
# INSTITUTE OF ELECTRONICS

# ANNUAL REPORT 2005

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 to conduct research and education as well as dissemination of scientific knowledge in the fields of Physical Electronics, Quantum Electronics and Radio science. Soon, the Institute of Electronics evolves as a leading scientific institution in these areas of applied physics and engineering within Bulgarian Academy of Sciences and in Bulgaria.

Throughout several decades of its history the activities of the Institute have been expanded toward fast developing fields of applied physics and engineering such as high tech material and manufacturing, nano science, photonics, optoelectronics, quantum optics, environmental monitoring, laser biomedical research and applications.

Key research areas:

The investigations in physical electronics are focused on the generation and control of electron and ion beams and in particular 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. Fundamental gas and plasma properties are studied, and techniques are developed for plasma-assisted formation of thin films and coatings, and realization of plasma-chemical processes.

The research in quantum electronics includes: experimental and theoretical studies of the interaction of laser radiation with matter; 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; laser bio-medical research and applications.

The research in radio sciences is concentrated on studying the processes of propagation, scattering and generation of electromagnetic waves in the visible, infrared and microwave ranges for laser radar remote sounding and monitoring of the atmosphere, microwave and optical radiometric sensing of the Earth surface, modeling the interaction of waves with dynamic media, detection and signal processing techniques for extraction and interpretation of the information, nonlinear processes in optical communication media.

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, installation for electron beam melting and welding as well several advanced e-beam, laser and plasma high technologies are successfully developed.

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.

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

**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 TECHNOLOGY
HEAD: Correspondent Member of BAS G. Mladenov, Dr.Sc.

SUPERCONDUCTIVITY AND CRYOELECTRONICS
HEAD: Assoc. Prof. T. Nurgaliev, Ph.D.

GAS LASERS AND LASER TECHNOLOGIES
HEAD: Prof. P. Atanasov, Dr.Sc.

CONDENSED MATTER LASERS
HEAD: Assoc. Prof. G. Todorov, Ph.D.

LASER SYSTEMS
HEAD: Assoc. Prof. N. Mihailov, Ph.D.

FIBER AND NONLINEAR OPTICS
HEAD: Assoc. Prof. L. Ivanov, Ph.D.

OPTICAL RADIOMETRY
HEAD: Prof. E. Ferdinandov, Dr.Sc.

LASER RADARS
HEAD: Prof. D. Stoyanov, Dr.Sc.

MICROWAVE REMOTE SENSING
HEAD: Assoc. Prof. B. Vichev, Ph.D.

MICROWAVE MAGNETICS
HEAD: Prof. I. Nedkov, Dr.Sc.

MICROWAVE SOLID STATE ELECTRONICS
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: **10**
RESEARCH SCIENTISTS: **6**
M. Mladenov; P. Georgiev; V. Varbanova: Ts. Valchovska, Pl. Petkov; Zh. Dimitrova.

## 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.

Modelling of an analogous experiment, 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 in 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 leads to reductions of the degree of layers' amorphity and, in the turn, of the necessity of additional annealing of the structures.

### 2. Focused ion beams Field emission A. Field evaporation

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 $\beta_n$ by which the solution exceeds that obtained when the quadratic field terms are neglected. Putting this equation into a suitable dimensionless form yields a much simpler fourth-order equation for $\beta_n$ that has a straightforward analytical solution. Solutions exist only for values of a 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 ionisation-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. Predicted enhancement factors lay between 1.03 and 1.47, with average 1.11.

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

Using an IBAD technique, $Ta_2O_5$ 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 in under way.

In order to determine the $Ta_2O_5$ sorption ability to $NH_3$, Quartz Crystal Microbalance (QCM) with thin $Ta_2O_5$ layers was investigated. The $Ta_2O_5$ film was used as a receptor for the $NH_3$ 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 resonance frequency shifts of QCM over aqueous solution of $NH_3$ with different concentrations from 10 ppm to 10000 ppm.

The obtained experimental results indicated, that variations of the resonance frequency depending on the ammonium concentrations and $Ta_2O_5$ thickness. It was found, that the process of sorption is reversible.

It could be concluded, that QCM covered with thin $Ta_2O_5$ layer is sensitive to ammonium vapor at room temperature and has ability to distinguish different $NH_3$ concentrations in the investigated range.

On the basis of an improved physical model of a hot filament ionisation system in magnetic field, a mathematical model of an ionisation gauge for UHV measurements as a controlled device was proposed and efficient feedback emission control was implemented.

A load disturbance was efficiently simulated, through the changes of a space charge by means of applying different magnetic fields applied axially with respect to the electrode system.

In the cases of an open loop and closed loop control system, experimental results were obtained when the disturbance is a gas flow and optimal transient responses were achieved.

**ONGOING RESEARCH PROJECTS:**

Finansed 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 Rossendorf, Germany, University of Edmonton, Canada.

LABORATORY

## PLASMA PHYSICS AND ENGINEERING

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

TOTAL STAFF: **12**
RESEARCH SCIENTISTS: **9**
Prof. L. Zarkova, Dr.Sc.; Prof. G. Vissokov, 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.
Ph.D. students: J. Alexieva; M. Dimitrova.

