-Bulgaria № IF-00-121/06 Laser opto-electronic system for optical tomography.
3. Contract financed by Optella Ltd Photophysical characteristics investigation of newly synthesized photosensitizers for photodiagnosis and photodynamic therapy of malignant cutaneous lesions.
4. Contract financed by SIEMENS-Medical Solutions Cooperation in the field of optical tomography.
5. Contract Rila between St. Kliment Ohridski University of Sofia and Ministry of education, in cooperation with the University of North Paris, Institute Galilee, Univercite Paris 13 (2007 - 2008), topic Study of atomic vapor layers of nanometric thickness and atom-surface interaction.

COLLABORATIONS:

1**.** Study of mechanisms of ultra-short laser ablation and desorption of biomolecules, ITSLEIF-exchange programme of the EU 2007.

2. Study of atomic vapor layers of nanometric thickness and atom-surface interaction, INTAS.
3. Development of small-size tunable laser sources, Institute of Physics, National Academy of Sciences of Belarus, Minsk, Belarus.
4. 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.
5. Investigation of the laser irradiation influence over the relative concentration changes of oxyhaemoglobin in the blood, Institute of Applied Problems of Physics and Biophysics, Ukrainian Academy of Sciences, Kiev, Ukraine**.**
6. Coherent population trapping effect in potassium vapor, University of Pisa, Italy.
7. High resolution spectroscopy in quantum optics and metrology, Institute of Physics, Belgrade, Serbia.
8. Coherent spectroscopy of gases and low temperature plasma, V. A. Fock Physics Institute, St. Petersburg State University, St. Petersburg, Russia.

SEMINAR OF THE INSTITUTE:

1. A. Daskalova, Femtosecond lasers: powerful tool for tissue investigation.
2. A. Daskalova, Preparation of a joint proposal for participation in Seventh Framework Programme (FP7) – main objectives.

OTHER SEMINARS:

1. A. Daskalova, Femtosecond laser ablation of biological tissue: from the aspects of mass spectrometry studies to recent advances and applications – invited lecture at the Charles University, Prague, Czech Republic.

LABORATORY VISITS:

1. N. Momchilov – work visit to perform measurements for improved photomultipliers for bioluminescence applications, January-April 2007, University of Sussex, UK.
2. A. Daskalova – work visit in Vienna University of Technology, Department of Physics, April 2007.
3. E. Borisova – work on proposal for FP7 project, February and April 2007, University of Sussex, UK.
4. E. Borisova – measurements in the field of tissue oxygenation evaluation; discussions on the possibilities for new common projects, May 2007, Institute of Physics, Minsk, Belarus.
5. L. Avramov, E Borisova – experiments on inducing of cataract with heavy ions and UV-radiation, June 2007, Joint Institute for Nuclear Research, Dubna, Russia.
6. A. Daskalova - work visit to perform measurements and discuss the perspectives for participation in FP7 project Development of a laser system for teeth caries removal with smart feedback channel, June 2007, Vienna, Austria.

GUESTS:
1. Prof. Wolfgang Husinsky, Vienna Univerisity of Technology, Vienna, Austria – April 2007.
2. Prof. Gabriela Pavalescu, INOE, Bucharest, Romania – April 2007
3. Dr. Grauman, Dr.Fratini - SIEMENS Medical Solutions – May 2007.
4. U. Plaksii and S. Mamilov - Institute of Biophysics, 110
Ukraine, September 2007.

LABORATORY

LASER SYSTEMS

HEAD: **Assoc. Prof. N. Mihailov, Ph.D.**

TOTAL STAFF: **13**
RESEARCH SCIENTIST: **11**
Assoc. Prof. S. Cartaleva, Ph.D.; Assoc. Prof. E. Alipieva, Ph.D.;
Assoc. Prof. S. Gateva, Ph.D.; Ch. Andreeva, Ph.D.; T. Karaulanov, Ph.D.;
P. Todorov, Ph.D.; O. Vankov, V. Sarova; E. Taskova; K. Vaseva; D. Atanasov.
Ph.D. student: N. Petrov.

RESEARCH ACTIVITIES:

Intensive studies have been performed recently world-wide on applying optical magnetometry for measurement of the heart magnetic field. Within the framework of a collaboration with the Institute of Physics at the State University of St. Petersburg, Russia, we have investigated Coherent Population Trapping (CPT) resonances in Hanle configuration, taking into account the high-rank polarization moments and the atomic velocity distribution. Together with colleagues from the University of Siena, we demonstrated magneto-cardiography of the human hear based on a scientific approach protected by a European patent. The advantage of this approach, based on CPT in alkali vapors in cm-sized volumes, is that the cardiography, i.e. registration of the weak cardio-magnetic signals, is performed without the use of expensive (about half million Euro) shielding of the Earth magnetic field. We have performed measurement of a magnetic signal, which is about a million times weaker than the background of the Earth magnetic field. Within the frame of a current INTAS project, financed by the EC and aiming at miniaturization of the CPT-based sensors, we carried out investigation of alkali vapor nano-layers.

In collaboration with the Armenian Academy of Sciences, we performed experiments, which showed that alkali vapors confined in nano-volumes have spectral behavior different from that in cm-sized volumes. A theoretical model was developed in conjunction with colleagues from the University of Sofia and University Paris 13, revising the classical saturated absorption for the case of vapors confined in nano-layers. CPT in nano-layers was investigated in cooperation with the University of Latvia. The results showed that the CPT spectroscopy in nano-layers has a very high potential for investigation of the atom-surface interaction. Besides the more fundamental results, the spectral investigations of atomic vapor nano-layers showed that such layers are promising for application as miniature photonics sensors.

PUBLICATIONS:

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   Cesium coherent population trapping magnetometer for cardiosignal detection in an unshielded environment,
   JOSA B 2007;24:2357-62.
2. Gateva S, Petrov L, Alipieva E, Todorov G, Domelunksen V, Polischuk V,
   Shape of the coherent-population-trapping resonances and high-rank polarization moments,
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3. Petrov L, Slavov D, Arsov V, Domelunksen V, Polischuk V, Todorov G,
   High rank polarization moments in a Doppler broadened ^{87}Rb transition,
   Proc SPIE 2007;6604:66040H.
4. Andreeva Ch, Cartaleva S, Petrov L, Saltiel S, Sarkisyan D, Varzhapetyan T, Bloch D, Ducloy M,
   Saturation effects in the sub-Doppler spectroscopy of Cesium vapor confined in an extremely thin cell,
   Phys Rev 2007;A76:013837.
5. Andreeva Ch, Atvars A, Auzinsh M, Bluss K, Cartaleva S, Petrov L, Slavov D,
   Ground-state magneto-optical resonances in Cesium vapour confined in an extremely thin cell,
   Phys Rev 2007;A76:063804.
6. Karaulanov T, Yanev A, Cartaleva S, Slavov D, Petrov N, Mijailovic M, Grujic Z, Krmpot A,
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   Proc SPIE 2007;6604:66040C-1–C-5.
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   Proc 7th Int Conf Solid-state Chemistry and Modern Micro- and Nano-technologies, (2007, Kislovodsk, Russia) pp 3-5.
8. Cartaleva S, Karaulanov T, Petrov N, Slavov D, Vaseva K, Yanev A, Mijailovic M, Grujic Z, Jelenkovic B,
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   Acta Physica Polonica 2007;A112/5:877.
9. Belfi J, Biancalana V, Cartaleva S, Dancheva Y, Mariotti E, Moi L, Nasyrov K, Slavov D, Todorov P, Vaseva K,
   Electromagnetically induced absorption resonance sign reversal,
   Acta Physica Polonica 2007;A112/5:823.
10. Vaseva K, Todorov P, Slavov D, Cartaleva S, Koynov K, Saltiel S,
    Fluorescence spectra study in extremely thin Cs-vapor layers,
    Acta Physica Polonica 2007;A112/5:865.
11. Grujic Z, Mijailovic M, Panic B, Minic M, Kovacevic A, Obradovic M, Jelenkovic B, Cartaleva S,
    Narrowing of Zeeman coherences due to diffusion induced Ramsey effects,
    Acta Physica Polonica 2007;A112/5:5.
12. Nasyrov K, Cartaleva S, Petrov N, Slavov D,
    Magneto-optical resonances in cells with low-pressure buffer gas, obtained by using elliptically polarized light,
    Proc 18th Conf Fundamental Atomic Spectroscopy, (2007, Zvenigorod, Russia).

13. Alipieva, E, Gateva S, Taskova E,
Influence of AC magnetic field on the CPT resonance obtained on two level degenerated system in Rb,
Proc SPIE 2007;6604:66040G.
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Coherent population trapping for continuous and alternating magnetic fields Measurements,
AIP Conf Proc 2007;CP899:175-6.
15. Decision for granting of a European patent, issued in 2007: European Patent No. EP1570282, Method and device for measurement of magnetic induction, Priority 03.12.2002.
16. Gateva S, Alipieva E, Petrov L, Taskova E, Todorov G,
Single frequency coherent-population-trapping resonances for magnetic field measurement,
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CONFERENCES:

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ECAMP IX 2007;We5-17.
2. Andreeva Ch, Cartaleva S, Petrov L, Saltiel S, Sarkisyan D, Varzhapetyan T, Bloch D, Ducloy M,
Sub-Doppler Spectroscopy of a vapour confined in an Extremely Thin Cell: Saturation effects and interplay between coherent resonances and incoherent losses,
IQEC CLEO'Europe 2007;IF-2-TUE.
3. Atvars A, Auzinsh M. Blush K, Andreeva Ch, Cartaleva S, Petrov L, Sarkisyan D, Varzhapetyan T,
Bright magneto-optical resonance sign reversal in Cs vapour confined in an extremely thin cell,
IQEC CLEO'Europe 2007;IF-2-TUE.
4. Cartaleva S,
Coherent population trapping in alkali atoms, Invited lecture,
ISCOM 2007, Belgrade, Serbia.
5. Befi J, Biancalana V, Cartaleva S, Dancheva Y, Mariotti E, Moi L, Nasyrov K, Slavov D, Todorov P, Vaseva K,
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ISCOM 2007, Belgrade, Serbia.
6. Slavov D, Karaulanov T, Cartaleva S, Petrov N,
AC magnetic field influence on the electromagnetically induced transparency resonance,
ISCOM 2007, Belgrade, Serbia.
7. Cartaleva S, Karaulanov T, Petrov N, Slavov D, Vaseva K, Mijailovic M, Grujic Z, Jelenkovic M,
All-optical magnetometer based on Rb atoms irradiation by frequency modulated diode laser light,
ISCOM 2007, Belgrade, Serbia.

8. Vaseva K, Todorov P, Slavov D, Cartaleva S, Koynov K, Saltiel S,
   Fluorescence spectra study in extremely thin Cs-vapor layers,
   ISCOM 2007, Belgrade, Serbia.
9. Atvars A, Andreeva Ch, Auzinsh M, Blush K, Cartaleva S, Petrov L, Sarkisyan D, Slavov D,
   Dark and bright resonances of Cesium vapor in an extremely thin cell,
   Young Optician School in Armenia 2007.
10. Slavov D, Cartaleva S, Nasyrov K, Karaulanov T, Petrov N,
    Magnetic fields measurements using coherent population trapping effect from a single ground-state hyperfine level of Rubidium,
    Young Optician School in Armenia 2007.

ONGOING RESEARCH PROJECTS:

Financed by the National Council for Scientific Research

F-1404/04, Coherent effects in gas-phase nano-layers.
F-1409/04, Nonlinear magneto-optical effects in a resonance medium.

Financed by other institutions

INTAS-06-1000017-9001, Study of atomic vapor layers of nano-metric thickness and atom-surface interaction

COLLABORATIONS:

Investigation of anisotropy of extremely thin cells by means of nonlinear, multi-photon and Raman atomic spectroscopy,
Coordinator: Dr. Christina Andreeva,
RILA French-Bulgarian collaboration program.

High resolution spectroscopy in quantum optics and metrology,
Coordinator from the Bulgarian side: Dr. Stefka Cartaleva,
Contract for international collaboration with the Institute of Physics, Belgrade, Serbia.

Coherent population trapping effect in alkali atoms,
Coordinator from the Bulgarian side: Dr. Stefka Cartaleva,
Contract under the Agreement for Scientific Collaboration BAS-CNR (Italy).

Development of stabilized diode lasers and their application to atomic spectroscopy and cooling of atoms,
Institute of Physics, Polish Academy of Sciences, Warsaw, Poland.

LABORATORY VISITS:

S. Cartaleva - IPCF – CNR, Pisa, Italy, 14 days.
P. Todorov, CNRS, Paris, France, 24 days.
Ch. Andreeva, Latvia, 180 days.
K. Vaseva, Institute of Physics, Warsaw, Poland, 10 days.
S. Gateva**,** Institute of Physics, Warsaw, Poland, 15 days.

GUESTS:

Gerardo Alzetta, Emilio Mariotti, Isabelle Maurin.

LABORATORY

FIBER AND NONLINEAR OPTICS

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

TOTAL STAFF: **4**
RESEARCH SCIENTIST: **3**
Assoc. Prof. L. M. Ivanov, Ph.D; I. Tunchev.
Ph.D. student: K. L. Kovachev.

RESEARCH ACTIVITIES:

1. Dynamics of attosecond and femtosecond optical pulses in linear regime

Optical pulses of few picoseconds or femtoseconds with approximately equal duration in the x, y and z direction (Light Bullets or LB), and fs optical pulses with relatively large transverse and small longitudinal size (Light Disks or LD) have been used in experiments for a long time. The evolution of the generated LB and LD in linear or nonlinear regime is quite different from the propagation of light beams and they have drawn the researchers' attention with their unexpected dynamical behavior. Recently, self-channeling was observed of femtosecond pulses with power little above the critical for self-focusing and also below the nonlinear collapse threshold (linear regime) in air. This is in contradiction with the well known self-focusing and diffraction of an optical beam in paraxial optics. Various unidirectional propagation equations have been suggested by other authors that found stable pulse propagation mainly in nonlinear regime. The basic studies in this field started with the so called spatio-temporal nonlinear Schrödinger equation (NSE) which is a compilation between paraxial approximation, group velocity dispersion (GVD) and nonlinearity. The influence of additional physical effects has been studied by adding different terms to this scalar model as small nonparaxiality, plasma defocussing, multiphoton ionization and vectorial generalizations. It is not hard to see that for pulses with low intensity (linear regime) in air and gases the additional terms as GVD and others become small and the basic model can be reduced to paraxial equation. This is the reason why diffraction of a low intensity optical pulse governed by this model at several diffraction lengths is equal to diffraction of a laser beam. On other hand, the experimentalists have discussed for long time that in their measurements the diffraction length of an optical pulse is not equal to that of a laser beam $z_{beam}^{diff} = k_0 r^2$, even when the additional phase effects of lens and other optical devices can be reduced. Here k_0 denotes laser light wave-number and r^2 denotes the beam waist. Thus, a deep difference between the existing models in linear regime, predicting paraxial behavior in gases, and the real experiments exist.

To obtain a theoretical model closer to the real experiments in [1-3] we performed a systematic study of linear propagation of ultra short optical pulses in media with dispersion, dispersionless media and vacuum and suggested a non-paraxial model. The new equations give us the possibility to solve several particular problems which appear in the theory.

The first one is to obtain (not slowly varying) amplitude envelope equation in media with dispersion governing the evolution of optical pulses in single-cycle

regime. This problem is natural in the femtosecond region where the optical period of a pulse is in the order of 2-3 fsec. The earliest model for pulses in single-cycle regime suggested by Brabec and Krausz is obtained after Taylor expansion of the wave vector $k^2(\omega)$ about ω. It is easy to show that this expansion diverge in solids for single-cycle pulses. The higher order dispersion terms start to dominate and the series cannot be cut off. This is why we attempted to derive the envelope equation more carefully and accurately before using Taylor series. In this way we obtain an integro-differential envelope equation without Taylor expansion of the wave vector $k^2(\omega) = \varepsilon(\omega)\mu(\omega)$ governing the evolution of single cycle pulses in solids [2].

The second problem is to investigate more precisely the slowly varying envelope equations governing the evolution of optical pulses with high number of harmonics under the envelope. The slowly varying scalar nonlinear envelope equation (NEE) is derived in many books and papers. After deriving the NEE, most authors use a standard procedure to neglect the nonparaxial terms as small ones. Only some partial nonparaxial approximations in free space and optical fibers have been studied. In [1, 2] we rewrote the NEE in a dimensionless form and estimated the influence of the different linear and nonlinear terms on the evolution of optical pulses. We found that both nonparaxial terms in NEE, the second derivative in propagation direction and the second derivative in time with $1/v^2$ coefficient, are not small corrections. In fs region they are of the same order as transverse Laplacian or start to dominate. These equations with (not small) nonparaxial terms were solved in a linear regime [3] and investigated numerically in a nonlinear regime [5, 6]. It is important to note that the vacuum linear amplitude equation (VLAE) is obtained without any expansion of the wave vector. This is why it works also for pulses in single-cycle regime (subfemto and attosecond pulses).

Last but not least, the nonparaxial equations for media with dispersion, dispersionless media and vacuum were solved in linear regime and new fundamental solutions, including the GVD influence, were found. In the case of fs propagation in gases and vacuum we demonstrated a significant decrease of the diffraction enlargement with respect to the paraxial beam model and a possibility to reach a practically diffraction-free regime.

2. Propagation of femtosecond pulses with power slightly above the critical for self-focusing

Typically, nanosecond, or hundred-picoseconds laser pulses or a laser beam with power a little above the critical for self-focusing can propagate from one to few diffraction lengths in materials before collapsing. The femtosecond pulse propagation in air and other gases demonstrate significant increase of this collapse/filamentation distance from a few meters up to several kilometers; this effect has been named arrest of the collapse. Various physical effects have been suggested to prevent the early collapse, and to increase the distance of propagation before significant self-focusing and fragmentation of the pulse. The most popular theories include plasma-induced defocusing. However, when the intensity of the pulses is below the threshold for plasma generation and in absence of ionization, collapse arrest is also observed. Other mechanisms for increasing the self-focusing distance such as nonparaxial, higher order of nonlinearity and dispersion were also investigated. The group velocity dispersion (GVD) can play some role in solids, where the dispersion length can be made of the order of the diffraction for femtosecond pulses, while for experiments in air, other gases and liquids the GVD is negligible and can not add significant effects on measurable distances. The

purpose of the works [2, 3] was to investigate the nonlinear propagation dynamics of femtosecond laser pulses in air, gases and liquids, governed by the nonparaxial nonlinear evolution equation. It was found that this nonlinear non-paraxial regime strongly depends on the initial form of the pulses. In case of long pulse (small transverse and large longitudinal size), the dynamics is closer to nonlinear paraxial dynamics of a laser beam, and the difference consists in large spectral and longitudinal spatial modulation of the long pulse. The non-paraxial terms play an important role on the evolution of light bullets and light disks. In regime of light bullets (relatively equal transverse and longitudinal size) weak self-focusing without large base and collapse arrest was obtained. Non-collapsed regime of light disks (pulses with small longitudinal and large transverse size) was also observed. Our results are in good agreement with the recent experiments on nonlinear propagation of femtosecond pulses. For first time we demonstrated that such non-paraxial model can explain effects as spectral broadening, collapse arrest and nonlinear wave guide behavior.