### RESEARCH ACTIVITIES:

### 1. Fundamental processes in gases at high temperatures

Our ongoing research on molecular interactions aimed at creating gas properties reference data has now been extended to include chlorine. This gas is of considerable importance for vinyl plastic manufacturing, biochemistry, metallurgy, water disinfection etc. Calculations of several chlorine thermophysical properties have successfully been done by deploying two spherically symmetrical interaction potentials, the Lennard-Jones with and without temperature dependence. Although the former produces slightly smaller deviations between theoretically predicted and measured values for the thermophysical properties of gaseous chlorine, the latter is preferable due to its simplicity. Tables with recommended data for the viral coefficient, viscosity and selfdiffusion of chlorine are thus obtained.

### 2. Plasma-chemical processes

**A.1.** In the cooperation with the Institute of Technical Thermodynamics, German Aerospace Center (DLR), Stuttgart, Germany, the possibility of LSM (Sr doped La-manganites) with perovskite structure formation by thermal plasma CVD method were studied.

The LSM are considered as favorite cathode materials for SOFC because of their high electric conductivity, good chemical stability and thermal expansion compatibility with the electrolyte solid layer.

The possibility of these type perovskites formation were studied theoretically (IE BAS) and experimentally (DLR- Germany). The influence of different initial conditions realized in a RF-IC plasma set-up on the perovskite formation was investigated. The plasma gas is a mixture of Ar + H2 or Ar + O2. The precursors for perovskite formation are aqueous solutions of La- Mn- and Sr nitrates.

The performed thermodynamic analysis relates to the system containing La, Mn, Sr, H, O, N, Ar. The pressure in the system is taken to be 20 KPa. The temperature is varied from 2500 to 500 K by decreasing step of 100K. The initial concentrations of the precursors are also varied.

The general trend of the thermodynamic calculations was found to be confirmed with experimental data (XRD) of the thermal plasma CVD perovskite coatings.

**A.2.** In the cooperation with the Institute of Plasma Physics (IPP), Academy of Sciences Czech Republic, gasification of biomass in water-stabilized DC arc plasma was studied. Crushed wood was used as a model substance for

treatment of organic waste materials. Test conditions for production of synthetic gas were investigated experimentally (IPP) and by thermodynamic calculations (IE). The conditions for production of synthetic gas with high content of CO and H2 were obtained.

**B**. In several publications including the monograph [1] the theoretical grounds of the plasma-chemical nanotechnologies, the nanomaterials, as well as their practical applications are presented. The fundamental definitions are formulated and the most important concepts are discussed of this emerging field of knowledge from the point of view of high-temperature thermodynamics and equilibrium and non-equilibrium chemical kinetics. Theoretical calculations are presented, together with a-priori concepts and original studies of the author concerning the plasma-chemical preparation of nano-dispersed powders (NDP) and nanostructures. The modelling is considered of the processes of motion, heating, melting, and evaporation of micron-sized particles under the conditions of high-enthalpy plasma jets. The thermodynamic, kinetic and technological aspects are analysed of the quasi-equilibrium and non-equilibrium plasma-chemical processes (PCP) used to prepare NDP. Based on the results of a large number of PCP in neutral, reducing, oxidizing, nitrogen and reducing-oxidizing (redox) media, the optimal parameters are pointed out in view of obtaining condensed products with controlled dispersity, chemical activity, morphology, structure and phase content. Some properties are presented comprehensively of plasma-chemically synthesized nano-dispersed, ultra-dispersed (or finely dispersed) and highly dispersed powders and structures. The electron structure, thermodynamics and properties (thermal, mechanical, electrical, magnetic – interaction with magnetic fields, optical, chemical, etc.) of the nano-materials are reviewed. Special attention is devoted to the structural phase and morphological features of the nano-materials and the nano-structures, together with the role of the additives.

Finally, the applications are discussed of the plasma-chemical nano- technologies in the chemical (inorganic and organic) industry, machine-building, metallurgy (powder and metal-ceramic), electronics (nano-devices and nano-sensors), communications, space industry, defense industry, ecology, as well as in the household, biology, pharmacy, medicine, education etc.

### 3. Electric arcs and arc plasma torches

**A**. Recent experiments on localised intensive plasma/electrode interaction performed in co-operation with the Berlin Branch of Max Planck Institute of Plasma Physics, Germany, were aimed at the Plasma/First Wall interaction in fusion devices. Our observations on erosion of W-covered graphite tiles of ASDEX Upgrade are interpreted using results from laboratory vacuum arcs on the same material.

**B**. Research of previous years has shown that chromatic modulation based methods are suitable for monitoring and control of arc torch plasma spraying. The method is now extended to include monitoring of plasma jet geometrical properties such as position, width and deviation from circular cross section. A high speed digital video camera was used to produce images of arc plasma jets with or without powder particles in atmospheric environment. Analysis of the images has demonstrated the potential of chromatic processing to extract dominating information about the plasma processes. This information would be essential to control the quality of deposited coatings.

Such measurements require the minimum of technical means (small number e.g. three to six photo-diodes, ADC, PC and basic software); however, the position sensor developed would

require adjustment to the specific conditions.

**4. Diagnostics of DC gas discharges at intermediate pressures**

In a DC discharge tube with sectional cathodes and a common grid anode, second derivative Langmuir probe measurements were performed in the Faraday dark space in argon gas discharge at intermediate pressures. Experimental results for different radial probe positions and different distances from the cathode in axial direction are presented. It is shown that the electron energy distribution function is bi-Maxwellian. Taking into account the electron depletion caused by their sinking on the probe surface, an extension of the Druyvesteyn formula is applied for more accurate determination of the electron temperature value, T, the electron density, n, and the plasma potential, Upl, from the experimental results acquired.

**PUBLICATIONS:**

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2. Hrabovsky M, Kopecky V, Konrad M, Hlina M, Kavka T, van Oost G, Beeckman E, Verstraeten J, Ledecky J, Balabanova E,
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3. Vissokov G,
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4. Vissokov G,
Synthesis of nanodispersed magnesium nitride in electric-arc plasma,
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5. Vissokov G, Panayotova M,
Plasma-chemical processing of minerals to nano-dispersed powders,
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6. Vissokov G,
Plasma-chemical synthesis of nanopowder nitrides,
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7. Balabanova E, Muler M,
Preliminary thermodynamic estimation of lantanium manganite perovskite formation under thermal plasma conditions,
Nanoscience & Nanotechnology, Balabanova E, Dragieva I (Eds), Heron Press, Sofia,
2005;5:31-33.

8. Tsvetanov T, Vissokov G, Grancharov I, Brakalov L,

High-temperature thermodynamic investigations of nanodispersed carbides obtained in thermal plasma,
Nanoscience & Nanotechnology, Balabanova E, Dragieva I (Eds), Heron Press, Sofia, 2005;5:88-90.

9. Vissokov G,
Magnetochemical Studies of Nanodispersed Ferromagnetic Catalysts for Ammonia Synthesis,
Nanoscience & Nanotechnology, Balabanova E, Dragieva I (Eds), Heron Press, Sofia, 2005;5:117-122.

10. Laux M, Schneider W, Juttner B, Balden M, Linding S, Beilis I, Djakov B,
Ignition and burning of vacuum arcs on tungsten layers,
IEEE Trans Plasma Sci 2005;33:1470-1475.

11. Laux M, Schneider W, Jüttner B, Lindig S, Mayer M, Balden M, Beilis I, Djakov B,
Modification of tungsten layers by arcing,
J Nucl Mater 2005;337–339:1019–1023.

12. Djakov B, Enikov R, Oliver D,
Production and diagnostics of plasma jets,
J Bulg Acad Sci 2005;5:18–25.

13. Popov T, Tsaneva V, Stelmashenko N, Dimitrova M, Blamire M, Barber Z, Evetts J,
Second derivative Langmuire probe diagnostics of $Ar/O_2$ gas discharge for DC YBCO – 124 sputtering,
Plasma Sources Sci & Technol 2005;14:184–190.

14. Guerassimov N, Ghelev C **(**Eds)**,**
Annual Research Report 2004 of the Institute of Electronics, 137 pages,
Institute of Electronics, 2005, Sofia, Bulgaria.

15. Guerassimov N, Ghelev C, Martev I, Petrov PI (Eds),
Abstract book of the 14th International Summer School on Vacuum, Electron and Ion Technologies, 132 pages,
Institute of Electronics, 2005, Sofia, Bulgaria.

16. Guerassimov N,
Fourteenth International Summer School on Vacuum, Electron and Ion Technologies,
Plasma Processes and Polymers 2005;2/6:513-514.

**CONFERENCES:**

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Precise determination of the electron density in ntermediate pressure gas discharges using Langmuir probe measurements,
Frontiers in Low Temperature Plasma Diagnostics, April 2005, Les Houches, France.

2. M. Dimitrova, Tsv. K. Popov, Tsv. G. Naidenova,

Second derivative Langmuir probe measurements in the Faraday dark space in Argon DC gas discharge at intermediate pressures,
First Int Workshop and Summer School on Plasma Physics, June 2005, Kiten, Bulgaria.

3. H. Y. Kovachev, Tsv. K. Popov, M.B. Mitov, M. Dimitrova,
A computerized experimental set-up for second derivative Langmuir probe measurements,
First Int Workshop and Summer School on Plasma Physics, June 2005, Kiten, Bulgaria.

4. M. Dimitrova,
Langmuir probe investigation of intermediate pressure gas discharge plasma for cathode sputtering,
6th Int Balkan Workshop on Applied Physics, July 2005, Constanta, Romania.

5. Tsv. K. Popov, M. Dimitrova, Tsv. G. Naydenova,
Second derivative Langmuir probe measurements in Faraday dark space in Argon-Oxygen DC gas discharge at intermediate pressures,
14th Int Summer School on Vacuum Electron and Ion Technologies, September 2005, Varna, Bulgaria.

6. D.H. Oliver, R. Enikov, E. Vasileva, B.E. Djakov,
A study of nozzle shapes for plasma spraying,
14th Int Summer School on Vacuum Electron and Ion Technologies, September 2005, Varna, Bulgaria.

7. B.E. Djakov, R. Enikov, D.H. Oliver, M.Hrabovsky, V.Kopecky,
Chromatic Monitoring of D.C. Plasma Torches: the Latest Developments,
14th Int Summer School on Vacuum Electron and Ion Technologies, September 2005, Varna, Bulgaria.

8. B.E. Djakov, D.H. Oliver, R. Enikov, E. Vasileva,
A simple optical monitoring technique for determining the geometrical characteristics of a plasma jet,
14th Int Summer School on Vacuum Electron and Ion Technologies, September 2005, Varna, Bulgaria.