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LECTURE COURSES:

Fiber Optic Communication Systems,
South-Western University, Blagoevgrad, Bulgaria.

Optics,
South-Western University, Blagoevgrad, Bulgaria.

Electricity and Magnetism,
South-Western University, Blagoevgrad, Bulgaria.

LABORATORY

LASER RADARS

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

TOTAL STAFF: **23**
RESEARCH SCIENTISTS: **13**
Assoc. Prof. I. Kolev, Ph.D.; Assoc. Prof. L. Gurdev, Ph.D.; Assoc. Prof. T. Dreischuh, Ph.D.; Assoc. Prof. V. Grigorieva, Ph.D.; V. Mitev, Ph.D.; S. Penchev, Ph.D.; V. Pencheva, Ph.D.; A. Deleva, Ph.D.; Z. Peshev, Ph.D.; G. Kolarov; B. Kaprielov; V. Naboko; I. Grigorov.

RESEARCH ACTIVITIES:

1. Lidar monitoring of the atmosphere

1.1. Systematic measurements within the EARLINET - ASOS project

D. Stoyanov, I. Grogorov, G. Kolarov, A. Deleva and Z. Peshev

During 2007, the research group "Aerosol Lidar with CuBr-vapor Laser" continued the regular climatological lidar measurements, in accordanc with the timetable of the "EARLINET-ASOS" project, Contract No. 025991 of EC FP6 (http://www.earlinet.org). As mentioned previously, the main goal of the project is to build a common database that is continuously updated and automatically collects the data provided by the individual lidar stations, making them available to the community and external users. However, the processing of data of Sofia-EARLINET-station encountered some difficulties. As the lidar measurements are made frequently, the amount of raw data accumulated is too large for one person to analyze, although armed with powerful software. A problem is also to consolidate the three profiles of the atmospheric backscattering calculated by the three lidar groups of Sofia lidar station into one profile in conformance with the EARLINET's requirement about the lidar data.

I. Grigorov

Within the frame of EARLINET-ASOS project, a numerical investigation was performed to test the correctness of the applied algorithm used by each lidar group to calculate the profiles of the atmospheric aerosol backscattering coefficient by the Raman method. This algorithm inter-comparison was established on the processing of simulated Raman backscattering data sent to all participants. Having calculated the needed atmospheric optical parameters applying their own algorithms, each group will send back the results to the auditors, who will assess the errors of the profiles. calculated

D. Stoyanov, I. Grogorov, G. Kolarov, A. Deleva and Z. Peshev

To perform the Raman algorithm inter-comparison, software working in MATLAB environment was developed and incorporated into the software system LIDAR for lidar data processing developed previously in the Institute of Electronics. It had an optional possibility to introduce model (or empirical) data profiles for temperature and pressure of the atmosphere necessary for the calculations, or to calculate them using a barometric formula.

Unfortunately, the analyzis of the inter-comparison showed unsatisfactory results of the calculations by our algorithm

for Raman data processing of the atmospheric backscatter, extinction and lidar ratio. The error varied in the range of 40% near the lidar to 95-120% at altitudes exceeding 2 km. We received recommendations and operating instructions from the auditoring team on how to proceed with the development of our Raman data-processing algorithm in order to obtain correct results from the calculations in the future when a Raman channel should be added to the Sofia lidar station.

D. Stoyanov, I. Grogorov, G. Kolarov, A. Deleva and Z. Peshev

The EARLINET-Community participates in the *Quid pro Quo* (QPQ) validation measurements (http://calipsovalidation.hamptonu.edu/QPQ_plan062206.htm) of the project Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO). This is a joint U.S. (NASA) and French (Centre National d'Etudes Spatiales/CNES) satellite mission with an expected three-year lifetime. CALIPSO represents a free-flying laser radar experiment (lidar) in space and provides crucial global data on atmospheric clouds and aerosols needed for climate studies. Ground located EARLINET stations were estimated as an optimal tool to validate CALIPSO lidar data and to provide the necessary information to fully exploit the information from that mission. In particular, aerosol backscatter measurements, provided by the network, would be important for the aerosol retrievals from the CALIPSO backscatter lidar.

I. Grogorov and G. Kolarov

The group "Aerosol Lidar with CuBr-vapor laser" continued in 2007 its work concerning correlative measurements for the CALIPSO QPQ-program. These measurements were performed in coincidence with CALIPSO overpasses. Each observation lasted for a minimum of 1 hour centered around the overpass time above or near Sofia. The calculated profiles of the atmospheric backscatter coefficient were uploaded to the servers of the common database in Hamburg. Monthly two daytime and two nighttime lidar measurements were planned. The nighttime measurements were impossible because of the specific conditions of the measurement site location and the limited manpower; so we canceled them. As compensation, we performed additional daytime measurements in those cases when Calipso overpasses Bucharest or Tessaloniki, so called case II measurements.

1.2. Lidar measurements in the atmosphere

V. Grigorieva, N. Kolev and I. Kolev

New observations were made on dynamics of the ground level ozone concentration. An analysis of the data on the behavior of the ground level ozone concentration during the partial (76 %) solar eclipse on March26, 2006 was performed. The presence of clouds decreased the effect of the changing solar radiation on the ground level ozone concentration. Nevertheless, the dynamics of the fast photochemical reactions forming the anthropogenic ozone is clearly manifested in the registered ozone concentration variations. The comparison of the data obtained with the ozone concentration variations observed during the 94 % solar eclipse on August 11, 1999, when the meteorological conditions were perfect, shows a similar character of the ground ozone concentration behavior. Additional studies were made and new information was obtained concerning the technique of UV optical absorption used for the measurement of the ground level ozone concentration. The effect of the dynamical factors on the ground level ozone concentration was studied in the

processes of mixing during the mixing layer development in two different regions of the Sofia city, namely, an urban area and a park zone.

V. Grigorieva, N. Kolev, I. Kolev, Ts. Evgenieva, B. Kaprielov and R. Nenchev

The different layers of the planetary boundary layer namely, the stable boundary layer (SBL), the residual layer (RL) and the mixing layer (ML) were studied in detail in space and time,. Their particular heights and periods of existence during the different seasons were determined. The results were compared with the data obtained involving the model of Whiteman and McKee. Studies were performed on the optical characteristics of the aerosol in the troposphere using a lidar and a sun photometer. Continuous measurements were performed using a lidar, an ozonemeter and a sun photometer to determine the influence of the atmospheric aerosol on the microclimate of the region of the IE. It was found that thir is a correlation between the ABL height over an urban area and the ground level ozone concentration, whereas in a park zone such relation was not observed. The concentration values of the ground level ozone in the park zone exceed those measured in the region of the IE.

Ts. Evgenieva, N. Kolev and I. Kolev

Systematic measurements of the aerosol optical depth and of the water vapor in the entire atmospheric layer were performed. The Angstrom parameters α and β were calculated. Winter, spring, summer and autumn campaigns were carried out using an aerosol lidar and a sun photometer Microtops II to determine the relations between the ABL height and the optical properties of the atmospheric aerosol. It could be concluded that the aerosol optical depth is highest in summer (τ_a=0.3-0.4) and lowest in winter (0.2-0.25); during the spring it is of a medium value of 0.25-0.3. Similar changes were observed concerning the α parameter of Angstrom which reaches α-1.6 during summer.

Z. Peshev and A. Deleva

Lidar measurements on both the surface and atmospheric layer contiguous to the northern slope of Vitosha mountain, were carried out. The data were statistically processed. Analysis of the results is in progress in view of publication.

2. Experimental and theoretical research

L. Gurdev, T. Dreischuh and D. Stoyanov

The possibilities were investigated for measuring by graydar the distribution of the partial density of a liquid matter (water) penetrated into a dense porous medium (soil). It was shown that at sensing gamma radiation source activity from 5 mCi to 50 mCi, soil density ~1g/cm^2, and signal accumulation time of 10^2 to 10^4 s, the soil moisture profile could be determined with accuracy of 5-10% down to depths from 15-20 cm to 40-50 cm.

L. Gurdev, T. Dreischuh and D. Stoyanov

A method was developed for continuous laser beam sensing of turbid media such as biological tissues. The method is aimed at detecting characteristic inside inhomogeneities (anomalies) and determining their localization, size, and optical characteristics (extinction and backscattering coefficients). To prove the method, an experimental arrangement was built and experiments were conducted with widely varying experimental parameters of importance, such as the optical

characteristics of the turbid medium and the inhomogeneities, the inhomogeneity localization and size, the geometry and the power of the sensing laser beam, and the directional diagram and the aperture function of the receiving optical system. An analytical theoretical description was also developed of the return signal as depending on the above-indicated parameters. Such a description was shown to allow one to solve the inverse problem as well, i.e., on the basis of the signal behavior to determine the inhomogeneity parameters. The numerical analysis of the theoretical expressions obtained shows that they describe correctly both the experimental results (the signal as a function of the experimental parameters) and the inverse procedures. As a whole, it was estimated experimentally and theoretically that in media with transport extinction coefficient of 0.6 to 1.2 mm^{-1} one could find, localize and distinguish inhomogeneities with sizes down to several millimeters (~3-5mm), to depths of 2-3 cm, at a 20-30% contrast by extinction.

D. Stoyanov, L. Gurdev and T. Dreischuh

An initial study was performed on the possibility of pulsed laser sensing of thermonuclear plasma on the basis of Thomson scattering effect. The main problem of interest here concerns the determination of the signal spectrum distorted by the transversal Doppler effect, at a restricted number (6-7) of observed spectral regions, a restricted signal-to-noise ratio, and a necessity of deconvolution procedures. Another important problem is the estimation of the radiation background of the thermonuclear reactor. At present, solving the above-listed problems is in progress and a complete model of the entire high-resolution sensing procedure (determination of the spectrum and then of the electron temperature and concentration in the reactor active zone) is under development.

L. Gurdev and T. Dreischuh

A cycle of publications was completed reflecting the results from the development of a novel original approach to the determination with high resolution (5-10 m) of Doppler velocity profiles in the atmosphere by coherent lidar.

Vl. Mitev

The possibility for simultaneous determination of the vector transfer velocity of statistically homogeneous objects by image recording was investigated. A correlation approach was developed allowing for simultaneous detection of several cross-correlation function peaks as obtained for two recorded images of some statistically homogeneous objects moving with different velocities.

In order to determine the atmospheric refraction index structural parameter, i.e. the atmospheric turbulence, an application of the two-dimensional Fourier transform to laser radiation detected by using an image receiver was investigated. The possibility was proven for evaluation of the detected laser radiation coherence length by using the two-dimensional spatial power spectrum resulting from the Fourier transform performed, rather than by direct defining of the receiving optical system correlation domain.

S. Penchev, V. Pencheva and V. Naboko

The theoretical model of determination of photothermal displacement (PTD) due to illumination of transparent media by a modulated laser beam was developed to its final stage. PTD data derived by the theoretical model and the experiments showed good correlation. The special case of PTD behavior of Si was studied, which deviated strongly from the model of determination of PTD of opaque media

that was used until now. The new model developed for transparent media demonstrated a comparatively better correlation of the theoretical and experimental results in the limit of the opaque case. The systematically greater PTD value derived by the theoretical model led us to propose an explanation of this behavior of Si via consideration of the specifics of its zone structure with nonlinear absorption and emission of phonons causing a drainage of a part of the absorbed energy outside of the diffusive volume to the crystal lattice. The direct measurement of the coefficient of optical absorption / depth of penetration of the laser beam into the target is of great importance for investigation of Si samples regarding planar- waveguide technologies. The results were reported at the 7th International Conference on Solid-State Chemistry and Modern Micro- and Nano Technologies held in September 2007 in Kislovodsk, Russia.

M. Danov and E. Angelova

Experimental system and methodology were developed for measurement of the spectral emissivity of rock samples. Spectral emissivity of hematite and limonite were measured as a part of remote sensing program of the Kremikovtsi open pit mine. The results obtained were presented at the Third seminar ”Evolution and Ecology”, organized by the Bulgarian Academy of Sciences and held in Sofia, April 19-20, 2007.

The values estimated of the emissivity were compared with those published in the literature; the emissivity data of NASA’s space-borne instrument ASTER shows similar spectrum for hematite. This comparison is reported at the conference ”Resent Advances in Space Technologies” that took place at Istanbul, Turkey, August 14-16, 2007.

3. Signal processing

D. Stoyanov

The theory was developed and tested by extended simulations of a novel method for retrieving true images in a grid step much finer than both the acquisition and the optical microscope limits. We believe that the method is promising in view of avoiding the limitations on the resolution improvement in direct imaging mode systems. Two basic concepts are involved: (i) random (up to 3D) relative displacements of objects with respect to the receiving matrix; (ii) the use of a reference object firmly fixed to small signal objects for avoiding the displacement measurements. The retrieved images are created by rearranging a set of true images acquired with a lower resolution equal to the matrix pixel size. We demonstrate the good quality of the retrieved images and the possibility to visualize and detect small (convolved) objects not observed into the captured images. The method provides good opportunities for effective applications of different inverse algorithms for improving the resolution requiring, as a rule, more precisely sampled images, but at arbitrary relations between the pixel size and the optical diffraction limit. We further demonstrated the application of some deconvolution procedures for extracting highly resolved images in the object and image planes in the presence of noise. The possibility to resolve small objects beyond the two classical limits is shown by means of simulations. The estimates for the method’s limiting resolution, combined with proper deconvolution processing, show that resolution in the lower nano-dimension scale (below 10 nm) could be achieved. The requirements to the implementation of the novel method are commented as well.

4. Lidar hardware & software

R. Nenchev and N. Kolev

Software for processing of the data from ALOMAR was developed.

A. Deleva and Z. Peshev

A specialized software for simultaneous detection, storage, and initial processing of lidar data received by the three lidar channels, is developed in OSML IF BNAS, within the framework of the joint project "Investigation of aerosol fields over industrial centers using lidar methods". Installation and initial testing of the new software is forthcoming.

A. Deleva and Z. Peshev

In close collaboration with scientists of the Optics of Scattering Mediums Lab (OSML) of the Institute of Physics, BNAS, Minsk, Belarus, the first Raman channel of the combined aerosol-Raman lidar was put in operation using a compact photon counting module developed in IF BNAS. The Raman channel is operated at a wavelength of 607 nm corresponding to a Raman-shifted line of N_2. Initial test measurements of atmospheric nitrogen were implemented. Installation of the third lidar channel (an aerosol one) for an operation at the fundamental laser wavelength of 1064 nm is in progress. It is based on an IR avalanche photodiode with a high gain coefficient. The lidar wavelength separating module was upgraded to a version allowing simultaneous lidar measurements with all three special channels (two aerosol channels and a Raman one).

S. Penchev, V. Pencheva and V. Naboko

During the period reported, studies were conducted on the prospects of expanding the spatial range and exploitation limits of the lidar based on laser diodes via a series of methodological and hardware solutions in the development of the optical and electronic systems of the lidar. We studied the technical details of photodetectors based on avalanche photodiodes (APD) and the specific demands regarding the use of preamplifiers. Assessment of the realistic signal and background noise of the lidar at Geiger and analog modes of operation was presented for the set lidar parameters.

An analogue-digital device was developed controlled by a microprocessor for digital presentation of boxcar-integrator signals aimed to successive processing by a computer. Specialized software is being developed.

A model of an amplifier based on fast SMD element with respect to the lidar signal in APD analogue mode was developed.

A source of selective illumination of plants with ultra bright LEDs was developed. The parameters of the ultra bright LEDs were measured and the proper practical solutions were implemented to ensure long-term stable operation.

Further improvements were introduced in the optical scheme of the laser multispectral system of nondestructive material analysis.

An opto-mechanic photodetector head with a highly sensitive APD (manufactured by Hamamatsu) in the near infrared spectrum is under construction.

Activities on programming the hardware of the DSP- module of the lidar were conducted in DMA mode and a testing program for assessment of the time relations of data transfer between the modules.

G. Kolarov and I. Grigorov

An additional receiving channel for detection of the backscatter at the second laser emission wavelength at 579 nm was constructed for the aerosol lidar with CuBr-vapor laser. It uses an HRD-2 Jobin Yvon monochromator as a filtering

element that permits also detection at different other wavelengths, including vibrational Raman lines of nitrogen. This channel is used only for nighttime measurements because of the small signal to noise ratio.

M. Danov and E. Angelova

A new system and methodology for measurement of directional emissivity distribution of rock samples are under current development aimed at the improvement of the treatment of remote sensing data. The system works in the spectral interval from 7 to 14 μm with an average resolution of 0.25 μm. An initial version of the system is realized and the signal to noise ratio is investigated experimentally.

The color characteristics of objects were determined by means of measurement of the descending solar radiation. Further transformation provides data suitable for coloring of digitally synthesized images. Two radiometers were used: (i) a logarithmic one, operating in the wavelength interval 400-1100 nm, used to determine the intensity ($W.m^{-2}$) of the radiation and (ii) a three-channel one which determines the color characteristics of the objects investigated.

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Mountain-surface mapping by using a powerful lidar system,
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Non-destructive photothermal analysis of transparent media,
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27. Pavlova P, Angelova E,
Colorimetrical Problems in Colour Identification of Objects in Computer Images,
Proc Workshop COST'529 WG4 Colour Aspects for Light Sources-Colorimetry and Its Applications in Industry and Environment (2006 Varna, Bulgaria) pp 41-5.
28. Dreischuh T N, Gurdev L L, Stoyanov D V, Protochristov C N, Vankov O I,
On the efficiency of a lidar-type single-sided gamma-ray tomography approach,
AIP Conf Proc 2007;889:778.
29. Iliev I, Grigorieva V, Kolev N, Evgenieva Ts, Kaprielov B, Kolev I,
Lidar, radiometer and ozonemeter measurements over urban area,
AIP Conf Proc 2007;899:735.
30. Borisova D, Nikolov H, Danov M, Tsanev V,
Comparison between reflectance/emittance spectra of iron-containing minerals,
Proc 3rd Int Conf Recent advances in space technologies (2007 Istanbul, Turkey), pp 252-5.
31. Danov M, Tsanev V, Petkov D,
Investigation of thermal infrared emissivity spectra of mineral and rock samples,
Proc 26th Symp of the European Association of Remote Sensing Laboratories New developments and challenges in remote sensing (2006 Warsaw, Poland) pp 145-52.

PATENTS:

1. D. Stoyanov, L. Gurdev, T. Dreischuh, O.Vankov, Ch. Protochristov,
Radar on single spontaneously emitted gamma-photons,
Reg. № 108818/ 23.07.2004.

2. D. Stoyanov, L. Gurdev, T. Dreischuh,O.Vankov, L.Avramov, E.Borissova, Optical multichannel transceiving system, Reg. № 109799/17.01.2007.
3. D. Stoyanov, L. Gurdev, T. Dreischuh, O.Vankov, L.Avramov, E. Borissova, I. Bliznakova, Ref: 2007P24470EP in Siemens, MD, AG.

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2. Ts. Evgenieva, N. Kolev, I. Iliev, I. Kolev, Aerosol optical depth determination by combination of lidar and sun photometer, 17th Int Conf Nucleation and Atmospheric Aerosols, Galway, Ireland, August 2007.
3. Ts. Evgenieva, N. Kolev, I. Iliev, P. Savov, B. Kaprielov, I. Kolev, Comparison of the aerosol optical characteristics obtained by lidar and sunphotometer, 2nd ACCENT Symp, Urbino, Italy, July 2007.
4. N. Kolev, V. Grigorieva, E. Donev, V. Aleksandrov, D. Ivanov, I. Kolev, Lidar and in-situ measurements of air pollution over urban area – Sofia (Bulgaria), 2nd ACCENT Symp, Urbino, Italy, July 2007.
5. Ts. Gogosheva, P. Simeonov, V. Grigorieva, B. Mendeva, B. Petkov, D. Krastev, T. Tasheva, Atmospheric state over Bulgaria during the Solar eclipse on 29 March 2006, 2nd ACCENT Symp, Urbino, Italy, July 2007.
6. I. Grigorov, G. Kolarov, Measurements of atmospheric parameters using aerosol lidar, Workshop Optoelectronic Techniques for Environmental Monitoring and Risk Assessment (OTEM 2007), Bucharest, Romania, May 2007.
7. D. Borisova, H. Nikolov, R. Kancheva, M. Danov, V. Tsanev, M. Tokmakchieva, B. Banushev, Monitoring of iron distribution in mine districts using remotely sensed data, Seminar of the Union of Scientists in Bulgaria "Evolution and Ecology - 3", Sofia, Bulgaria, April2007.

ONGOING RESEARCH PROJECTS:

Financed by the National Science Fund

1. Ph-1408 Development of high-power Raman lidar for sounding the molecular components in the low and middle atmosphere.
2. ES-1406 Peculiarities of ozone variations and investigation of processes, responsible for their existence.
3. Ph-1511 Lidar methods for high resolution probing of inhomogeneities objects by optical and gamma radiation.
4. YS Ph-1510 Simulated and experimental investigations on retrieving of time-resolved profiles at dynamic photon fluxes in laser radars.
5. ES YS-1502/05 Investigation of emission and reflectance characteristics of mixed spectral classes of rocks and minerals.
6. TS–1523/05 Effects of atmospheric turbulences on the parameters of: laser communication systems in open media; lidar and radiometric systems for ecomonitoring; systems for analysis of optical images of natural (inc. space) objects.

Financed by the Steering Council of the Bulgarian Academy of Sciences

1. Raman lidar by Nd:YAG laser for remote sensing of atmospheric parameters.
2. Remote determination of some statistical characteristics of non-uniform media by image processing.
3. Lidar Methods for determination of planetary boundary layer heights.
4. Investigation of orographic disturbances in the atmosphere above the city of Sofia by lidar probing of the vertical aerosol layers distribution.
5. Statistical analysis of the concentration fluctuations at lidar sensing of the atmospheric aerosol.
6. Lidar monitoring of atmospheric gaseous components by powerful pulsed diode lasers
7. Ozone variations in the low atmosphere in different temporal scales.

Financed by other institutions

1. **NIF - IF-00-121/06** Laser optoelectronic system for optical tomography, Siemens MS AG, Germany**.**

COLLABORATIONS:

1. European Aerosol research lidar network: advanced sustainable observation system EARLINET – ASOS.
2. 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).
3. Optical, gamma and MW remote characterization of dynamic small-size submicron structured systems in life-sciences and industry,
University of Liege, Belgium.
4. Advanced lidar technologies for tropospheric aerosol studies,
Istituto di Metodologie per l'Analisi Ambientale, CNR, Italy.
5. Improving the resolution of Thomson scattering LIDARs by application of novel deconvolution – based algorithms,
EFDA – JET, Culham, UK.
6. Lidar investigation of aerosol fields transformations in urban industrial zones,
Institute of physics, National Academy of Belarus, Minsk, Belarus.
7. Experiments of optical tomography,
Siemens MS AG, Germany.

AWARDS:

Academician E. Djakov award for the best publication:
V. Pencheva, S. Penchev, V. Naboko, T. Donchev, S. Kolev, T. Kutzarova,
Laser heterodyne measurement of photothermal displacement of material surface characterization,
Plasma Processes and Polymers 2006;3:253-6;
V. Pencheva, S. Penchev, V. Naboko, K. Toyoda, T. Donchev,
Laser heterodyne photothermal nondistructive method: extension to transparent probe,
Proc SPIE 2007;6604:283-7.

Award of the Institute of Nuclear Research and Nuclear Energy, BAS in the field of applied research:
D. Stoyanov, L. Gurdev, T. Dreischuh, O. Vankov, Ch. Protochristov,
cycle of papers on GRAYDAY – application on lidar method with spontaneously emitted gamma-photons.

LABORATORY

MICROWAVE REMOTE SENSING

HEAD: **Assoc. Prof. B. Vichev, Ph.D**.

TOTAL STAFF: **13**
RESEARCH SCIENTISTS: **12**
Prof. Z. Genchev, Dr.Sc.; Assoc. Prof. M. Mikhalev, Ph.D.; Assoc. Prof. V. Atanassov, Ph.D.; Assoc. Prof. O. Yordanov, Ph.D.; Assoc. Prof. N. Nedeltchev, Ph.D.; Assoc. Prof. N. Kostov, Dr.Sc.; I. Sirkova, Ph.D.; E. Krasteva, Ph.D.; I. Atanasov, PhD; K. Kostov; L. Mladenov; L. Vulkova.

RESEARCH ACTIVITIES:

1. Microwave radiometers for remote sensing applications

The Bulgarian-Vietnamese joint research project "Design and development of a C-band microwave radiometer and its applications for remote sensing of vegetation cover and sea surface environment in Vietnam" was successfully completed.

The experimental radiometric data obtained in Vietnam in November 2006 over bare and vegetation fields using the C-band radiometer *CRM* were thoroughly analysed and compared with the experimental results obtained in Vietnam in October 2001 using L- and C-band radiometers. Very good correspondence with the ground-truth soil moisture data is observed for the bare soil plots confirming the effectiveness of the proposed procedure for estimating the soil surface roughness from the radiometric data for dry soil. The estimated *b*-parameter values for the rice canopy are in good agreement with the published data for wheat for L- and C-band.

The recently proposed original algorithm for estimating the sea brightness temperature from the *CRM* radiometric data was tested with L-band radiometer data. The estimated sea brightness temperature may be used for calculating sea surface salinity or sea surface temperature, respectively, using *a priori* information about the other parameter.

Different algorithms for correction of temperature drift effects in total power radiometers were tested using real radiometric data. Problems related to thermal drift in low-budget total power radiometers designed using components for satellite TV receivers were studied.

The radiometer *CRM*, developed under this contract, is the final result of our long-term research efforts for designing and developing low-budget total power radiometers using components for satellite TV receivers. The radiometer *CRM* is a valuable instrument for remote sensing investigations and ecosystem monitoring.

2. Comparison between rough surface reflection coefficients: application to the microwave ducting propagation

The recently published in the literature phase correction to the Ament's rough surface reflection coefficient is applied to the case of microwave propagation over the sea under tropospheric ducting conditions. Comparisons are made between propagation factors for microwave range calculated with phase corrected Ament's rough surface reflection coefficient, with Miller-Brown rough surface reflection coefficient and with non-phase-corrected Ament's rough surface reflection coefficient. The calculations are based on the parabolic wave equation method.

3. Emergent structures and collective behavior in extended and distributed chaotic systems

Anisotropy and scaling properties of YBa_2Cu3O_{7-x} thin films grown on $SrTO_3$ substrate by pulsed laser deposition are studied by using two-point, two-dimensional statistical functions. It is found that films whose deposition conditions differ by the pulse deposition rate and the chemical treatment of the substrate have significantly different anisotropies and scaling intervals. This is interpreted as branching of initially identical growth mechanisms into two modes. The branching occurs at lateral scales of about 80 nm and above.

The studies of the properties of the approximately scale-invariant stochastic fields were further extended. The latter included proposing a new, more accurate method, for computer simulation of such fields and implementing it as a computer algorithm. A PhD thesis was successfully defended on basis of the research conducted on these topics.

4. Physics of electromagnetic interactions in layered media

During this year we explored the influence of van der Waals and Casimir-Polder forces on some typical parallel plate configurations frequently encountered in micro- and nano-electromechanical systems. These systems are used as electrostatically actuated microswitches. Several concrete systems were studied theoretically. For a single homogeneous slab embedded from both sides by two semi-infinite substances we take into account the smooth variation of the dielectric permittivity function. The new formula for the force per unit area (the pressure) contains as a limiting case the well-known from the literature result for sharp boundaries. As a second application of the general theory we considered two ideally conducting plates separated by a vacuum gap. Taking into account that one plate is fixed and the other one is able to move as a mechanical string we formulated an expression for the net force acting on the plate capable to oscillate. A voltage application between the two electrodes was assumed. We showed that at small separations the Casimir-Polder attractive force which is due to electromagnetic fluctuations must be taken into account. These investigations of electromagnetic interactions in layered media can be used in future experimental studies aiming to measure fluctuational forces with high precision.

PUBLICATIONS:

1. Sirkova I,
Phase correction to the Ament's rough surface reflection coefficient: application to the microwave ducting propagation,
COST 2100 3rd MCM, September 2007, Duisburg, Germany p 7.
2. Yordanov O I,
Approximate scale-invariant random fields: a review and current developments,
Bellagio Int Workshop on Mathematical Modelling, Simulation, Visualization and e-Learning, Bellagio, Italy, November 2006 (Springer Verlag, Berlin), 2007 pp 253-67, Content and the abstracts of the book are available at: http://www.math.vt.edu/bellagio/yordanov.pdf.
3. Genchev Z D,
Influence of submicron phenomena in nanostructures for MEMS/NEMS microswitches,
Nanoscience & Nanotechnology, Eds. E. Balabanova, I. Dragieva, (Heron Press Ltd, Sofia, Bulgaria) 2007;7:16-18.

4. Genchev Z D, Boyadjiev T L, Stoev L,
Stability of electrostatically actuated MEMS
Proc Conf Computational Phys, Brussels, Belgium, September 2007, p 251.
5. Atanassov V, Mateev E,
Spatial structures arising along a surface wave produced plasma column: an experimental study,
J Phys: Conf Ser 2007;63:012025.
6. Gerdjikov V S, Kostov N A, Valchev T,
N-wave equations with orthogonal algebras: Z_2 and $Z_2 \times Z_2$ reductions and soliton solutions,
SIGMA 2007;3:039.
7. Gerdjikov V S, Kostov N A, Valchev T,
Exact solutions for equations of Bose- Fermi mixtures in one-dimensional optical lattice,
SIGMA 2007;3:071.
8. Kostov N A, Kostova Z T,
Exact solutions of completely integrable systems and linear ODE's having elliptic function coefficients,
Lecture Notes in Computer Science (Springer-Verlag, Berlin) 2007;4770:252-64.
9. Kostov N A, Dandoloff R, Gerdjikov V S, Grahovski G G,
The Manakov system as two moving interacting curves,
Topics in contemporary differential geometry, complex analysis and mathematical physics, Eds. S. Demiev, K. Sekigawa (World Scientific, Singapore) 2007;168-78.
10. Kostov N A,
Exact solutions of the Manakov system,
Topics in contemporary differential geometry, complex analysis and mathematical physics, Eds. S. Demiev, K. Sekigawa (World Scientific, Singapore) 2007;158-67.
11. Gerdjikov V S, Kostov N A, Valchev T,
Hamiltonian aspects of soliton equations with deep reductions,
Topics in contemporary differential geometry, complex analysis and mathematical physics, Eds. S. Demiev, K. Sekigawa (World Scientific, Singapore) 2007;85-96.
12. Kostov N, Gerdjikov V,
On the soliton interactions in NLS equation with external potentials,
Proc SPIE 2007;6604:66041S.
13. Kostov N A, Atanasov V A, Gerdjikov V S, Grahovskii G,
On the soliton solutions of the spinor Bose-Einstein condensate,
Proc SPIE 2007;6604:66041T.

ONGOING RESEARCH PROJECTS:

Financed by the National Scientific Research Council

BV-3/07 Design and development of a Dicke-type microwave X-band radiometer and its utilization for environmental investigations.

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.

DEFENCE OF PhD THESIS

Ivaylo S. Atanasov, Approximate self-affine models of time series and surface morphologies.

LABORATORY VISITS:

Z. Genchev, Universités Libre de Bruxelles, Brussels, Belgium.
Z. Genchev, Johannes Guttenberg Universitat, Mainz, Germany.
I. Sirkova, University of Duisburg-Essen, Germany.
I. Sirkova, European Commission – projects reviewer, Brussels, Belgium.

LABORATORY

MICROWAVE MAGNETICS

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

TOTAL STAFF: **10**
RESEARCH SCIENTISTS: **6**
Assoc. Prof. K. G. Grigorov, Ph.D.; T. Koutzarova, Ph.D.; S. Kolev, Ph.D.;
Ch. Ghelev; T. Merodiiska; T. Beneva.
Ph.D. students: L. Slavov; P. Lukanov.
WFS guest scholarship student: E. Daikova.

The Microwave Magnetics Laboratory has long years of experience in studying the processes of electromagnetic radiation interaction with magnetic media. The recent rapid developments in the field of nanotechnologies placed new challenges before the scientists in this respect. By applying an original technique that makes use of the single and double microemulsion technologies, homogeneous in shape and size nanosized particles of highly anisotropic barium hexaferrite were prepared in the laboratory with average particles size 80, 130 and 280 nm. The hexaferrite's fine magnetic structure was studied. The studies by transmission Moesbauer spectroscopy showed that the by-pyramidal 2*b* site in the crystal lattice is responsible for the appearance of new magnetic properties of the nanoparticles, in particular, for the increase of the magneto-crystalline anisotropy ($K_1 = 3.3\times10^5$ Jm^{-3}). Nanostructured hexaferrite powders were produced whose saturation magnetization (M_s) values are among the highest quoted so far in the literature.

The original results obtained on nanostructured oxides allowed the development of a novel type of composite microwave (MW) absorbers with a very narrow absorption band, whose peak frequency can be shifted in a controlled way by varying the size and the anisotropy of the nanosized magnetic filler. This was achieved by way of combining magnetic nanoparticles with high and low anisotropy with dielectric nanostructured carbon. The novel structures were tested under industrial conditions.

Based on the model developed in the Microwave Magnetics Laboratory [1] for the defects in the surface layer of a nanosized ferroxide particle and on an original technique for optical control of nano-objects in a ferrofluid [2], multifunctional ferrofluids were prepared [5] containing superparamagnetic biocompatible particles of magnetite with a very short relaxation time during interaction with an RF electromagnetic field, which increase the contrast and decrease the exposure time in NMR imaging of living tissues. The experiments on animals [3] performed in the NMR laboratory of the Faculty of Biology of St. Kliment Ohridski University of Sofia demonstrated that such fluids can successfully replace the traditional Gd-containing fluids and can form the basis for the development of a new generation contrast materials for NMR imaging. Furthermore, time-controlled hyperthermia was observed in these fluids [4], namely, a temperature rise from 3.5 to 12°C during irradiation by an electromagnetic field with frequency 40 κHz and amplitude 10 A/m. The possible applications of the hyperthermia phenomenon are now considered as very promising for *in vivo* treatment of tumors. Part of the studies of the fluids prepared in

the Microwave Magnetics Laboratory were carried out in the Paul Sabatier University, Toulouse, France, and in the University of Gent, Gent, Belgium, under joint projects between CNRS, FWO and the Bulgarian Academy of Sciences.

PUBLICATIONS:

1. Nedkov I,
   Nanosized magnetite for biomedical applications**,**
   J Optoelectr Adv Mater 2007;9:2429.
2. Stoyanov D, Nedkov I, Ausools M,
   Retrieving true images through fine grid steps for enhancing the resolution beyond the classical limits: theory and simulations,
   J Microscopy 2007;226:270–83.
3. Kolev S, Koutzarova T, Yanev A, Ghelev Ch, Nedkov I,
   Microwave properties of polymer composites containing combinations of micro- and nano-sized magnetic fillers,
   J Nanoscience and Nanotechnology 2007;10, doi: 10.1166/jnn.2007.B069.
4. Nedkov I, Vandenberghe R E, Marinova Ts, Thailhades Ph, Merodiiska T, Avramova I,
   Magnetic structure and collective Jahn–Teller distortions in nanostructured particles of $CuFe_2O_4$,
   Appl Surf Sci 2006;253:2589-96.
5. Kalionsky R, Merodiiska T, Dencheva-Zarkova M, Todorpva L, Naydenova S, Lovchinov V, Lalchev Z, Nedkov I, Petrov A,
   Magnetic resonance imaging by specially formulated iron oxide nanoparticles,
   Comptes rendus de l'Academie Bulgare des Sciences 2007;60:893-98.
6. Grigorov K, Massi M, Maciel H S, Freita F M, Toku H, Pessoa R S,
   Etching of DLC films exposed to a plasma jet,
   J Optoelectr Adv Mater 2007;9:382-85.
7. Beshkova M, Grigorov K G, Zakhariev Z, Abrashev M, Massi M, Yakimova R,
   Sublimation epitaxy of AlN layers grown by different conditions on 4H-SiC substrates,
   J Optoelectr Adv Mater 2007;9:213-216.
8. Pessoa R S, Murakami G, Massi M, Maciel H S, Grigorov K, da Silva Sobrinho A S, Petraconi G, Marcuzzo J S,
   Off-axis growth of AlN thin films by hollow cathode magnetron sputtering under various nitrogen concentrations,
   Diamond and Related Mater 2007;16:1433-6.
9. Guerassimov N, Ghelev Ch (Eds),
   Institute of Electronics Annual Report 2006, 112 p., Sofia, Bulgaria, 2007.
10. Koutzarova T, Nedkov I, Kolev S, Grigorov K, Vandenberghe R E, Mathieu J-Ph, Ausloos M, Ghelev Ch, Palewski T, Gajda D,
    Structural and magnetic properties of nanosized barium hexaferrite powders obtained by microemulsion techniques,
    Nanoscience& Nanotechnology, Eds. Balabanova E, Dragieva I, (Heron Press Ltd, Sofia, Bulgaria) 2007:56-8.
11. Lukanov P, Slavov L, Dimitrov D, Tailhades Ph, Vandenberghe RE, Nedkov I,
    Hyperthermia of superparamagnetic ferrofluids,
    Nanoscience& Nanotechnology, Eds. Balabanova E, Dragieva I, (Heron Press Ltd, Sofia, Bulgaria) 2007:259-61.

ONGOING RESEARCH PROJECTS:

Financed by the National Science Fund

HT – 1-01/2003 Nano-structures for microwave and optical measurements.

Financed by other funds

3D- TV Network of 6FP.
NATO Reintegration Grant EAP.RIG.981472 Nanocomposites - Magnetic Superconductors and Ferroxides for Microwave Applications.

COLLABORATIONS:

Doping effects in magnetic ceramics and optical and microwave remote characterization of dynamic small-size submicron-structured systems in life sciences and industry,
University of Liege, Liege, Belgium.
Nanostructured ferroxide powders for biomagnetic applications,
University of Gent, Gent, Belgium.
Les fluides et les composites superparamagnetiques pour des applications biomagnetiques et electroniques,
University P. Sabatier, France.
Magnetic interactions in nanoscale ionic crystals at high magnetic fields. Ferrofluids and composites for biomedical and electronic applications,
Forschungszentrum Rossendorf, Hochfeld-Magnetlabor Dresden, Germany.
Surface anisotropy and magnetic behavior in superparamagnetic ferroxides particles with two and more magneto-crystalline sublattices,
Institute of Low Temperatures and Structure Research, PAS, Wroclaw, Poland.