9. D. Dimitrov, R. Todorovska, D. Oliver, S. Atanasova, N. Petrova, C. Dushkin, D. Todorovski,
Oxygen detection using a junction based on thin films of yttriastabilized zirconium doped with plarinum and pure yttria-stabilzed zirconium,
7th Int Workshop Nanoscience &Nanotechnology, November 2005. Sofia, Bulgaria.

10. G.P. Vissokov,
On the increased chemical activity and the passivating of nanodispersed powders synthesized in thermal plasma,
7th Int Workshop Nanoscience &Nanotechnology, November 2005. Sofia, Bulgaria.

11. K. Ouzounov, I. Grancharov, G. Vissokov, L. Brakalov,
Thermodynamic investigation of systems consisting of mineral raw materials and wastes in a plasma chemical treatment,
7th Int Workshop Nanoscience &Nanotechnology, November 2005. Sofia, Bulgaria.

12. L. Zarkova, U. Hohm, M. Damyanova,
Calculation of the potential –dependent properties of gases by means of a Lennard-Jones temperature-dependent potential,
11th Russian Conf Thermophysical Properties, November 2005, SPB, Russia.

13. L. Zarkova, U. Hohm, M. Damyanova,
Intermolecular potentials and thermo physical properties of binary low-density gas mixtures containing ethane,
6th Int Balkan Workshop on Applied Physics, July 2005, Constanta, Romania.

14. L. Zarkova, U. Hohm, M. Damyanova,
Intermolecular potentials and thermo physical properties of binary low-density gas mixtures containing methane,
14th Int Summer School on Vacuum Electron and Ion Technologies, September 2005, Varna, Bulgaria.

15. E. Balabanova, M. Muller, R.Ruckdaeschel,
Possibility of Sr doped La-manganite perovskites formation by thermal plasma CVD method,
7th Int Workshop Nanoscience &Nanotechnology, November 2005. Sofia, Bulgaria.

16. E.Vasileva,
Optical monitoring the geometrical properties of plasma jets,
6th Int Balkan Workshop on Applied Physics, July 2005, Constanta, Romania.

**ONGOING RESEARCH PROJECTS:**

Financed by the National Science Fund

F-1105 Investigation of a plasmachemical reactor with co-axial electrodes for technological applications.

**COLLABORATIONS:**

Development and implementation of a joint IHT RAS – IE BAS data on interaction potential and kinetic coefficients of atomic and molecular gases, Institute of High Temperatures, Russian Academy of Sciences, Moscow, Russia.

Low temperature plasma and its technological application,
Institute of Plasma Physics, Czech Academy of Sciences, Prague, Czech Republic.

**LECTURE COURSES:**

Inorganic chemistry, General and Inorganic Chemistry,
University of Mining and Geology, Sofia, Bulgaria; College of Mining and Geology, Kardjaly, Bulgaria.
Fundamentals of Catalytic Processes, Equipping and Design of Chemical Enterprises, University of Chemical Technology and Metallurgy, Sofia, Bulgaria.
Plasma Diagnostics, Gas Discharge Plasma Sources, Plasma Technologies,
University of Sofia, Sofia, Bulgaria.

Elementary Applied Physics,
American University in Bulgaria, Blagoevgrad, Bulgaria.

LABORATORY

# PHYSICAL PROBLEMS OF ION TECHNOLOGIES

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

TOTAL STAFF: **5**
RESEARCH SCIENTIST: **4**
Assoc. Prof. J. Kourtev, Ph.D.; P. Nikolova; R. Kozhuharova; Y. Dyulgerska.

## RESEARCH ACTIVITIES:

### 1. Conversion of magnetron deposited TiC films into $TiO_2$

$TiO_2$ films can be obtained by a wide variety of technologies ranging from thermal oxidation, through PVD methods to a direct CVD growth. Our research work is focused on two-step fabrication of thin films of $TiO_2$ (rutile). For the first time as a starting material TiC films deposited on monocrystalline silicon wafers by magnetron dc-sputtering were used. The TiC thin films were treated by a $H_2O$/HCl gas mixture and Ar as a carrier gas at temperatures up to 1000ºC and atmospheric pressure. TiC films were converted into thin rutile films with traces of carbon. The microstructure and composition of the as-deposited TiC films and of the films after treatment were investigated by Scanning Electron Microscopy (SEM), by x-ray diffraction (XRD) with a Co Kα ($\lambda$ = 0.179 nm) and with a Cu Kα source ($\lambda$ = 0.154 nm) and by Raman spectroscopy.

It was found that with the increase of the temperature of treatment the diffraction peaks of TiC almost disappear but rutile peaks appear and increase, thus confirming the conversion of TiC into rutile.

The SEM image of the surface morphology of the as-deposited layers showed TiC grains with an average size of $d \approx 60$ nm.

After the treatment as a result of the presence of HCl in the gas mixture the grains have grown to a considerably larger size $d \approx 200$ nm. A Raman spectrum of a sample treated at T=1000ºC showed all rutile peaks and in addition very small peak related to amorphous carbon.