GUESTS:

Prof. R. Vandenberge, University of Gent, Belgium,
Joint Research Project Nanostructure ferroxide powders for biomagnetic applications, 14 days.
Dr. Lionel Presment, University P. Sabatier, France, 8 days.
V. Valchev, PhD-student, Catholic University of Louvain, Belgium, 1 day.

LABORATORY VISITS:

I. Nedkov – Paul Sabatier University, Toulouse, France, Nanostructure magnetic materials, 14 days (invited professor).
I. Nedkov - University of Gent, Belgium, Joint Research Project Nano-structured ferroxide powders for biomagnetic applications, 14 days.
K. Grigorov - Institute of Low Temperatures and Structure Research, PAN, Wroclaw, Poland, Joint Research Project Surface anisotropy and magnetic behavior in superparamagnetic ferroxides particles with two and more magneto-crystalline sublattices, 20 days.
K. Grigorov – Forschungszentrum Rossendorf, Hochfeld-Magnetlabor Dresden, Germany, Magnetic interactions in nanoscale ionic crystals at high magnetic fields. Ferrofluids and composites for biomedical and electronic applications, 24 days.
T. Koutzarova – University of Liege, Belgium; Doping effects in magnetic ceramics and optical, gamma and microwave remote characterization of dynamic small-size submicron-structured systems in life sciences and industry, 14 days.
S. Kolev – Josef Stefan Institute, Ljubljana, Slovenia, Hexaferrite films prepared by elecrophoretic deposition, 9 months.
T. Merodiiska – Okayama University and Kurashiki University, 8 days.
P. Lukanov - Paul Sabatier University, Toulouse, France, RTN CARBIO, 11 months.

LABORATORY

MICROWAVE SOLID STATE ELECTRONICS

HEAD: **Assoc. Prof. A. Yanev, Ph.D.**

TOTAL STAFF: **9**
RESEARCH SCIENTISTS: **8**
Assoc. Prof. N.M. Nikolov, Ph.D.; Ph.D.; M. Taslakov, Ph.D.; P. Zubov, Ph.D.; B. Simeonova, Ph.D.; A. Enikova; V. Ranev; L. Kokonchev; K. Markov.

RESEARCH ACTIVITIES:

1. Microwave multi-octave low-noise transistor amplifiers

A methodology was developed for computer simulation and optimization of the parameters of a multi-octave low-noise transistor amplifier intended for operation in the 1 - 14 GHz frequency range. Equivalent matching circuits (at the input, at the output, and between the separate amplifier stages) were proposed allowing one to determine the minimal noise figure achievable for a given transistor at preset gain, gain flatness, and standing wave coefficient (SWC) at the input and the output. Besides the standard resistive feedback between the gate and the drain, additional frequency dependent resistive circuits were used, which resulted in better flatness without worsening the noise coefficient. Using the equivalent circuit of the amplifier with perfect components (frequency independent impedance transformer and negative reactive components), the amplifier's matching circuits were synthesized by means of discrete components (inductances and capacitances). The values of the components were determined by comparing the two circuits using the formalism for the input impedance of single-pole circuits over the entire frequency band. The results obtained demonstrated the possibility to synthesize circuits with parameters close to those of the original equivalent circuit in a frequency band comprising several octaves. After optimization of the amplifier's characteristics, the following parameters were calculated: noise coefficient less than 2.4 dB, gain greater than 28 dB at flatness ±1 dB, SWC less than 2.5 at the input and less than 2 at the output, within the 1 - 14 GHz frequency range.

The amplifier was implemented based on microstrip technology using packaged transistors and chip capacitors and resistors. The parameters measured were in very good agreement with the simulation and comparable to those quoted in the literature for monolithic integral circuits in the same frequency range.

Furthermore, the effect was studied of various parallel and in-series feedbacks between the transistor's gate, drain and source on the transistor's S parameters with the purpose of improving the noise coefficient and the gain flatness. Based on these studies, a design was proposed of a three-stage amplifier employing a combined frequency-dependent feedback between the gate of the first transistor and the source of the second transistor. Thus, besides the improvement of the parameters cited above, a considerable reduction was achieved of the number of components in the inter-stage matching circuits. The optimization performed resulted in obtaining the following characteristics: gain 24.5 dB at flatness ±0.5 dB, noise coefficient 1.4 - 2 dB, and SWC at the input and output less than 2.4 and 2,

respectively, within the frequency range 0.5 - 12 GHz. The comparison of the characteristics of the amplifier using a parallel feedback between the gate and the source with those of the amplifier with the combined feedback proposed by us showed that the latter design exhibits lower noise coefficient.

2. Spectroscopic monitoring of atmospheric compounds

A portable system based on a pulsed quantum cascade laser (QCL) was developed. The QCL operates at near to ambient temperature in a pulsed mode with a relatively long pulse duration in the range of 200 – 500 ns. The system design is flexible, allowing using it for a number of open path or cell-internal applications. Due to the so called fingerprint spectral region, high haze and turbulence immunity and low beam divergence, this system can be used in various applications. The first group includes environmental monitoring of a number of trace gases as CH_4, NH_3, CO, O_3, CO_2, HNO_3, hydro-carbons and many others. Meteorological applications include measuring of the average humidity and temperature. Industrial surveillance control is another important application. Remote measurement of some physical parameters, as temperature or pressure, as well as interferometric measurements of the object thickness are also possible. Space resolved studies of air turbulence even in a fog is another promising application. Space resolution of 15 m is demonstrated at 100 ns pulse duration. The space resolution can be improved by using shorter pulses. The security, speed control, open path data transfer and remote readout of information are a few other real applications of our QCL based portable system.

3. High-quality conversion of electric energy by means of power electronic convertors

Theoretical models were proposed for the current consumed by single-phase A.C. choppers with pulse-width modulation of two and three pulses for a half-period of line voltage in the case of active load. On the basis of the method developed for calculating the converters' power efficiency, we calculated the relative values of the amplitude of the first and the more significant higher harmonics in the input current curve and the respective power factors in full control range.

The results showed that for some of models with two pulses for a half- period of line voltage, the first higher harmonic with significant amplitude is the fifth, and with three pulses, the third and fifth are strongly reduced or absent. This results are not only some contribution to the theory of power electronics, but widen the possibilities for practical uses A.C. choppers.

PUBLICATIONS:

1. Slavov D, Bevilacque G, Biancalana V, Cartaleva S, Dancheva Y, Karaulanov T, Moi L, Petrov N, Yanev A,
   Coherent population trapping for continuous and alternating magnetic fields measurements,
   Proc AIP BPU6 2007:175-6.
2. Karaulanov T, Yanev A, Kartaleva S, Slavov V, Petrov N, Mijailovic M, Grujic D, Krmpot A,
   Coherent population trapping resonances on the DI line of rubidium,
   Proc SPIE 2007;6604:66040C-1–C-5.

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9. Petrov P, Georgiev C, Zubov P,
Creation of superhard C_3N_4 by electron beam processing,
Proc 7th Int Conf Solid-state Chemistry and Modern Micro- and Nano-technologies, (2007, Kislovodsk, Russia) p 3.

COLLABORATIONS:

Technology and development of devices for optical spectroscopy,
Technical University of Lozana, Switzerland.

LABORATORY VISITS:

M. Taslakov, one year at the Technical University of Lozana, Switzerland, Specroscopic monitoring af atmospheric comppounds.

LABORATORY

PHYSICAL TECHNOLOGIES

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

TOTAL STAFF: **6**
RESEARCH SCIENTISTS: **5**
Assoc. Prof. I. N. Martev, Ph.D.; Assoc. Prof. Ts. D. Uzunov, Ph.D.;
D. A. Dechev; N. P. Ivanov; N. Lutakova.

RESEARCH ACTIVITES:

1. Multilayer nanostructures of alternating TiN and W_2N films

The investigations performed were a continuation of the work on previous stages, namely, deposition of single films of transition metal nitrides (TiN, W_xN and MoN) and studying their physical and mechanical properties. The activity included deposition of multilayer structures of alternating TiN/W_2N films with nanometer thickness, the so called superlattices, their structural characterization and investigation of their hardness. Multilayer structures were deposited by reactive DC magnetron sputtering. Two types of practical substrates, machine steel and sintered hard alloy, were used. Several multilayer structures with various numbers of TiN/W_2N couples were produced. The couple thickness is about 20 nm (TiN and W_2N single films have the same thickness, about 10 nm).

The adhesion of these coatings to the substrates was studied by the Rockwell-C Impact test. It was found that the adhesion decreases as the total thickness of the multilayer is increased. The morphology of the substrate surfaces and the surfaces of the deposited multilayer coatings with different thickness were observed by a metallographic microscope. It was seen that the coating morphology replicates that of the substrate with a homogeneous grain structure. The microstructure of the composing TiN and W_2N single films with higher thickness (200 nm) deposited at the same experimental conditions was studied by transmission electron microscopy (TEM) and selected area electron diffraction (SAED). The TEM observations showed that the TiN and W_2N films are polycrystalline and homogeneous with uniformly distributed nano-crystals varying in size from 30 to 50 nm for the TiN and 50 to 100 nm for the W_2N films. According to the SAED patterns, there exists some tendency towards texturing of the TiN films. The SAED patterns of W-N films confirm the presence of the W_2N nano-sized polycrystalline phase.

The measurements of the Vickers hardness showed that the multilayer coatings have hardness that is 40% higher than that of single TiN or W_2N films and more than twice as high as that of the substrates.

2. Evaluation of mechanical properties by sheet resistance measurements of vacuum annealed TiN and WN single-layer coatings on instrumental materials

TiN and WN single-layer coatings were deposited by DC magnetron sputtering on different type of instrumental steel (R18, Y8, 12CrNi3A) substrates and on substrates of hard alloy (sintered TiC-WC powders with Co as a binding material). The microhardness, the Young's modulus and the energy of plastic deformation were measured before and after annealing of the

coatings in vacuum in mid-temperatures range. The adhesion of the TiN and WN coatings on the substrates of instrumental steel R18 was determined by the "normal stretch" method. The sheet resistance of the films was measured and the influence of the vacuum annealing of TiN and WN films on the changes of their sheet resistance was determined. A hypothesis for a correlation between vacuum annealing, sheet resistance changes and mechanical characteristics changes was confirmed. A computerized module was developed for sheet resistance measurements of thin films, together with a method for express relative evaluation of the influence of vacuum annealing on sheet resistance of TiN and WN films on glass substrates.

PUBLICATIONS:

1. Slavova B, Petrov S, Uzunov Ts D,
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2. Uzunov Ts D, Dechev D, Martev I N, Ivanov N,
   Deposition and mechanical properties of titanium nitride (TiN) and tungsten nitride (W_2N) coatings,
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3. Dechev D, Uzunov Ts D, Milusheva P. Ivanov N P, Lutakova N K,
   Adhesion of metal coatings deposited by ion sputtering on polymers,
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4. Uzunov Ts D, Nikolov S,
   Physics teaching in engineering education,
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5. Krustev P, Uzunov Ts D, Ivanov N, Parashkevov D,
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   Proc FEP TU Anniversary Conf 2007;11/4:35-36.
6. Guerassimov N, Ghelev Ch, Martev I, Petrov P I (Eds),
   Abstract Book of the 15th International Summer School on Vacuum, Electron and Ion Technologies, 126 pages, 2007, Sozopol, Bulgaria.

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Characterization and properties of highly adhesive titanium nitride and tungsten nitride thin films,
15th Int Summer School on Vacuum, Electron and ion Technologies, 17-21 September 2007, Sozopol, Bulgaria.

ONGOING RESEARCH PROJECTS:

Financed by the National Science Fund

F–1514 Physical characteristics and mechanical properties of multilayer nanostructures of complex nitrides of transition metals
F-1208 Optical coatings on polymer optics

Financed by the Bulgarian Academy of Sciences

Interaction of neutrals and ions with solid surfaces

Financed by the Technical University, Sofia

N 952 NI-16/2006 Computerised module for sheet resistance measurements of thin films

LECTURE COURSES:

Assoc. Prof. I. N. Martev, Ph.D.:
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University of Chemical Technology and Metallurgy, Sofia.

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Materials Science: Laser, Electron and Ion Technologies; Physics of Metals; Ecology.
Faculty of Engineering and Education (Sliven) of the Technical University of Sofia.

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LABORATORY VISITS:

I. N. Martev, Ph.D., Department of Materials Science and Metallurgy, Cambridge University, Cambridge, UK.

SELECTED PROJECTS

- **Some Peculiarities of the Resist Profile Simulation in the Case of Positive Tone Chemically Amplified Resists at Electron Beam Lithography**
- **EC-Project EARLINET-ASOS**
- **Magnetic Nanocomposites for Microwave Applications**

SOME PECULIARITIES OF THE RESIST PROFILE SIMULATION IN THE CASE OF POSITIVE TONE CHEMICALLY AMPLIFIED RESISTS AT ELECTRON BEAM LITHOGRAPHY

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1. Introduction

Chemically amplified resists (CARs) have served as a workhorse resist platform for the semiconductor industry due to their sensitivity and high resolution. The requirement for high throughput of the lithography process in the micro-fabrication of patterns with characteristic size of ~100 nm has become critical due to the high costs associated with the equipment and the materials. The constant shortening of the time-to-market, and the difficulties in the experimental optimization of specific preparation procedures and regime judgment concerning lithography processing of the new generations of nano-electronic devices have led to the need of improving the existing computer simulation tools and of determining more precisely the simulation parameters used [1-4].

The energy deposited during electron beam (EB) exposure (step 1, Fig. 1) is used to initiate resist solubility modification when CARs and conventional resists are used in EB lithography. The main part of the absorbed energy is deposited in the chief component of CAR called base matrix polymer. In this case, upon exposure of the matrix polymer, the energy passes on to the molecules of a resist component known as photo-acid generator (PAG) via electron transfer or some other means [5]. Through this mechanism, or after direct energy absorption, the PAG molecules exit and

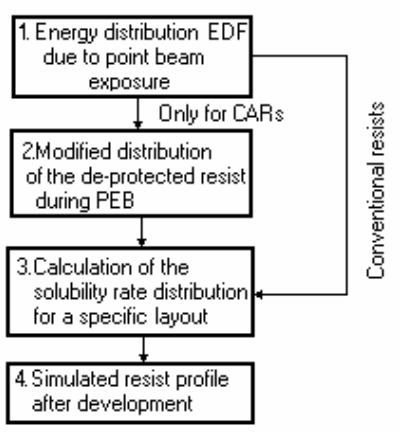

Fig. 1. Flowchart of the proposed simulation procedure for CARs and comparison with the simulation procedures of conventional (non-chemically amplified) resists.

decompose. As a result, catalyst molecules (acid) form within the resist film. The acid-loaded resist film is then baked for 0.3 - 20 min at elevated temperatures (80-150 ^{o}C) in a process known as post exposure bake (PEB). During PEB, the acid catalyzes the reaction of dissociation of the protection group (de-protection reaction), thus rendering the matrix polymer component of the positive tone resist soluble in a suitable developer.

The average distance between the energy dissipation region and the acid generation point is about 6 nm [1]. During PEB, the thermal diffusion changes the original acid distribution in such a way as to repeat the absorbed energy spread. Thus, a modified space distribution of the latent image is formed consisting of resist with altered solubility. The average diffusion length is 5 - 60 nm [6,7,8]. In

some CARs, resist thickness loss (10 - 20 %) during PEB is observed [9,10]. This is caused by the removal of the volatile de-protection-reaction products. Therefore, in the case of CARs, one should consider a modified latent image that represents the de-protected resist distribution (step 2, Fig. 1).

During development, a liquid developer is applied to the sample and the soluble areas of the positive tone resist film are selectively removed (step 3, Fig. 1). The result of the EB lithography is a developed relief profile in the resist, CAR or conventional one (step 4, Fig. 1). The amplification of the radiation-assisted chemical reaction in CARs is due to the fact that one acid molecule can catalyze many de-protection reactions leading to the solubility switch.

For computer simulation of the overall process that creates developed resist profiles, one needs adequate models of the complicated processing steps and numerical data for the description of the reaction kinetics. Various modeling approaches have been published to simulate profiles in chemically amplified resists. Some of them consist of models of coupling between diffusion and kinetic reactions; other models describe nonlinear or linear diffusion; there are also various development-rate models [11,12]. Surface changes (retardation or increase) of the development rate is evaluated by using the depth dependencies of the resist solubility rate during development [13,14]. The processes of resist de-protection and resist removal could show threshold or strongly nonlinear behavior. This is why the choice of a suitable overall lithography simulation model for the concrete resist-developer pair and alternating processing conditions is a difficult one. Due to many reasons, a final experimental calibration is needed of the model parameters set used in such a simulation [15-17]. Some of these reasons are the following: (i) the variations of the resist-developer pair utilized and the development conditions; (ii) the different values of PEB times and temperatures used; (iii) the different procedures of acquiring the experimental parameters; (iv) the dependence of the parameter values on geometrical factors; (v) the batch to batch variations in the characteristics of the resist material.

The project explores a possible verification procedure that minimizes the number of experiments for determining the quantities relevant to the simulation of the development kinetics of the resist profile at a concrete resist-developer system and selected processing parameters and conditions. Object of our attention are also specifics of the development process due to the complicated mechanism of resist removal from soluble areas of the resist layer.

2. Computer simulation and results for positive tone CARs

2.1. Exposure modeling

To simulate the exposure of polymer resist films – the first main step of a complete mathematical model for the electron beam lithography simulation - we used our Monte Carlo algorithm and computer programs [18-20]. The simuation is based on a single scattering model and a continuous slowing down approximation, assuming the screened Rutherford elastic scattering cross section and the Bethe energy loss equation. E-beam exposure was applied by a 30 keV pattern generator (modified ZBA 10/1 of Carl-Zeiss, Jena, Germany) onto CAMP6, a t-BOC protected polyhydroxysterenesulfone copolymer. The experimental development characteristics were obtained by using resist layers of 0.6 - 1.7 μm thickness covered by a 65-nm thick BC-5 protective coating. The film thicknesses were measured using either a Talystep or a Dektak stylus profilometer. The process sequences for the CAMP6 resist are shown in Table 1.

Table 1. CAMP6 - resist treatment sequence.

Operation	**Characteristics**
Wafer priming in air	HMDS / 60s
Resist spin coating and film thickness	650nm, 6000 rpm 1000nm, 2379 rpm
Pre-bake on hot plate in air	120°C, 60s
Protective layer spin coating(BC5)	65nm, 4000 rpm
Pre-bake on hot plate in air	120°C, 60 s
E-beam exposure	30 keV
PEB on hot plate in air, immediately after exposure	120°C±2°C, 60s±5%
Development (immersion)	ORD-262 Developer
Rinse	DI-water, 20s
Dry spinning in air	1000 rpm, 60s
Hard bake on hot plate in air	120°C, 60 s

The results of the first step of the computer simulation (step 1, Fig.1) are discrete data (a two-dimensional data array) for the radial energy deposition function (EDF) at various resist depths from the point of beam incidence. It is possible to use various cell dimensions at different radial distances: lower values near the point of beam incidence and higher values far away from this point. The present calculations were performed for a point electron beam (δ-function) with 10 000 electrons penetrating the resist (for each simulation) using our MC simulation tool. Fig. 2 compares the experimental and simulation results for the radial distribution of the energy absorbed in a 100-nm thick resist film.

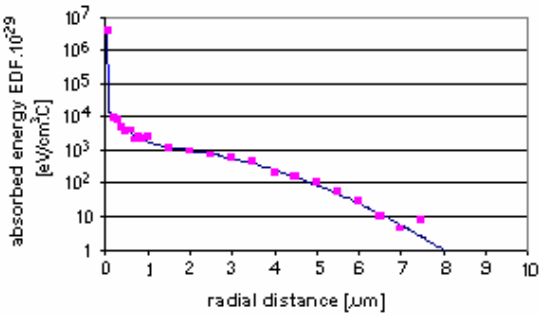

Fig. 2. Comparison between the energy deposition function (EDF) in the case of CAMP6 on Si at the interface resist/silicon and the corresponding analytical fit (Eqn.1). The electron beam is focused on a surface point. The initial electron energy is 30 keV and the resist thickness is 100 nm. The symbols (■) present the results of MC calculation, the line, $f(r)$.

The radial distributions of the energy absorbed in the resist, obtained numerically, describe quantitatively the proximity effect and could be approximated by a combination of double Gaussians and exponential functions:

$$f(r) = \frac{k}{\pi(1+\eta+\nu)}\left[\frac{1}{\alpha^2}\exp(-\frac{r^2}{\alpha^2}) + \frac{\eta}{\beta^2}\exp(-\frac{r^2}{\beta^2}) + \frac{\nu}{2\gamma^2}\exp(-\frac{r}{\gamma})\right] \quad (1)$$

called "proximity function" (r is the distance from the beam axis). The values of parameters α, β, γ, η, ν and k were calculated using an original Monte Carlo technique [21], instead of the commonly used non-linear least-squares method. In this way the problem concerning the insufficient statistics of the discrete data for the energy absorbed in the case of large lateral distances is overcome. This technique comprises a mean square deviation minimization by the interval length decrement for each of the parameters chosen. The minimization is performed in an iteration loop. One can see that the combination of a double Gaussian and exponential functions is a good approximation of the discrete data

(Fig. 2). Tables 2 and 3 present the calculated values of the proximity function parameters, k, η, ν, the standard deviations of the forward scattering (α) and the backscattering (β) contributions and of the exponential index γ. The results are obtained for 30 keV beam energy. Fig. 3 compares the radial distributions of the absorbed energy density, obtained by simulation, for a 1000-nm thick CAMP6 resist on a Si substrate at two resist depths - near the resist film surface and at the resist/Si substrate interface.

Table 2. Values of the f(r) parameters for CAMP6/Si (point source) on the resist surface; d is the resist film thickness

d [nm]	α [nm]	β [μm]	γ [μm]	η	ν	k
100	23.03	2.9464	0.2596	1.8220	0.3104	72172
200	25.79	3.2187	0.3639	1.6099	0.4016	54680
600	18.28	3.2018	0.3291	1.0058	0.3665	61759
1000	21.60	3.1439	0.1596	2.2421	0.3207	44630
1500	14.74	3.1692	0.2435	2.0625	0.3318	42246

Table 3. Values of the proximity function parameters (point source) for CAMP6/Si at the resist/substrate interface; d is the resist film thickness

d [nm]	α [nm]	β [μm]	γ [μm]	η	ν	k
100	23.03	2.9464	0.2596	1.8220	0.3104	72172
200	22.18	3.0941	0.3706	1.5000	0.3713	76629
600	31.84	2.8745	0.1557	2.2099	0.5491	89862
1000	47.25	3.2179	0.1543	1.4898	0.8878	117188
1500	47.59	3.1019	0.1570	0.9840	0.9680	190059

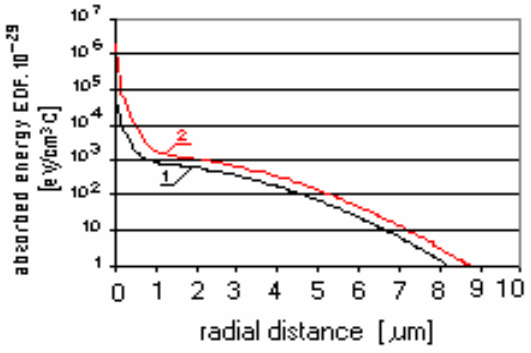

Fig. 3. Analytical fits of the EDF in CAMP6 on Si at two resist depths: 100 nm (curve 1) and 1000 nm (curve 2) for a zero-width δ-function electron beam. The resist thickness is 1000 nm and the beam energy, 30 keV.

The next step in the exposure simulation is describing the transfer of the absorbed energy distribution to a latent image. Many papers and patents deal with simulation of the latent image spreading during PEB [6,7,8,22,23]. The modification of the point-exposure f(r) is mainly due to diffusion of the exposure catalyst product (acid) during PEB. Assuming Fickean diffusion (constant diffusivity) the point-spread function (DPSF) in one-dimensional case is simply a Gaussian:

$$\mathrm{DPSF}(x) = \frac{1}{\sigma_D\sqrt{2\pi}}\exp\left(-\frac{(x-\bar{x})^2}{2\sigma_D^2}\right), \quad (2)$$

where σ_D is equal to the diffusion length.

The de-blocking reaction that controls the development process is accompanied by acid diffusion. For the simplified case of no acid loss, the integral over time of the exposure products (acid) will define the final latent image. In [24], a reaction-diffusion point spread function RDPSF is proposed to calculate the reaction kinetics of the PEB as if no diffusion had taken place. The RDPSF definition is:

$$\mathrm{RDPSF}(x) = \frac{1}{t_{PEB}} \int_0^{t_{PEB}} DPSF.dt = \frac{1}{t_{PEB}\sqrt{4\pi D}} \int_0^{t_{PEB}} \frac{\exp(-x^2/4Dt)}{\sqrt{t}} dt = \tag{3}$$

$$= 2\frac{\exp(-x^2/2\sigma_D^2)}{\sigma_D\sqrt{2\pi}} - \frac{|x|}{\sigma_D^2} erfc\left(\frac{|x|}{\sigma_D\sqrt{2}}\right).$$

Here the deviation σ_D is affected by the time of PEB and $\frac{\sigma^2{}_D}{2t}$ is the acid diffusivity in the resist. The first term on the right-hand side (Eq. 3) is twice the DPSF and accounts for the diffusion. The second term causes the RDPSF to fall off in x much faster than the DPSF. As an example, the full-width half maximum (FWHM) for the DPSF is about $2.35\sigma_D$, but for the RDPSF it is about σ_D. This means that the reaction-diffusion mechanism tolerates more diffusion than the case of pure diffusion mechanism.

To take into account the initial acid concentration, one can use the pre-diffusion absorbed energy deposition function due to beam exposure of a specific layout SEDF(r,t=0). For the calculation of SEDF(r,t=0) the proximity function f(r) is convoluted initially with the beam current distribution and then with the layout that is going to be simulated. This distribution is connected with the acid concentration distribution at the start of PEB. After convolution between the SEDF and the RDPSF, the distribution obtained can be assumed as being the spread distribution of the de-protected resist material. In this way, an overestimation is performed of the spread distribution due to neglecting the acid loss and the presence of a base quencher (which may also diffuse), as well as to threshold and nonlinear de-protection reaction. The advantage of the approximation assumed is that to simulate the latent image modification during PEB, one only needs to know the σ_D value at a concrete PEB temperature, which could be measured or evaluated [6,7,8,24-28]. Table 4 presents an example of the parameters that characterize the dispersion of the modified distributions of the de-protected resist volume (for 200 nm thick CAMP6 on Si) after PEB on a hot plate at 105 ^{o}C during 60 s estimated on the basis of acid diffusion.

Table 4. Dispersion parameters calculated on the example of the space distribution of de-protected resist at beam spot dispersion 10 nm and PEB heating 120 ^{o}C during 60 s in air.

d [nm]	α [nm]	β [μm]	γ [μm]	η	ν	k
200	65.764	3.257	0.370	0.0000221	0.0523	176849

2.2. Resist development modeling

The development kinetics is simulated using the assumption that the local solubility rate S is calculated by the dependence of the experimental data for the solubility rate at different depths on the various exposure doses D. The development rates of unexposed and exposed areas, with different doses D, can be measured by using development rate monitoring. A second simple approach for estimating the development rate is to use contrast curves $d(D)$ at different times of development. The curves $S(D)$ permit one to distinguish between linear and nonlinear behavior of the resist-developer pair [29]. In the linear case (namely, a development rate uniform in depth or time for a given D), one of the development rate equations could provide a good fit to the experimental profiles. In the case of linear behavior, the dependence of the solubility

rate S on the exposure dose D at the electron energy used and other bake and development conditions could be written as:

$$S(D) = S_0\left(1 + D\frac{E}{E_0}\right)^{\alpha}, \qquad (4)$$

where S_0, E_0 and α are experimental parameters that characterize the development rate of the unexposed resist area, the efficiency and critical energy threshold, as well as the developer strength. Using the algorithm of our computer simulation tool, extended for adequate simulation of non-chemically amplified conventional resists in the sub-250 nm EB lithography region [30-33,20], the development kinetics of resist profiles of the CAR used can be simulated taking into account its characteristics and making corresponding algorithm modifications.

The CAR - CAMP6 resist presented as

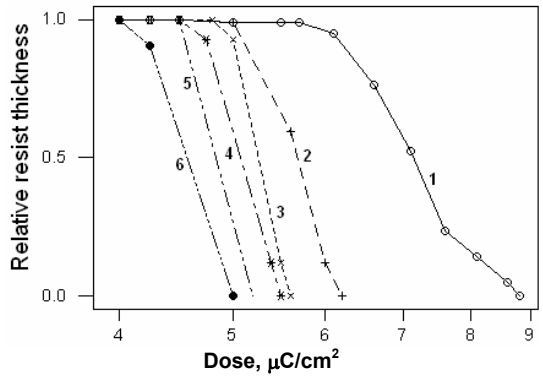

Fig. 4. Contrast curves for 1-μm thick CAMP6 CAR at various development times: 1 – 15 s; 2 – 30 s; 3 – 60 s; 4 – 120 s; 5 – 240 s; 6 – 360 s. Thickness loss due to the PEB is 23 % and d_o = 770 nm.

an example here has non-linear development behavior. It also exhibits a delay between the moment of immersion in the developer and the start of the resist development. Fig.4 presents experimental contrast curves of the CAR studied during development of a set of experimental areas exposed with doses that increased by a very small increment (25 nC/cm^2). The dependencies evaluated of the respective average solubility rates on the exposure dose at various moments of development

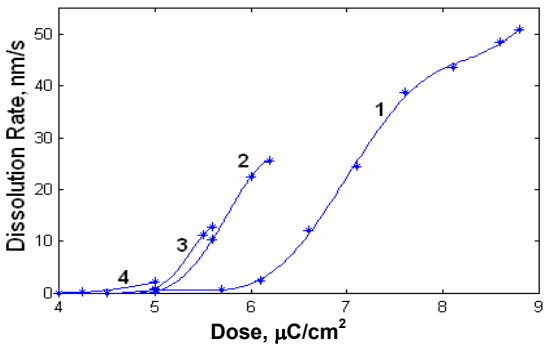

Fig. 5. Experimental characteristics of the solubility rate vs the dose of electron exposure at various times of development: 1 – 15 s; 2 – 30 s; 3 – 60 s; 4 – 360 s.

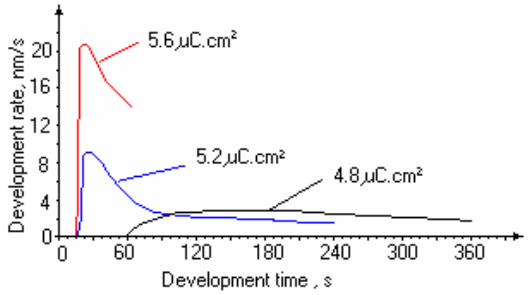

Fig. 6. Experimental dependencies of CAMP6 development rate on the time of development (respectively on the depth of the resist layer) for three exposure doses.

are shown in Fig. 5. One can see a slow development rate at low exposure doses and a sharp increase of resist removal at higher doses (and various development times). Fig.6 presents time dependencies of the solubility rate, which are also connected with changes of the development rate along the resist depth.

The simplified continuum and strong surface character of the resist dissolution removal during wet development have limitations at small critical dimensions and is discussed in connection with the line edge roughness [34,35]. Of basic importance here are such phenomena as: (i) concentration of the de-protected polymer molecules or fractions; (ii) penetration of the developer molecules in the resist; (iii) swelling of the polymer surface layer; (iv) ionization of monomer parts of the polymer chain with which the developer molecules are in contact; (v) critical ionization fraction threshold;

(vi) transport of polymer chains and fragments through percolation or an aggregate extraction.

The development model [30-33,19,20] is modified according to these specifics of the CAMP6 resist used. The physical resist surface and the processes occurring between the developer and the resist are approximated using image macro-modifications and the resist surface mathematical motion. The delay effect necessitates to divide resist volumes with various exposure doses where the delay time (and dissolution mechanism) is identical. Each evolving point from the developed contour advances along the normal to the profile with its local solubility rate using experimental data (Fig. 4, Fig. 6) instead of Eq. (4) (for the linear case). There is a procedure to increase the contour accuracy by increasing the number of the evolving points in the regions with a significant modified tilt in the pattern. A cubic spline in the 2D case and a bicubic spline in the 3D case are used to describe the developed profiles. The simulated developed profiles in the CAMP6 resist when ORD-262 developer is used (after 30 s, 45 s and 60 s development times) are presented in Fig.7. The high dissolution rates in the zones with higher exposure doses applied lead to the appearance of a central region of the exposed structure where quick removal of the resist takes place. The profile fragment generated has nearly vertical walls and bottom, which very quickly come to the interface resist/Si. This resist profile is then extended to the periphery of the structure by assuming the necessary delay time at the boundaries of the different zones. During development process, the line edge roughness is different at different moments.

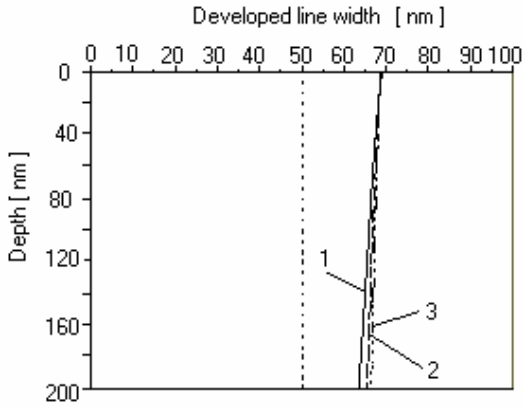

Fig. 7. Comparison of the simulated resist profiles at different times of development of an isolated 100 nm line created in 200 nm CAMP6 using ORD-262 developer (a half of the developed profiles are shown). The exposure dose is 5.6 μC/cm^2. The times of development are: 1 – 30 s; 2 – 45 s; 3 – 60 s. The dashed line represents a half of the exposed line.

3. Conclusions

There is still no consensus concerning simulation of electron-beam lithography when CARs are used due to the complicated processes of generation and spread of the latent image, the various mechanisms of resist solubility removal and the respective development models. We discussed an overall lithography simulation algorithm with an emphasis on the development phase. The simulation tools, described in the literature, are applicable only to linear solution process (solubility rate is uniform at various resist depths and developing times and is a function of the exposure dose only). We also present modeling of real resist profiles in the case of CAR with non-linear and exhibited delay effect. A Monte Carlo method is used to simulate the electron penetration in the target and to obtain radial absorbed energy distributions in the resist during exposure of structures consisting of CAMP6 resist layers with thickness 100, 200, 600, 1 000 and 1 500 nm on silicon at beam energy 30 keV. These distributions are approximated by a proper analytical function (combination of a double Gaussian and exponential functions), whose parameters are calculated by a Monte Carlo technique and are used in modeling the process of development of the resist.

Acknowledgements

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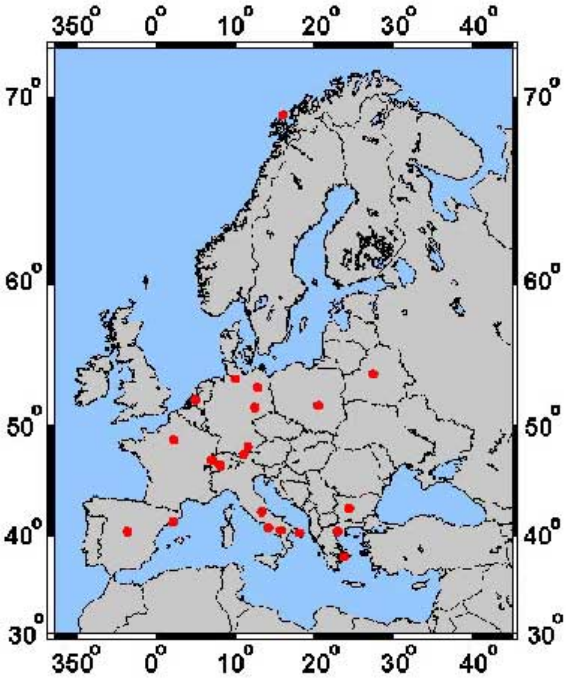
EC-Project EARLINET-ASOS

EARLINET-ASOS (European Aerosol Research Lidar Network - Advanced Sustainable Observation System) is an Integrated Activity implemented as Coordination Action within the EC Sixth Framework Programme.
EC FP6 Specific Programme: Structuring the European Research Area Specific Programme - Research Infrastructures Action.
Contract Number 025991.

EARLINET-ASOS is a 5-year project started on 1 March 2006.

Project summary

EARLINET-ASOS started on the basis of the European Aerosol Research Lidar Network (EARLINET) [1], and at present covers 20 lidar stations located across Europe. The main objective of the project is to improve the EARLINET infrastructure resulting in a better spatial and temporal coverage of the observations, continuous quality control of the complete observation system, and fast availability of standardized data products. EARLINET-ASOS is organized in six networking activities (NA).



Networking activities

● NA1. *Management*
Management comprises the areas of communication with the Commission for all contractual and administrational matters.
● NA2. *Exchange of expertise*
Exchange of expertise with the main goal of defining and disseminating best practice and knowledge.
● NA3. *Quality assurance*
Quality assurance program for both algorithms and instruments for assessing and assuring common high quality standards.
● NA4. *Optimization of instruments*
Optimization of instruments for achieving a better temporal coverage and standardization of performance.
● NA5. *Optimization of data processing*
Optimization of data processing with the aim of establishing an automatic processing from raw data to final products.
● NA6. *Database construction and operation*
Establishing a database provided with an user interface for dissemination of data.

Project objectives

The overall objectives are:

● To extend the development of the European Aerosol Research Lidar Network as a world-leading instrument for the observation of the 4-dimensional spatial-temporal distribution of aerosols on a continental scale, resulting in accurate, well-defined, and easily accessible data products for use in science and environmental services.