### 2. Decomposition kinetics of amorphous magnetron sputtered gold oxide thin films

The deposition of thin amorphous films of noble metal oxides is not only of fundamental, but also of great practical interest. Such films could be successfully applied in production of microelectronic integrated circuits and devices, of chemical sensors and optical switches, as effective surface passivation layers in high temperature superconducting devices, or as very active catalysts. Up to now, thin amorphous films of noble metal oxides such as $AuO_x$, $AuAgO_x$ and $PtO_x$ have been obtained, using radio frequency (rf) magnetron sputtering or electrochemical methods. Their application is, however, limited due to the comparatively short life-time (up to 6 months for $PtO_x$ films and not longer than several months for $AuO_x$ and AuAgOx films).

We studied the thin amorphous AuOx films deposited by reactive sputtering in an unbalanced magnetron system with controllable ion-to-neutral flux ratio. The influence of deposition parameters on the film specific electric resistance and film decomposition stability towards spontaneous thermal reduction to pure gold was systematically investigated. The film time durability was investigated under standard conditions. In this way, a set of

optimal conditions was found for depositing $AuO_x$ films with lifetimes reaching up to 3 years – 6 times longer than relevant data reported so far in the literature. The film decomposition kinetics at room temperature was thorough investigated. It was established that it could be described as a phase formation process beginning from the surface of amorphous grains building up the AuOx films.

## 3. Irradiation effects in YBCO thin films

Oxide superconductors are very sensitive to electron or ion beam irradiation/implantation. In the past 19 years after high-$T_c$ ($HT_c$) superconductivity was discovered in these materials, many aspects of interactions of accelerated particles with $HT_c$ thin films were investigated.

Particle modification is already used successfully for patterning of the HTc superconducting films, as well as for fabrication of Josephson junctions and SQUIDs. Two- and tree dimensional areas in $HT_c$ superconductors can be created and new phenomena were observed in such systems.

Recently we investigated high harmonic generation in YBCO film modified by 100 keV oxygen ions. We found that the harmonic generation can be influenced by the ion implantation of the samples. While in homogeneous samples the amplitudes of the high harmonics decrease monotonically with its number, in inhomogeneous samples some harmonics are depressed and others are enhanced. The processes involved are very complicated therefore we used a model of magnetic flux changes during one AC cycle. Fourier transformation of this curve gives a spectrum, where some harmonics disappear and other rise, which can explain at least quantitatively our experimental results.

## 4. Optical properties of PECVD deposited DLC films prepared with air addition

Diamond-like carbon (DLC) films with addition of atmospheric air to benzene were prepared by DC discharge plasma enhanced chemical vapor deposition (PECVD). These films were compared with films made from benzene/argon mixture. Some properties of the films including their optical transmission, hydrogen content and Raman spectra were investigated.

It is well known, that the hydrogen content of DLC films is an important factor for stabilization of DLC films and improving their optical properties. All our films deposited on different substrates, such as silicon, glass or metals, exhibit uniform distribution of hydrogen, as obtained by NRA, over the whole layer depth, the hydrogen concentration being from 21 to 25%.

Distributions of all other elements were determined by ERDA, which are nearly constant over the whole film depth for all samples. As expected in the films made with benzene/Ar mixture argon was detected, while in films prepared with air addition nitrogen and oxygen content was present.

It was found that such films fabricated with air addition (even at low vacuum) exhibit properties suitable for optical applications.

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1. Tinchev S,
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2. Kourtev J, Pascova R,
Thin amorphous AuOx and $Au_{0.85}Ag_{0.15}O_X$ films deposited by unbalanced magnetron sputtering,
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3. Tinchev SS, Nikolova PI, Dyulgerska YT, Danev G, Babeva T,
a-C:H absorber layer for solar cells matched to solar spectrum,
Solar Energy Materials & Solar Cells 2005;86/3:323-328.

**CONFERENCES:**

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Spectrally Selective Absorbers Based on a-C:H,
Symp 4 Solar Cells and Solar Energy Materials, IMRC2005, August 2005, Cancun, Mexico.

2. S.S.Tinchev,
Harmonic generation in ion implanted YBCO thin films,
10th Int Superconductive Electronics Conf, September 2005, Noordwijkerhout, The Nederlands.

3. S.S.Tinchev,
Changing and control of harmonic generation in superconducting films,
7th European Conf Applied Superconductivity EUCAS '05, September 2005, Vienna, Austria.

4. P. Nikolova, M. Petkov, S. Tinchev, Y. Dyulgerska,
Conversion of magnetron deposited TiC films into $TiO_2$,
14th Int Summer School VEIT, September 2005, Sunny Beach, Bulgaria.

5. S.S.Tinchev,
Irradiation effects In YBCO thin films,
3rd Int Symp Irradiation Induced Phenomena in Chalcogenide, Oxide And Organic Thin Films, June 2005, Tryavna, Bulgaria.

6. S.S. Tinchev,
High-order harmonic generation from high–$T_c$ superconducting films,
Int Conf Advances in Physics and Astrophysics of the 21st Century, September 2005, Varna, Bulgaria.

**ONGOING RESEARCH PROJECTS:**

Financed by the National Council for Scientific Research-Bulgarian National Projects

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.

**LECTURE COURSES:**

Materials Science and Technology,
Technical University of Sofia, Sofia, Bulgaria.

**OTHER SEMINARS:**

International Humboldt Conference "Challenges to the science in south-east European countries before their membership in European Union", Sofia, Bulgaria, 14-16 October 2005, S.S. Tinchev, New carbon based materials for electronics.

**AWARDS:**

Laureate of competition "Academician Emil Djakov" for the best research works for 2004 year.

LABORATORY

## PHYSICAL PROBLEMS OF ELECTRON BEAM TECHNOLOGY

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

TOTAL STAFF: **19**
RESEARCH SCIENTISTS: **13**
Assoc. Prof. K. Vutova, Ph.D.; Assoc. Prof. P. Petrov, Ph.D.; Assoc. Prof. S. Sabchevski, Ph.D.; Assoc. Prof. V. Vassileva, Ph.D.; Y. Gueorgiev, Ph.D.; M. Petkov, Ph.D.; Ch. Georgiev; P. Vlaev, M. Kardjiev, E. Koleva, M.Beshkova, T. Nikolov, E. Georgieva, S. Velinova, D. Mollov.
Ph.D. student: G. Djanovski.

TEMPORAL WORKING GROUP *VACUUM AND GAS/SURFACE INTERACTION PHYSICS*
HEAD: Assoc. Prof. I. Martev, Ph.D.
TOTAL STAFF: 2

### 1. Quality improvement and statistical analysis at electron beam welding

Characterization of intense electron beams is an actual task. The reliable investigations and robust applications are realized by using maximal stabilization of the electron beam control electronics and the utilized power sources, which increase the expenses of the equipment. The operator visually adjusts the electron beam parameters. The technology is created through destruction tests and every change in EB machine requires new tests.

From the analysis of constructions of known electron beam analyzers as main characteristics of these devices the Fourier spectra of signals and the modulation transfer function are chosen. It is concluded that the space-frequency characteristics of scanning(modulation) system is limiting factors for distortions of transferred signal. Matrixes of 32x32 sufficiently short impulses and a transfer rate twice higher than the maximum spectrum frequency can create an adequate image of the beam current radial and angular distributions.

There are done computer simulations for evaluation of the beam profiles and emittance, using previously presented method of three beam radial distributions, as well other new approaches.

On the base of multi-response statistical approach there are studied the thermal efficiency at electron beam welding. This approach allows one to establish empirically (by fitting a mathematical model) the type of relationship that is present between performance characteristics and its influencing factors. Optimal regimes are found through thermal efficiency optimization as well as choice of beam focusing plane towards the weld work-piece surface. In order to improve the quality of the process, by a decrease of the deviation from a target value of the weld geometry characteristics, two models (for average value and for the dispersion) of the weld depths and weld widths are minimized together.

### 2. Electron and Ion beam lithography

At execution of a project, financed by NATO, a lot of numerical experiments were fulfilled. There are simulated processes of exposure and development of the nano-images with critical dimension of order of 150nm and less. For adequate results on the developed resist profile

characteristics the used computer models were adjusted on base of more deep studies of processes and on optimization of algorithms.

A detailed study was performed of ion beam lithography (IBL) patterning of poly-methil metacrylate (PMMA). It has been short description of used algorithms. It is shown calculated numerical data for the ranges and energy losses for 7 types light ions at accelerating energy 100 keV in PMMA. Also data for trajectory and projected ranges, moments along, across and mixed ones toward the ion penetration, that permit a reconstruction of space distributions of the implanted particles and adsorbed energy during its penetration, calculated for He in PMMA at energy range 30-300keV are given. The radiation efficiency, dose for good development and contrast parameters at IBL of PMMA at developing with methil-isobutil keton and isopropanol.

An new optimization approach, based on the regression model evaluation was applied for the EBL and IBL. The optimization procedures aim to form nearly vertical side-walls of the developed resist profiles.More difficult is optimization of profile of very thin resist layers (of order of 100nm) suitable for mastering the images of order of tens nano-meters.

In the case of applications of ion beam lithography (IBL) for development of the images with critical dimension 100-300nm suitable ion is He, but for development of images with dimensions of the order of 50 – 100 nm more appropriate are ions of Ga and Ar due to lower dispersion across penetration direction and the lower resist thickness is advantage.

**3. Electron beam melting and refining of metals in vacuum**

There are studied the factors, controlling the refining processes at electron beam melting and refining (EBMR) of the refractory and reactive(at higher temperatures) metals as titanium, hafnium, tantalum and zirconium. The thermodynamic conditions in the temperature range 1500-3000 K and pressures $10^{-3}$ are analyzed. The free energy (isobar-isothermal potential) through the partial pressure and solubility of the components of base metal control the process direction (refining or increase the content) or the chemical reaction direction.

It is found, that components as Si, Fe, V, Zr, and Hf in the Ti ; Cu, Al, Mo and Zr in in the Hf; as well as Cu and Zn in the Ta do not decrease the concentration during EBMR. The refining of Al, Ni and Mo in the Ti as the Cr in the Hf depends on the duration of EBMR. The refining of Ca and Cr in the Ti; Fe, Ca, Zr, and Ti in the Hf; as well Ni, Mo and Nb in the Ta depends on the temperature of liquid metal.

The Oxygen exists in the composition of studied reactive metals as solid solution in the base metal, or as stable oxides of the refining metal and its metallic components. The Oxygen removal is realized through two ways. The Oxygen solubility decreases in the studied metals at heating in vacuum. The experiments shows, that concentration of soluble Oxygen in the Zr and Hf strongly decrease at temperature rise in vacuum. That dependence is much weak at Ti.