Project Partners

Principal Investigator	Participating Institution	Principal Investigator	Participating Institution
Gelsomina Pappalardo (Project Coordinator)	Consiglio Nazionale delle Ricerche - Istituto di Metodologie per l'Analisi Ambientale, Potenza, Italy	Jens Bösenberg (Project Deputy Coordinator)	Max-Planck-Gesellschaft zur Fürderung der Wissenschaften e.V. represented by Max-Planck-Institut für Meteorologie, Hamburg, Germany
Dimitris Balis	Aristotle University of Thessaloniki, Thessaloniki, Greece	Adolfo Comeron	Universitat Politecnica de Catalunya, Barcelona, Spain
Matthias Wiegner	Meteorologisches Institut der Ludwig-Maximilians-Universität, Munich, Germany	Albert Ansmann	Leibniz-Institut für Troposphärenforschung, Leipzig, Germany
Arnoud Apituley	National Institute for Public Health and the Environment, Bilthoven, The Netherlands	Christine Böckmann	Zentrum für Dynamik komplexer Systeme, Universität Potsdam, Potsdam, Germany
Anatoli Chaikovsky	Institute of Physics National Academy of Sciences, Minsk, Bjelarus	Georg Hansen	Norwegian Institute for Air Research, Tromsö, Norway
Valentin Mitev	Observatory of Neuchatel, Neuchatel, Switzerland	Alexandros Papayannis	Ethnikon Metsovion Polytechnion Athinon, Athens, Greece
Maria Rita Perrone	University of Lecce, Italy	Vincenzo Rizi	Universita degli Studi L´Aquila, Italy
Valentin Simeonov	Ecole Polytechnique Federale de Lausanne, Switzerland	Aleksander Pietruczuk	Institute of Geophysics, Polish Academy of Sciences, Belsk, Poland
Nicola Spinelli	Instituto Nazionale per la Fisica della Materia, Napoli, Italy	**Dimitar V. Stoyanov**	**Institute of Electronics, BAS, Sofia, Bulgaria**
Thomas Trickl	Forschungszentrum Karlsruhe, IMK-IFU, Garmisch-Partenkirchen, Germany	Francois Ravetta	Institute Pierre Simon Laplace, Paris, France
Manuel Pujadas	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas, Department of Environment Air Pollution Unit, Madrid, Spain		

● To enhance the operation of this instrument to foster aerosol-related process studies, validation of satellite sensors, model development and validation, assimilation of aerosol data into operational models, and to build a comprehensive climatology of the aerosol distribution.

● To play a leading role in the development of a global observation network for the aerosol vertical distribution as a major innovative element of Global Earth Observation System of Systems (GEOSS), by setting the standards for instruments, methodology, and organization in this specific area.

To facilitate the verification of achievements, more specific technical objectives are defined:

● Maintain quality assurance [2] for all 20 stations at the highest possible level. This includes spreading of good practices for system control and operation as well as end-to-end checks of performance.

● Establish common standards for advanced aerosol lidar instruments with improved temporal coverage, operation procedures, data processing, and retrieval of optical, microphysical, and other derived parameters.

● Extend an observation scheme of regularly scheduled measurements and additional measurements for special purposes towards better temporal coverage.

● Collect data, including auxiliary data, in a comprehensive data base and implement a user interface providing fast and easy access to well structured data for both internal and external users, e.g., atmospheric researchers, global and regional climate modelers, satellite community, and environmental agencies.

● Establish a platform for cooperation and coordination with the relevant observation and user communities, and serve as a nucleus for a world-wide aerosol lidar network.

The LIDAR systems of the Institute of Electronics – BAS

Three lidars of the Institute of Electronics of the Bulgarian Academy of Sciences are involved in the project EARLINET-ASOS. This equipment is operated by a team of 8 persons: D. Stoyanov, I. Grigorov, I. Kolev, G. Kolarov, Z. Peshev, A. Deleva, B. Kaprielov and N. Kolev, who also perform the data processing and analyses.

Some of the technical parameters of the lidars are shown in Table1.

Table 1. Technical parameters of the lidars.

	Lidar 1	Lidar 2	Lidar 3
Laser	CuBr	Nd:YAG	Nd:YAG
Wavelength [nm]	510.6	532, 1064	532
Pulse energy [mJ]	0.07	10	80
Pulse repetition rate [Hz]	13 000	12.5	2
Telescope [mm]	D = 200 F = 1000	D = 150 F = 2250	D=700 F=1960

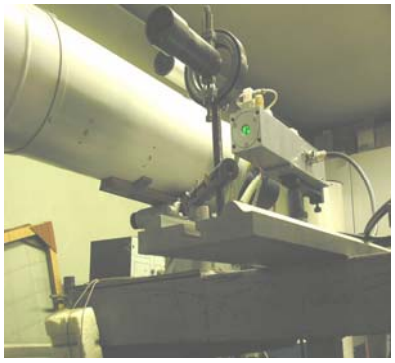
The first lidar system [3] (Lidar 1) uses a CuBr-vapor laser with pulse repetition rate of 13 kHz and average power of 1 W. This allows signal registration in photon-counting mode throughout the entire sounding range, from 900 m to about 10000-12000 m. The receiving electronics permits adjustment of the sampling step at 0.1 or 0.2 μs (spatial resolution of 15 or 30 m). The second lidar system [4] (Lidar 2) is equipped with a Nd-YAG laser and an analog-to-digital converter of the

lidar response. It performs measurements from 75 m to about 1800-2000 m with data sampling at a step of 7.5 m. The third lidar system [5] (Lidar 3) was developed recently, and, besides the Nd-YAG laser and the analog signal detection of Mie backscattering of atmospheric aerosol, an additional Raman channel is being implemented for independent aerosol extinction and backscatter coefficients measurements. Its range is expected to be 25-30 km with spatial resolution of 15 m.

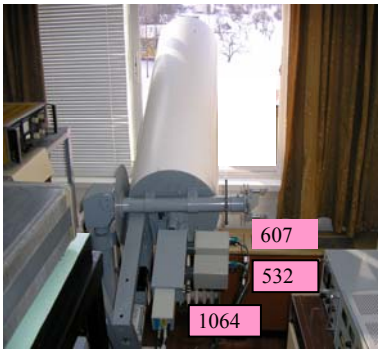
The three lidars are located on the same site, at a distance of 50 m from one another. Lidar 1 and Lidar 2 perform measurements of the atmospheric aerosol distribution in a vertical direction. The field-of-view of Lidar 3 is inclined and the slope of its axis can be adjusted from 0^o to 35^o with respect to the horizon.

The assessment of the accuracy of operation [6] of the three lidars was carried out by a comparison of the aerosol backscatter profiles calculated from the measurements data. The mean difference yielded a value of 1.38×10^{-7} (sr m)$^{-1}$, which was below the permissible limit 5×10^{-7} (sr m)$^{-1}$ [2]. The same applied to the standard deviation of the differences. The preliminary test to check the algorithm used by the lidar teams in Sofia to calculate the aerosol backscatter showed a relative error of 10.96 % at altitudes of approximately 3.5 km [7].

Lidar 1



Lidar 2



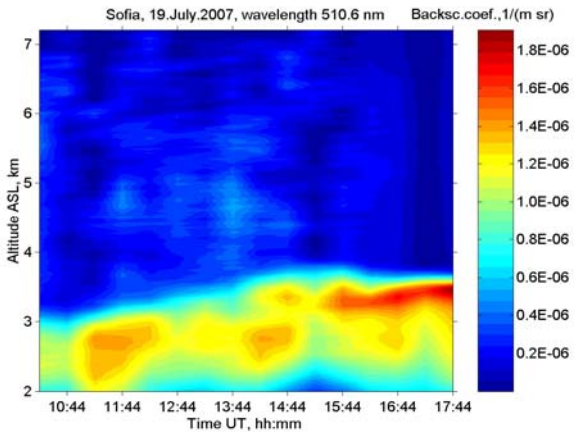
Lidar 3

Three types of lidar measurements are performed in Sofia lidar station:

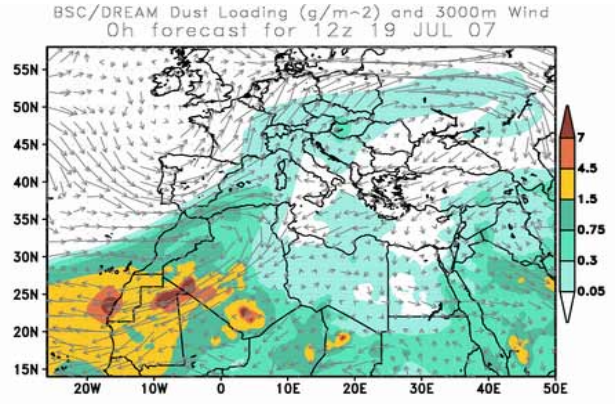
- Regular lidar measurements within the objective to establish a common database from measurements of profiles of the atmospheric aerosol backscatter coefficient. Measurements are conducted twice weekly, every Monday at noon when the sun is in zenith, and in the evening during sunset, and every Thursday at sunset.
- Observation of special phenomena, such as an unusually high concentration 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. In some cases such aerosol layers are detected at significant altitudes – 4-6 km above the ground surface.
- Measurements in the frame of cooperation with satellite missions within the objective of detailed comparison of ground-based and space-borne lidar data sets over Europe.

A large database was created of atmospheric aerosol backscattering coefficient profiles, regularly measured each Monday and Thursday by the three lidars in Sofia. Gaps in the measurement-schedule are due to cloudy or rainy weather, when risks of damaging the lidar optics existed. Failures in the lidar system have occasionally caused omissions in regular measurements. The tree lidars used the same algorithm for data processing, namely, Fernald inverse method [8]. This database is being continuously complemented with the newest lidar profiles of the measured atmospheric optical parameters.

Regular climatological measurement
Sofia_EARLINET station
19 July 2007, measurement start time 10:14 UTC, measurement stop time 18:14 UTC.
Measurement type - aerosol backscatter at 510.6 nm. Comments - dust layer at about 3200 m ASL.

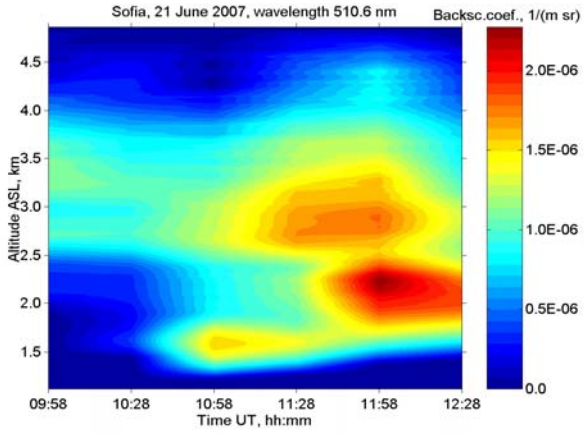


Lidar measurement on 19 July 2007.

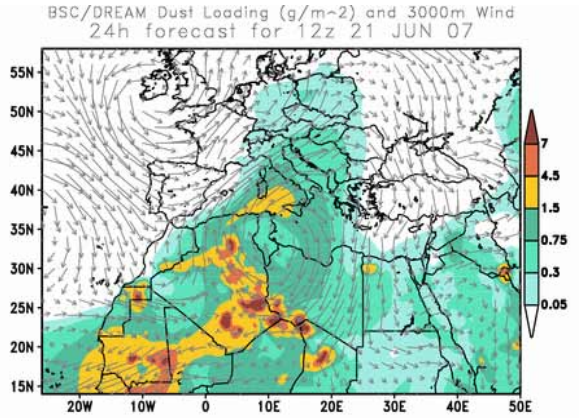


Map of Saharan dust load – DREAM forecast.

Measurement on alert Saharan dust over Europe
Sofia_EARLINET station
21 June 2007, measurement start time: 09:58 UTC, measurement stop time 12:58 UTC.
Measurement type - aerosol backscatter at 510.6 nm. Comments - dust layer above 2000 m ASL.



Lidar measurement on 21 June 2007.



Map of Saharan dust load – DREAM forecast.

EARLINET and CALIPSO project

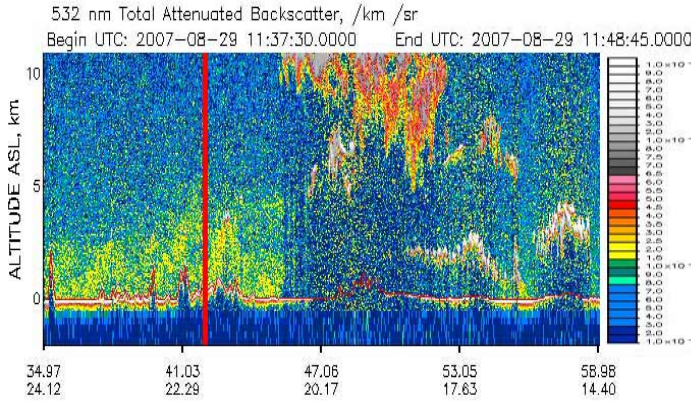
The EARLINET-Community participates in the *Quid pro Quo* (QPQ) validation measurements of the project Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO). This is a joint US (NASA) and French (Centre National d'Etudes Spatiales/CNES) satellite mission with an expected three-year lifetime. CALIPSO is a free-flying laser radar experiment (lidar) in space and provides crucial global data on atmospheric clouds and aerosols needed for climate studies. Ground located EARLINET stations were assessed to be an optimal tool to validate CALIPSO lidar data and to provide the necessary information to fully exploit the information from that mission. In particular, aerosol extinction measurements, provided by the network,

would be important for the aerosol retrievals from the CALIPSO backscatter lidar.

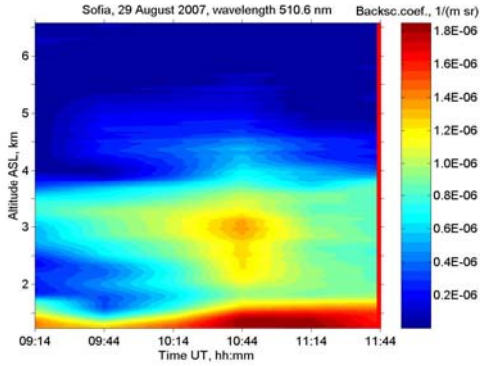
The group "Aerosol Lidar with CuBr-vapor laser" started correlative measurements for CALIPSO in June 2006. These measurements were performed so as to coincide with CALIPSO overpasses. Each observation lasted for a minimum of 1 hour centered on the overpass time above Sofia. Longer recordings were performed for special case studies (Saharan dust layers, forest fires, etc.). More than 200 profiles of the atmospheric backscatter coefficient, measured by the lidar group, have been transferred to the servers of the common database in Hamburg.

CALIPSO correlative measurement

Sofia_EARLINET station
29 August 2007, Case 2 measurement, distance 238.037 km (CALIPSO overpass Tessaloniki_EARLINET station).
Measurement type - aerosol backscatter at 510.6 nm.
Measurement start time 09:14 UTC, measurement stop time 12:14 UTC.
CALIPSO overpass time 11:45:40 - 11:46:00 UTC.
Comments - Saharan dust above 2000 m ASL.



Calipso lidar CALIOP measurement on 29 August 2007. The vertical red line marks the closest position to Sofia EARLINET lidar-station.



Lidar measurement on 29 August 2007. The vertical red line marks the CALIPSO overpass time.

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MAGNETIC NANOCOMPOSITES FOR MICROWAVE APPLICATIONS

T. Koutzarova

We present the main results obtained under the NATO Reintegration Grant Project (RIG 981472) "Nanocomposites - magnetic superconductors and ferroxides, for microwave applications".

1. Introduction

The polymer magnetic nanocomposites with ferromagnetic or superparamagnetic nano-particles in polymers, which were studied during the present project, are now being extensively investigated as promising materials for different applications (high-capacity magnetic storage media, microwave absorbing devices, possible elements of nano-scale integral circuits).

The physical properties of an inorganic nanostructure are fundamentally related to its chemical composition, size, crystal structure and morphology, which vary depending on the preparation route. One of the main tasks were related to studying the structural, magnetic and microwave properties of high-temperature magnetic superconductors based on $Y(Dy)Ba_2Cu_3O_7$, single-domain nano-sized magnetic oxides and their composites. We were particularly interested in the synthesis of nanoscale Fe_3O_4 as a model structure for spinel ferroxides and $BaFe_{12}O_{19}$ as a model structure for hexa-ferrites with high magneto-crystalline anisotropy (K_1).

2. Nanosized magnetic oxide powders

2.1 Experimental

Our attention was focused on studying the properties of two types of nano-sized magnetic oxide powders with spinel and hexagonal structures. During the investigations we developed a method based on the single microemulsion technique for preparation of homogeneous nano-sized magnetic oxide powders.

For synthesis of nanosized powders we used a water-in-oil reverse microemulsion system with cetyltrimethylammonium bromide (CTAB) as a cationic surfactant, n-butanol as a co-surfactant, n-hexanol as a continuous oil phase, and an aqueous phase. In contrast to the classical double microemulsion techniques, the single microemulsion technique makes use of a microemulsion system whose aqueous phase contains metal ions only. In our experiments, we initiated the precipitation by adding an aqueous solution of ammonia, NaOH or TMAH. In the case of synthesis of hexaferrite powders, the hydroxide precursors were calcined at 900°C. During our research we investigated the properties of magnetic oxides powders obtained by other methods, as co-precipitation and double microemulsion.

2.2 Nanosized magnetite powders

Our research on Fe_3O_4 demonstrated that the particle size decreases with decreasing the concentration of ferric and ferrous ions in the aqueous phase. We did not observe a significant difference in the particles size obtained by double and single microemulsions. In the case of single microemulsion, the amount of surfactant affects substantially the size of the particles obtained when the ferric and ferrous ions concentration in the aqueous phase is high.

Furthermore, the Fe_3O_4 powders produced had a strongly defective structure. This leads to changes in the magnetic properties of the powders (Fig. 1a). The studies performed of the magnetic characteristics of the powders produced revealed a decrease in the value of the saturation magnetization M_s compared with the available data for powders composed of micron-size particles. For example, the M_s value for particles with

average size 30 nm is 78 emu/g at 55 kOe. Another particularity in the magnetic behavior of nano-sized magnetite powder is the fact that its magnetization does not reach saturation even in magnetic fields as high as 55 kOe (Fig. 1b) - very high magnetic fields for this type of material.

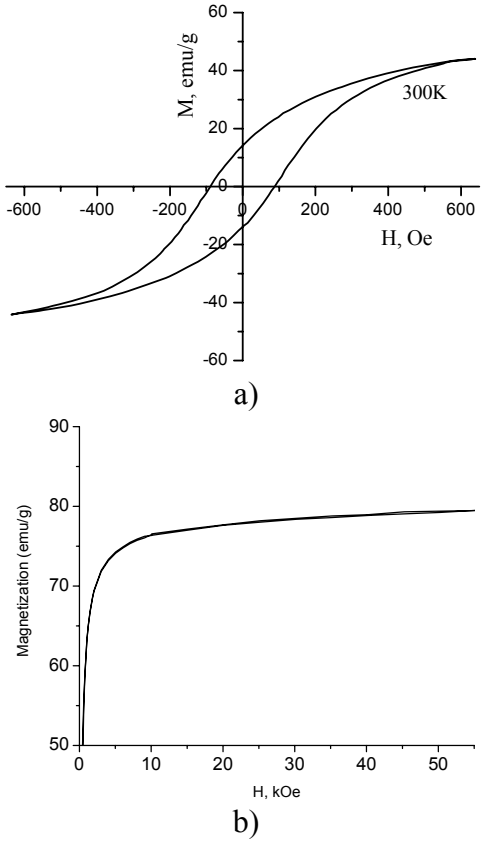

Fig. 1. Magnetization curves of nanosized magnetite at room temperature.