The second mechanism of Oxygen removal during EBMR is re-bonding of Oxygen by metallic components from the molecule of based refined metal. Through these oxides the Oxygen is transferred to the interface of molten metal with vacuum. There the thermal-dynamic conditions are disturbed and reaction take direction on oxide dissociation. The refining of Al, Ca, Ni, Cu and Si from Ti; of Al, Ca, Ni, Cu, Si , Fe, Cr, V and Mn from Hf and Zr take place through thermal degassing by dissociation of its oxides, and refining of V, Cr, Mo, Mn from the Ti and of Mo in the Hf and Zr realized by distillation of their oxides.

There are found the optimal conditions

of EBMR of concentrate or/and wastes of refractory and reactive at high temperatures metals and alloys. As a result the Oxygen contamination of Hf is decreased four times, in the Zr-7times and in the Ti-10 times. The contents of metal components as Al, Ca, Ni and Cu in these metals is decreased to 30 times.

It has demonstrated that during EBMR of strongly oxidized wastes of studied metals containing low concentration of metal impurities, the adding of metal sponge to the raw material is as economically justified, but also and technological needed operation.

## 4. Thin film deposition

The electron beam physical vacuum deposition was used for production of $CeO_2$ thin films on silicon substrates. Motivation is to integrate that process in mastering of high temperature superconducting layers on silicon. $CeO_2$ layer is a good buffer for growth of high quality $YBa_2Cu_3O_{7-x}$ films on Si(100) substrates due to its small lattice mismatch with $YBa_2Cu_3O_{7-x}$ (1%) and Si(0,35%)and stability at high temperatures. The characterized epitaxial $CeO_2$ films were with thickness about 200nm (measured by oscillating quartz) deposited at temperatures in 100-400$^oC$ range. XRD measurements in θ-2θ scan showed an almost complete (100) orientation at 100$^oC$ and Oxygen pressure $1,5x10^{-2}$Pa and beam current 5-10mA.Theoretically and experimentally (by SEM analysis) were found an average crystallite dimension of order of 60nm - i.e. the produced films have a nano-crystalline structure. A correlation between the Oxygen pressure, deposition temperature and orientation of grooving $CeO_2$ film was obtained.

## 5. Electron beam modification of materials

Electron beam surface modification of ion nitrided steel (with nominal composition in wt% : C-0,42%, Cr--0,96%, Mn--0,6%, Si-0,37%, balance Fe) . The hardness of previously hardened (by gas discharge in $N_2$) and irradiated with electron beam layer varies in the range 800-850 HV. The wear resistance of the electron beam treated layer is twice as high as that of the ion nitrided specimens. After electron beam treatment in the layer can be obtained ά-solid solution (nitrous martensite) and γ-solid solution (nitrous austenite) and dispersed fine nitride precipitates.

## 6. Computer simulation of electron guns for gyrotrons

It was published original theoretical results on auto-resonance interaction of relativistic spiral-like electron beam with TE and TM electromagnetic wave. A concept for development of tuning gyrotron, on base of which could be created spectroscope of nuclear magnetic resonance utilizing dynamic nuclear polarization for the signal amplifying.

## 7. $TiO_2$ thin films obtained by reactive DC magnetron sputtering

The study is directed to investigate the humidity-sensing properties of amorphous titanium dioxide thin films measured by a quartz microbalance. For this purpose a two-layer structure was assembled on quartz resonators. This structure consists of a polymer sublayer and a sensing titanium dioxide layer. The polymer sublayer was synthesized by a plasma process from hexamethyldisiloxane to protect the resonator's surface during the deposition of the titanium dioxide film by magnetron sputtering. The $TiO_2$ films were characterized by X-Ray Diffraction and Auger Electron Spectroscopy. The film composition was determined to be close to that of the stoichiometric $TiO_2$. The sensitivity to humidity was found to be from 5 Hz/%RH to 10 Hz/%RH for a

thickness of $TiO_2$ films lying in the range of 10-70 nm. The increase of the film thickness above 20 nm did not increase the sensitivity. This can be explained by a water sorption occurring mainly at the surface of the titanium dioxide film. It was found that 30-60 min of sorption time is necessary to completely eliminate the hysteresis which suggests that the process is reversible. These results could be of use at the development of sensor devices for measuring the relative humidity in the air.

The optical constants, refractive index $n$ and absorption coefficient $k$, as well as the thickness of the films were estimated by a previously developed 3-step algorithm including transmittance and reflectance measurements at normal light incidence. A thickness dependence of $n$ due to different porosity was established. All films are transparent in the visible and NIR spectral range. The respective values of $k$ were about $10^{-3}$ for all film thicknesses. Further, the values of the optical band gap of the $TiO_2$ films, $E_g$, increase slightly with thickness, from 3.2 to 3.3 eV.

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Electron beam lithography developed resist profile improved by quality analysis,
Vacuum 2005;77/4:361-370.

2. Koleva E,
Electron beam weld parameters and thermal efficiency improvement,
Vacuum 2005;77/4: 413-422.

3. Koleva E, Vuchkov I,
Model-based approach for quality improvement of electron beam welding applications in mass production,
Vacuum 2005;77/4:423-428.