2.3 Nanosized hexaferrite powders

In what concerns the hexaferrites, our attention was focused on the synthesis and properties of nanosized $BaFe_{12}O_{19}$ and Al-substituted barium hexaferrite ($BaFe_{12-x}Al_xO_{19}$, where $x = 0.1 \div 2.2$). Al-substitution in $BaFe_{12}O_{19}$ results in a decrease in the value of K_1 and, hence, in a change in the material's magnetic characteristics.

Barium hexaferrite powders

The synthesis techniques developed allowed us to produce $BaFe_{12}O_{19}$ powders with homogeneous in terms of size and shape particles in the range 80 - 280 nm depending on the method of precursor preparation and the type of co-precipitating agent. For example, using co-precipitation we obtained particles of nearly plate-like shape and average particle size 180 nm; the particles in the barium hexaferrite sample obtained by double microemulsion had uniform hexagonal plate-like shape with average particle size of 280 nm when the precipitating agent was NaOH; in the case of single microemulsion the particles had irregular shape between spherical and hexagonal plate and average size of 130 nm. The smallest particles (80 nm) were obtained when the precipitating agent was TMAH.

The magnetic properties of these powders depend on the samples homogeneity, both with respect to the size and the shape. For a sample with particles size about 80 nm we did not observe saturation for fields applied up to 30 T (Fig. 2). We relate the magnetization curve behavior at fields exceeding 12 T to the relative increase of the surface as the particle size is decreased and, respectively, to the increased role of the disordered magnetic structure of the surface layer.

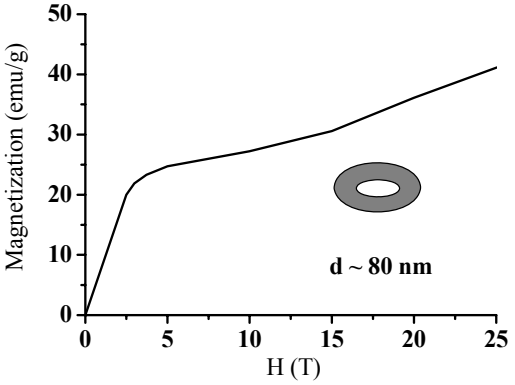

Fig. 2. Magnetization dependence on the magnetic field (H) measured at 4.5 K for a sample with particles size 80 nm.

The magnetic studies data illustrated in Fig. 3 demonstrate that the sample with average particles size 130 nm exhibits the highest saturation magnetization value, namely, 62.09 emu/g, and coercivity field H_c of 3.9×10^5 A/m at room temperature.

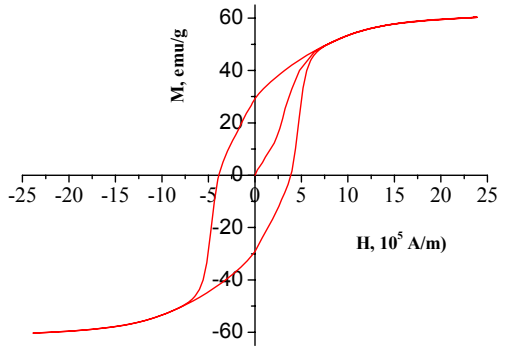

Fig. 3. Magnetization dependence on the magnetic field (H) measured at 300 K for a sample with particles size 130 nm.

Al-substituted barium hexaferrite powders

We present here the results of the studies on the composition $BaAl_2Fe_{10}O_{19}$. The particles in the sample synthesized by single microemulsion had size below 100 nm and needle-like shape.

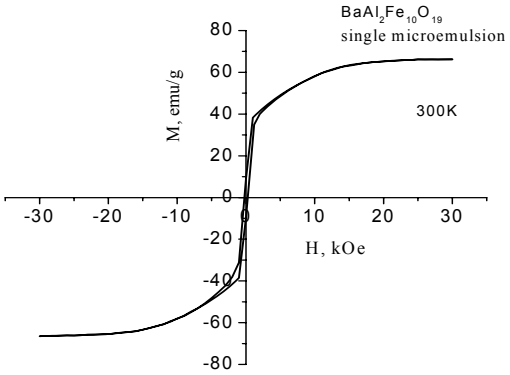

Figure 4. Hysteresis curves of monodomain $BaAl_2Fe_{10}O_{19}$.

The values measured of the saturation magnetization M_s were very high - 66.12 emu/g, in comparison with those obtained by other methods e.g., the M_s value of $BaAl_2Fe_{10}O_{19}$ synthesized by us using co-precipitation was 53.69 emu/g. As is seen in Fig. 4, the hysteresis loop is very narrow. The small coercivity field H_c value (1.3×10^4 A/m) has to do with the small particles size and indicates that the particles are close to a superparamagnetic state.

5. Applied studies of magnetic nanocomposites in the microwave range

We studied two types of nanocomposites. The first one consisted of Fe_3O_4 powder with particle size of 30 nm dispersed homogeneously in a polymer matrix of silicone rubber. The second one consisted of silicone rubber with homogeneously dispersed Fe_3O_4 powder with particles size 30 nm and $SrFe_{12}O_{19}$ powder with particles size 6 μm.

One of the main research tasks of the project reported was related to determine the role of the Fe_3O_4 content on the nanocomposite's microwave properties. Figure 5 presents the reflection losses (R_L) frequency dependence of nanocomposite absorbers with different weight % filling of the matrix for samples with identical thickness (4 mm) and for polymer without filler (P). The weight % was increased by an identical step from sample 1 to sample 4.

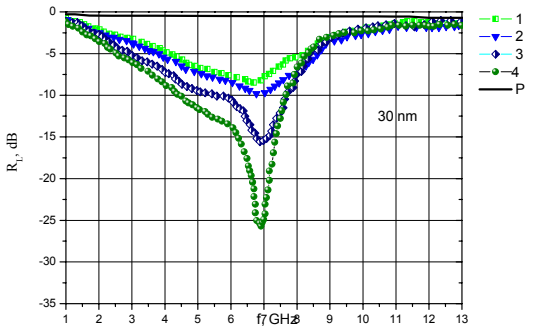

Figure 5. Frequency dependence of R_L of nanocomposite absorbers with different filler density.

As can be seen, the absorption peak is observed in a range that narrows as the filler density is increased but at the same peak frequency of 6.7 GHz, regardless of the filler concentration; at the maximum filling the composite behaves as a reflecting material and also opens up a possibility to implement a narrow-band absorber. In order to estimate the role of the magnetic and dielectric losses, we determined ε_r^* and μ_r^* of the samples studied. We observed a shift of the magnetic losses to higher frequencies in

comparison with the bulk material. This should be related to changes in the anisotropy constant and the saturation magnetization.

Bearing in mind the results of the studies cited above, we chose to focus our attention on investigating the influence of adding micron-sized ($SrFe_{12}O_{19}$ with high magnetocrystalline anisotropy) powder to a nanocomposite sample containing nanosized magnetite (with low magnetocrystalline anisotropy) filler. We investigated the influence of the filler concentration and the filler ratio (Fe_3O_4 / $SrFe_{12}O_{19}$) in the polymer matrix on the microwave nonlinearity within a large frequency range (1 ÷ 18 GHz). The results obtained showed that the highly anisotropic particles become centers of clusterification and the small magnetite particles form magnetic balls with different diameter depending on the concentration (Fig. 6).

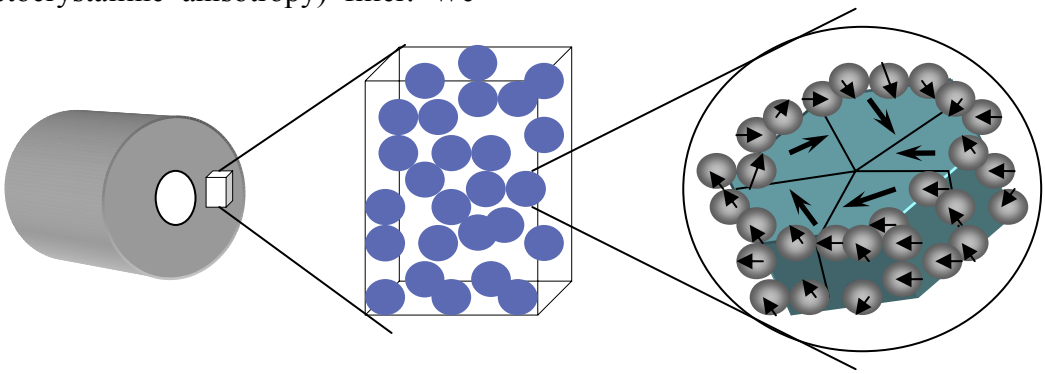

Figure 6. Schematic representation of a nanocomposite structure.

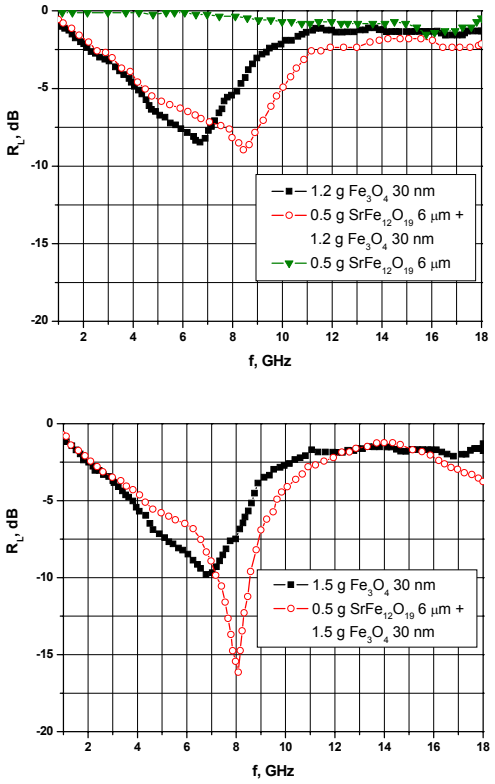

Figure 7. Reflection losses (R_L) frequency dependence of a nanocomposite absorber.

The reflection losses (R_L) of the nanocomposite samples with different filling, different fillers and equal thickness as a function of the frequency are given in Fig. 7. As one can see, a composite containing strontium hexaferrite only as a magnetic filler (sample 1) exhibits no reflection losses in the frequency interval studied (1 ÷ 18 GHz). The curves of composite samples containing a two-component filler (nanosized magnetite and micron-sized strontium hexaferrite) exhibit a matching frequency shift (to approximately 8.1 GHz) as compared with the nanocomposite containing nanosized magnetite only, i.e. a FMR frequency shift to the shorter wavelengths part of the spectrum. In the case of a two-component filler, as in the case of a nanosized filler, the matching frequency does not change as the filling density is increased, which proves that the losses are due to the FMR, rather than to geometric effects related to the sample size.

4. Conclusion

The scientific results obtained during the project implementation can be summarized as follows:

1. A method was developed for preparation of magnetic nanosized oxides based on the single microemulsion technique. This method is an effective way of synthesizing nanoparticles with a narrow size distribution.
2. A strongly defective structure of the nano-sized Fe_3O_4 was observed, which resulted in changes in the powders' magnetic properties. No saturation was achieved at high magnetic fields for this type of powders, which is typical for magnetic materials with low magnetocrystalline anisotropy and micron-sized particles.
3. The synthesis techniques developed allowed us to produce $BaFe_{12}O_{19}$ powders with homogeneous in terms of size and shape particles in the range 80 - 280 nm. The particles with sizes below 180 nm did not reach saturation in fields up to 25 T. We refer this behavior to the contribution of the surface magnetic anisotropy arising from the interaction between the disordered surface layer and the ordered internal magnetic structure of the particle.
4. Al-substituted $BaFe_{12}O_{19}$ powders were also prepared composed of particles near the superparamagnetic state, with a very high value of the saturation magnetization (66.12 emu/g) and with a very low coercivity field H_c (1.3×10^4 A/m).
5. The microwave characteristics were investigated of absorbing nanostructures containing nano-sized monodomain Fe_3O_4 as well as the role of mixtures of nanosized monodomain Fe_3O_4 and micron-sized multi-domain $SrFe_{12}O_{19}$ fillers in the formation of these properties. The resonance magnetic losses in a ferrocomposite with nanosized filler are shifted to the higher frequencies in comparison with a conventional ferrocomposite with micron-sized Fe_3O_4 filler. This change can be related to the K_{eff} of the nanosized particle.
6. The effect of adding micron-sized $SrFe_{12}O_{19}$ to the nano-sized Fe_3O_4 filler in composite absorbing structures consists in shifting the FMR to the higher frequencies and, in the case of a particular combination of the two fillers, in a substantial increase of the absorption. The two-component filler exhibits saturation magnetization and anisotropy constant values differing from those of either $SrFe_{12}O_{19}$ or Fe_3O_4, which results in an increase of the effective anisotropy field. The results demonstrate the possibility to vary the nanocomposite's absorption characteristics in a controlled way by introducing a second magnetic material.

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   Phys Stat Sol C 2006;3:1302-07.
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   Iron oxides nanoparticles produced by

microemulsion techniques,
Proc 7th Workshop on Nanostructured Mater Appl & Innov Transfer, Eds Balabanova E, Dragieva I, (Heron Press Ltd, Sofia, Bulgaria) 2006 pp 42-5.

4. Koutzarova T, Nedkov I, Grigorov K, Kolev S, Vandenberghe R E, Mathieu J-Ph, Ausloos M, Ghelev Ch, Palewski T, Gajda D,
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5. Koutzarova T, Kolev S, Yanev A, Ghelev Ch, Nedkov I,
Microwave properties of polymer composites containing combinations of micro- and nano-sized magnetic fillers,
J Nanosciences and Nanotechnology 2008;8:650-4.
6. Koutzarova T, Kolev S, Ghelev Ch, Grigorov K, Nedkov I,
Structural and magnetic properties and preparation techniques of nanosized M-type hexaferrite powders,
Advances in Nanoscale Magnetism, Eds Aktas B, Mikailov F (Springer-Verlag Publ, Berlin) 2008 accepted for publication.
7. Koutzarova T, Kolev S, Grigorov K, Ghelev Ch, Nedkov I, Ausloos M, Cloots R, Midlarz T, Zaleski A,
Nanosized Barium hexaferrite powders obtained by a single microemulsion technique,
Solid State Phenomena, accepted for publication.

SCIENTIFIC EVENTS

- **Fifteenth International Summer School on Vacuum, Electron and Ion Technologies**
- **Activities of SPIE - Bulgaria Chapter**

Fifteenth International Summer School on Vacuum, Electron and Ion Technologies (VEIT 2007)

The International Summer School on Vacuum, Electron and Ion Technologies (VEIT) has been organized biennially since 1977. It is a forum for the interchange and dissemination of knowledge and ideas on the latest developments in electron-, ion-, and plasma-assisted technologies. The organizers of the event (since 2001) have been the Institute of Electronics, Bulgarian Academy of Sciences, Sofia, Bulgaria, the Institute of Ion Beam Physics and Materials Research, Forschungszentrum Dresden-Rossendorf, Dresden, Germany, and the Evrika Foundation, Sofia, Bulgaria.

The fifteenth meeting of VEIT was held in the Black Sea resort of Sozopol, Bulgaria from 17–21 September 2007 and was attended by around 120 participants from 17 countries: Australia, Belgium, Bulgaria, Canada, Czech Republic, Germany, Hungary, Italy, The Netherlands, Poland, Pakistan, Romania, Sweden, Switzerland, Ukraine, UK and USA.

Following the tradition of publishing the VEIT Proceedings, a selection of papers presented at the event is published in *Journal of Physics: Conference Series* (vol. 113, 2008), all peer reviewed to meet the originality and quality criteria of the journal. The school consisted of 11 oral and 3 poster sessions. There were 17 invited talks of general interest and 12 progress reports were presented orally. In total 86 contributed papers were presented during the three poster sessions. There were several scientific highlights covering the fundamentals of gas discharges and interaction of fast particles with solids, a wide range of conventional and novel applications such as for hard coatings and optical/protective layers, nanosized structures produced by evaporation, sputtering or external irradiation. Recent achievements in the modification of materials using charged particles or laser beams, thin layers deposition, properties, and characterization and novel materials, techniques, devices were highlighted.

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 reception, a conference banquet, and an outing to historical landmarks in the vicinity of Sozopol.

VEIT 2007 owes its success to many people. The International Advisory Committee shaped the scientific program and ensured high-quality plenary presentations by careful selection of invited speakers. The Local Committee, consisting mainly of staff and students from the Institute of Electronics, bore the brunt of the organization both at the conference site and in dealing with correspondence, abstracts, and manuscripts of the Proceedings VEIT 2007. We are grateful to our sponsors Forschungszentrum Dresden-Rossendorf, Dresden, Germany, Bulgarian Academy of Sciences, Sofia, Bulgaria, Hauser Techno Coating Ltd, Venlo, The Netherlands, and Evrika Foundation, Sofia, Bulgaria for their generosity that enabled us to support the attendance of students and provided support to deal with mailing, printing, renting the conference site, etc. We would like to also thank all authors for their valuable contributions to the Proceedings VEIT 2007 and to the school, as well as all reviewers for their important work.

The next conference in the series will be held in September 2009.

Activities of SPIE - Bulgaria Chapter

SPIE Bulgaria Chapter is a nonprofit society dedicated to advancing scientific and engineering applications of optical, photonic, imaging, electronic, and optoelectronic applied science and engineering. Its members are scientists, researchers, engineers, students, and users interested in the development and reduction to practice of these technologies. The chapter provides the means for communicating new developments and applications information to the scientific, engineering, and user communities through SPIE publications, international conferences and workshops in Bulgaria. The journals Optical Engineering, Journal of Biomedical Optics, Journal of Microlithography, Microfabrication, and Microsystems, and Journal of Electronic Imaging, kindly provided by SPIE, are donated to the Library of Physics of the Bulgarian Academy of Sciences and the Library of the Faculty of Physics of "St. Kliment Ohridski"Sofia University in order to reach the largest possible audience of scientists.

In August 2007 SPIE announced some necessary changes to its Regional Chapter program, determined by the need for an improved arrangement to identify opportunities, build relationships, and engage people from key organizations throughout the world. The Regional Chapter model was replaced in January 2008 with a new SPIE Global Outreach Program. The expanded program provides opportunities for local professional communities to interact directly with SPIE as a more effective means of supporting global outreach. This new program will allow SPIE Members working with qualifying organizations such as universities, optics centers, science centers, youth clubs, regional optics groups and national societies to apply directly to the Society to sponsor education and outreach projects through competitive grants and funding.

The changes to the SPIE program were discussed between the Executive Director of SPIE Dr. Eugene Arthurs and Dr. Tanja Dreischuh during their meeting in September 2007. Dr. Arthurs expressed SPIE's appreciation for the opportunity to cooperate with the Bulgaria optics community in developing optics programs, publications and events over the last 13 years. The SPIE Board of Directors looks forward to future opportunities to work together and hopes that Bulgarian scientists will continue to invite SPIE to participate in regional activities and events as a formal sponsor. Considering the economic situation in Bulgaria, SPIE offered the reduced special consideration rates for Members from Bulgaria, including full Society privileges. Moreover, all the members of SPIE – Bulgaria Chapter received a one year Complimentary Membership for 2008 without any charge. Dr. Dreischuh expressed the deep gratitude of the members of the Bulgaria Chapter to SPIE for the valuable support in our common activities for providing information and organizing events to help the development of optical science and engineering in Bulgaria. The main topic of the meeting was to discuss in more detail how we could receive support from SPIE for photonics-related education and projects through its Outreach Program. Special attention was paid to the next 15th International School on Quantum Electronics, which will take place in the Black Sea resort Bourgas from 15 to 19 September 2008. The main purpose of the School is to provide opportunities for exchange of ideas and discussion of results among well-known scientists and young researchers, working in the field of lasers and their applications in material processing, non-linear optics, spectroscopy, remote sensing and medicine. Leading scientists from Europe, America and Japan are invited to deliver lectures on "hot" topics in the fundamentals of laser physics as well as on applications of lasers, giving both the background and the latest developments of a particular problem. As a result from the discussion and the following correspondence an agreement was signed for the publication of the School Proceedings as a part of Proceedings of SPIE. SPIE Europe will also serve as a cooperating organization for ISQE'2008 and will help to promote and support the goals of the School.

HONORARY AWARDS

- **Prof. Dr. Minoro Obara**
- **Prof. Dr. Alexandros Serafetinides**
- **Prof. Dr.Sc. Peter Atanasov,**
  Assoc. Prof. Dr. Nikolay Nedialkov

At a special ceremony held in the Embassy of Republic of Bulgaria in Japan, Academician Blagovest Sendov, Bulgarian Ambassador to Japan, conferred the Decoration of Honor for special Merits to the Bulgarian Academy of Sciences in the field of photonics and optoelectronics to Professor Dr. Minoro Obara, Keio University, Japan.

Prof. Obara was born in 1947 in Tokyo. He obtained the BS, MS and PhD degrees from Keio University, Yokohama, Japan. In 1993 he was elected professor in the Faculty of Electronics and Electrical Engineering, Keio University. He was Dean of the same faculty in the period 2000-2003. In 2004 he was appointed Director of the High School on Engineering Integral Design. He was a guest scientist in the Los Alamos Federal Laboratory, USA, and in RIKEN (Institute on Chemical and Physical Investigations), Tokyo. He was awarded the prize for the best scientific publications in 1982, 1992, and 2001 by the Laser Society of Japan. He was elected Fellow of IEEE (1999) and OSA (1996), USA.

Prof. Obara has published over 300 scientific publications in international journals. He is author and co-author of the books “Optics and Quantum Electronics” (Corona, Japan, 1991), “Laser Applied Engineering” (Corona, 1998), “Laser Applied Optical Engineering” (Kyoritsu, Japan, 1998), “Excimer Lasers” in Encyclopedia of Physical Sciences and Technologies (Academic Press, USA, 2002), and “Laser Ablation and its Applications” (Springer, 2006). He is an editor of IEEE J. of Quant. Electronics, IEEE Selected Topics in Quant. Electron. (1995, 2000, and 2003), “Handbook of Laser Appl.” (IOP, UK, 2003), and in IEEE JSTQE (2004). He is a member of the Organizing and Program Committee of the International Conferences CLEO, LEOS и SPIE. He is President of the Tokyo Section of the Laser Society of Japan and of the Technical Committee of IEEE Lasers and Electro-Optics Society. His scientific and application contributions are in the field of femtosecond laser technologies, nanostructuring and nanotechnologies, optoelectronics, development of optical nets, and memory with large capacity.

Prof. Obara has significant contributions to the implementation of advanced scientific research in cooperation with scientists of the Institute of Electronics in the field of femtosecond laser technologies, nanostructuring and nanotechnologies, and optoelectronics. He and his PhD students are co-authors of over 20 scientific joint publications with scientists of the Institute of Electronics. He delivered invited lectures at the 12^{th} and 13^{th} International Schools on Quantum Electronics held in Bulgaria. He was instrumental in ensuring the funds necessary for visits by scientists of the Institute of Electronics with the purpose of carrying out joint research.

At a special ceremony held in the Central Administration Building of the Bulgarian Academy of Sciences, Academician Nikola Sabotinov, President of the Bulgarian Academy of Sciences, conferred the Decoration of Honor for special Merits to the Bulgarian Academy of Sciences in the field of photonics and optoelectronics to Professor Dr. Alexandros Serafetinides of the Faculty of Physics, School on Applied Mathematics and Physical Sciences of the National Technical University of Athens, Greece.

Prof. Serafetinides graduated from the National Technical University of Athens, Greece. He defended his PhD thesis in Essex University, United Kingdom. He is an international expert in the field of laser physics, laser technologies and biomedical laser applications. He has published over 150 scientific publications in reputable international scientific journals has delivered over 100 invited lectures and reports at international forums. Prof. Serafetinides was a member of the scientific teams which proposed, implemented and studied the photon-drag detector and the laser telemeter, as well as resistive and inductive preionization techniques in gas and chemical lasers; he was active in theoretical studies of pulsed lasers and of interaction of laser radiation of various wavelengths with biological tissues. His publications in the field of gas and chemical lasers with semiconducting preionization are the most quoted in the scientific literature in the respective field. In the past several years his research interests have been focused on biomedical photonics and protection of the environment.

Prof. Serafetinides is the founder and leader of the Lasers and Applications Laboratory at NTUA where he has trained a large number of undergraduate and graduate students. His monographs “Lasers” and “Optoelectronics” are widely read by students at various universities in Greece. He has designed and implemented more than 260 Nd:YAG laser telemeters and six CO_2 laser systems under projects financed by various organizations in Greece.

For more than 20 years now Prof. Serafetinides has carried out fruitful scientific cooperation with the Institute of Electronics and other research institutions of the Bulgarian Academy of Sciences. As a result, more than 25 common papers were published and two PhD students, one Bulgarian and one Greek, successfully defended their theses. The joint Greek-Bulgarian team studied thoroughly the sliding discharge and applied it for the first time for pumping of different gas and chemical lasers operating in the UV, VIS, and IR ranges of the optical spectrum.

Being an excellent lecturer, Prof. Serafetinides participated actively in the work of the International School on Quantum Electronics. He was a member of the International Program Committee in the past three editions of the School. When attending the School, he was always accompanied by several students and co-workers. He also ensured direct financial support to the past several editions of the School.

INSTITUTE OF ELECTRONICS BULGARIAN ACADEMY OF SCIENCES

LAUREATES ACADEMICIAN DJAKOV AWARD 2007

The Scientific Council of the Institute of Electronics awarded the 2007 Academician Emil Djakov annual award for research in the fields of physical electronics, quantum electronics and radio science to

Prof. Dr.Sc. Peter Atanasov
Assoc. Prof. Dr. Nikolay Nedialkov

For the results of the studies on

Generation and evolution of metal nanoparticles during utrashort laser ablation and plasmon excitation of gold nanoparticles,

Published in

Amoruso S, Bruzzese R, Wang X, Nedialkov N N, Atanasov P A,
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Appl Surf Sci 2007;254:794-8.

GENERATION AND EVOLUTION OF METAL NANOPARTICLES DURING UTRASHORT LASER ABLATION AND PLASMON EXCITATION OF GOLD NANOPARTICLES

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Application area: *photonics, surface science, nanostructuring, optical memory, biophotonics*

The ultrashort laser ablation of solid materials is the basis of different modern and advanced scientific and technological areas as fabrication of metal and semiconductor nanoparticles, deposition of nanostructures and their embedding in optical films, or deposition on their surfaces in order to alter existing properties or obtaining new. A growing scientific interest has been recently focused on some specific properties of noble metal nanoparticles. The efficient excitation of plasmons in these structures significantly influences the interaction of the electromagnetic filed with the nanoparticle and contributes to the appearance of new effects that are not observed in bulk materials.

The main results obtained on the topic are the following:

Generation and evolution of nanoparticles during ultrashort laser ablation of metals in vacuum

Novel experimental and theoretical results are obtained assisting in the clarification and explanation of the mechanisms of generation and initial evolution of nanoparticles produced during ultrashort laser ablation of metals (Al, Ni). A numerical model is developed based on molecular dynamics (MD) describing the interaction of the laser pulse with the metal target. The experimental analyses realized on the basis of emission spectroscopy show that the ablated material is composed of single atoms and nanoparticles (Fig. 1). The nanoparticles are formed during the stage of material decomposition (Fig. 2) as a consequence of phase explosion and/or fragmentation of the overheated material. The realization of these mechanisms can explain the experimentally observed dependences of the velocity distribution of the ablated atoms and nanoparticles (Fig. 3), and the sizes and size distribution of the nanoparticles generated by laser ablation at wavelengths in the UV and visible spectral ranges. The results indicate that the laser wavelength can be used as a parameter for efficient nanoparticles size control.

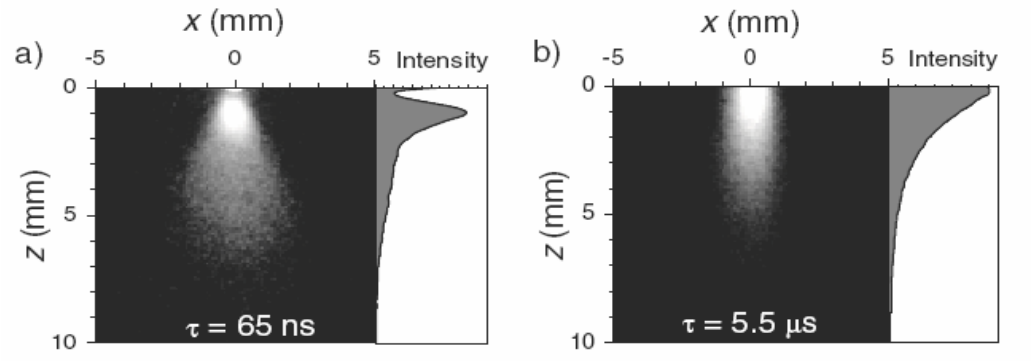

Fig. 1. Snapshots of ablated plume at laser ablation of Ni obtained by emission spectroscopy at two time delays after the laser pulse. (a) short time delay – emission from single atoms; (b) long time delay – emissions from nanoparticles. F ≈ 0.8 J/cm^2. z = 0 mm corresponds to the target surface.

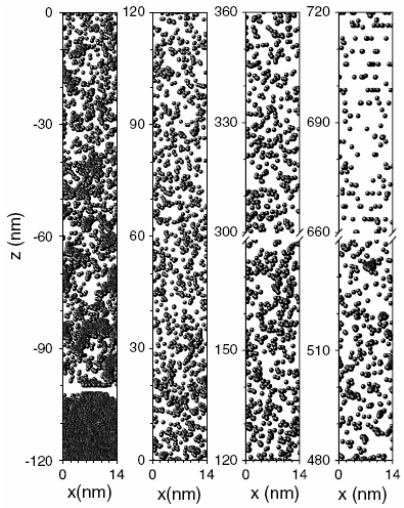

Fig. 2. Snapshot of the simulation system in different areas obtained by MD simulation 150 ps after the laser pulse off set. F = 0.7 J/cm^2; λ = 527 nm; τp = 300 fs. z = 0 is the initial position of the material surface.

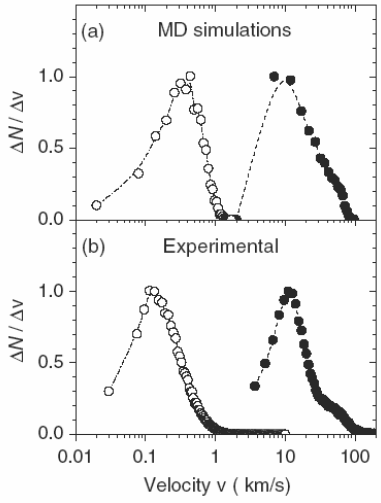

Fig. 3. Velocity distribution of the ablated atoms (•) and nanoparticles (◦): (a) MD simulation at F = 0.7 J/cm^2; (b) experimental results at F ≈ 0.8 J/cm^2.

Plasmonics and surface nano-structuring

The theoretical basis of a new technique for surface nanostructuring is developed using the finite-difference time-domain simulation technique. The technique proposed is based on the effect of field enhancement in the near-field zone in the vicinity of a nanoparticle under efficient plasmon excitation. The results indicate that the intensity of the electromagnetic field in the near-field zone is significantly enhanced with respect to the incident one (Fig. 4). The enhancement factor is found to depend on the parameters of the incident irradiation, the nanoparticles dimensions (Fig. 5) and the dielectric properties of the surrounding. The analysis can used to define optimal conditions for efficient surface nano-structuring of dielectrics, semiconductors, and metals. The theoretical findings are confirmed experimentally by nano-structuring of SiO_2, Si, and Au (Fig. 6, 7). The results obtained clearly indicate that the method proposed can be applied as an efficient tool for precise nano-modification of different types of materials.

The presented work is a result of international cooperation with Dr. S. Amoruso, Prof. R. Bruzzese and Dr. X. Wang from Univerity Federiko II, Napoli, Italy, and Prof. M. Obara from Keio University in Japan. Eight works in the presented field are published in international journals in 2007.

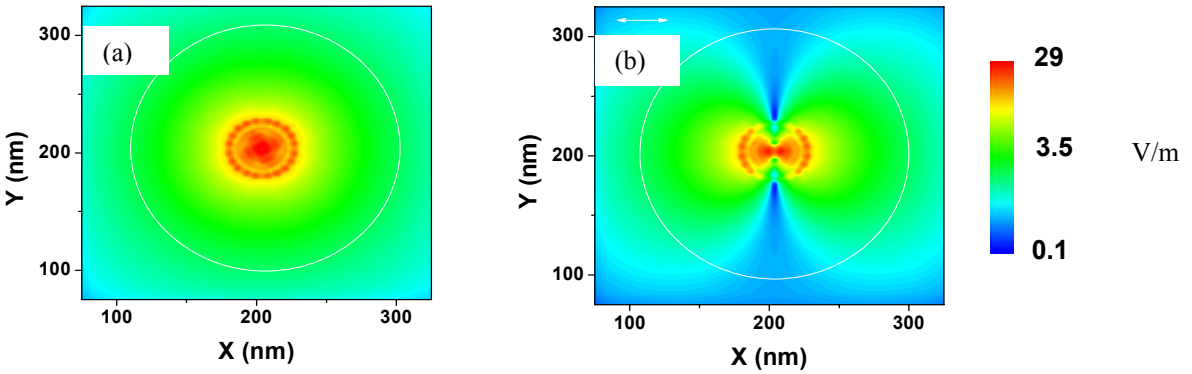

Fig. 4. Distribution of the electric field on substrate surface at different polarizations of the incident irradiation. The simulation system consists of 200 nm Au nanoparticle on Si. The electric field strength of the incident irradiation is 1V/m. (a) circular polarization; (b) linear polarization (the polarization direction is shown by arrow). The white circle shows the particle delineation.

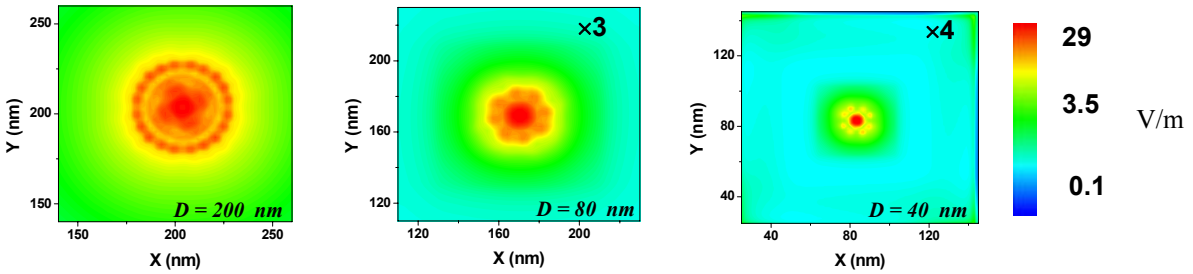

Fig. 5. Distribution of the electric field on Si surface with particles with different diameters (D). The incident irradiation has circular polarization. The electric field strength of the incident irradiation is 1V/m. The obtained electric field strength at D = 80 nm and D = 40 nm is multiplied by factor of 3 and 4 respectively.

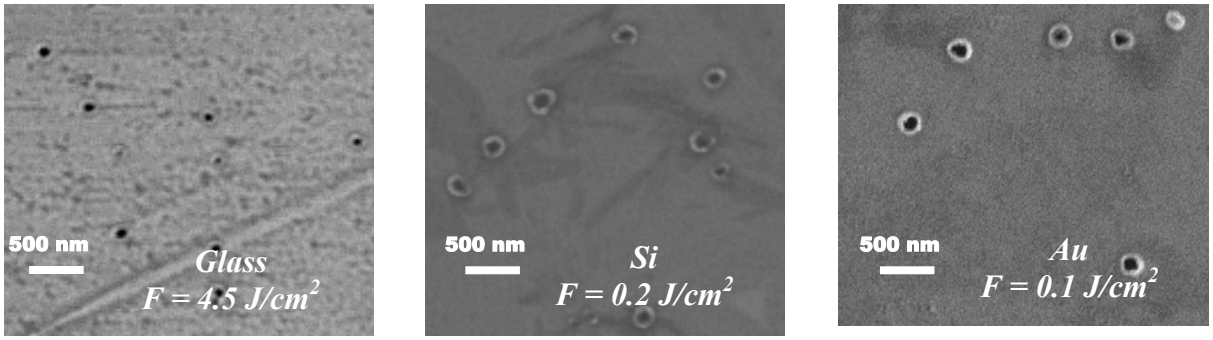

Fig. 6. SEM images of nanoholes in different materials produced by enhanced field of 200 nm gold particles. λ = 800 nm. The laser fluence (F) is shown for each case.

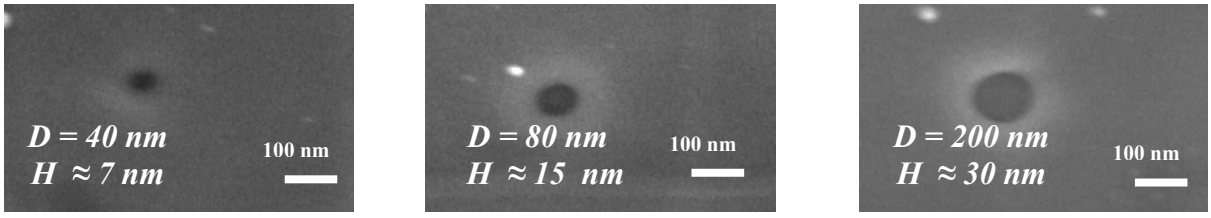

Fig. 7. SEM images of nanoholes in Si produced when gold particles with different diameters are used (D). F = 0.185 J/cm^2, λ = 800 nm. The depth of the holes (H) obtained by AFM analysis is also shown.