4. Koleva E, Mladenov G,
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Vacuum 2005;77/4:457-462.

5. Vassileva V, Mladenov G, Vutova K, Nikolov T, Georgieva E,
Oxygen removal during electron beam drip melting and refining,
Vacuum 2005;77/4:429-436.

6. Krinberg I, Mladenov G,
Formation and expansion of the plasma column under electron beam-metal interaction,
Vacuum 2005;77/4:407-412.

7. Vutova K, Mladenov G, Tanaka T, .Kawabata K,
Simulation of the energy absorption and the resist development at sub-150 nm ion lithography,
Microelectronic Engineering 2005;78-79:533-539.

8. Idehara T, Ogawa I, Mitsudo S, Iwata Y, Watanabe S, Itakura Y, Ohashi K, Kobayashi H, Yokoyama T, Zapevalov V, Glyavin M, Kuftin A, Malygin O, Sabchevski S,

Development of a high harmonic gyrotron with an axis-encircling electron beam and a permanent magnet,
Vacuum 2005;77/4:539-546.

9. Sabchevski S, Idehara T, Glyavin M, Ogawa I, Mitsudo S,
Modelling and simulation of gyrotrons.
Vacuum 2005;77/4:519-525.

10. Sabchevski S, Idehara T,
Cyclotron Autoresonance with TE and TM guided waves,
Int J Infrared and Millimeter Waves 2005;26/5:669-689.

11. Sabchevski S, Idehara T, Mitsudo S, Fujiwara T,
Conceptual Design Study of a Novel Gyrotron for NMR/DNP Spectroscopy,
Int J Infrared and Millimeter Waves 2005;26/24:1241-1264.

12. Georgiev YM, Henschel W, Fuchs A, Kurz H,
Surface roughness of hyddrogen silsesquioxane as a negative tone electron beam resist,
Vacuum 2005;77/4:117-124.

13. Wahlbrink T, Mollenhauer T, Georgiev YM, Henschel W, Efavi JK, Gottlob HDB, Lemme MC, Kurz H, Niehusmann J, Haring Bolivar P,
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Microelectronic Engineering 2005;78-79:212-217.

14. Vassileva V, Vutova K, Georgieva E, Mladenov G,
Investigation of refining processes during EB regeneration of reactive metals of group IV B,
Proc DAE-BRNS Symp Electron Beam Technol and Appl SEBTA 2005, Sept 2005, Mumbai, India, pp 295-306.

15. Mladenov G,
Fundamentals of powerful electron optical system design,
Proc DAE-BRNS Symp Electron Beam Technol and Appl SEBTA 2005, Sept 2005, Mumbai, India, pp 38-54.

16. Koleva E, Vutova K, Mladenov G,
Characterization of powerful electron beams,
Proc DAE-BRNS Symp Electron Beam Technol and Appl SEBTA 2005, Sept 2005, Mumbai, India, pp 307-322.

17. Младенов Г, Вутова К,
Симулация на процесите при електронна и йонна литография,
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18. Бешкова М, Захариев З, Абрашев М, Birch J, Якимова Р,
Екитаксиални слоеве от алуминиев нитрид като нов материал за микроелектрониката,
Електротехника и Електроника 2005;5-6:22-25.

## ONGOING RESEARCH PROJECTS:

Financed by NATO Science for Peace Program
SubHTS, SfP973718, Damage free sub-micron structures of high temperature superconducting thin films.

Financed by the National Council for Scientific Research
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 Syntesis and modification of YBCO films for IR sensors.
F-1514 Physical characteristics and mechanical properties of multilayer nanostructures of complex nitrides of transition metals.
F-1208 Optical Coatings on Polymer Optics.

## COLLABORATIONS:

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

High power electron beam equipment for EBMR.Characterization of intense electron beams,
Bhabha Atomic Research Centre, Mumbai, India, Nuclear Fuel Complex, Hyderabat, India.

## LECTURE COURSES:

Electron beam technologies - Theory and applications of beams of charged particles as radiation and thermal source in materials modification: electron and ion lithography; electron beam melting and welding,
European school for advanced studies: Application of ionising radiation in material studies, University of Pavia, Italy.

Electron beam melting - equipment and technology,
Technical University of Sofia, Sofia, Bulgaria.

Electron beam welding - equipment and technology,
Technical University of Sofia, Sofia, Bulgaria.

## LABORATORY FELLOWS VISITS:

Assoc. Prof. S. Sabchevski – University of Fukui, Japan.
Dr. Y. Georgiev - University of Aachen, AMO Ltd, Germany.
Prof. G. Mladenov – University of Pavia, Italy.

LABORATORY

**SUPERCONDUCTIVITY AND CRYOELECTRONICS**

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

TOTAL STAFF: **8**
RESEARCH SCIENTIST: **6**
Assoc. Prof. T.C. Nurgaliev, Ph.D.; S.I. Miteva, Ph.D.; E.S. Mateev, Ph.D.; L.I. Neshkov; R.V. Todorovska; B.S. Blagoev.

**RESEARCH ACTIVITIES:**

**1. Anisotropy of HTS films grown on tilted substrates**

Tilted substrates can stimulate growth of high quality High Temperature Superconducting (HTS) thin films. On the other hand such films demonstrate some peculiarities, which are induced by the specific properties (including a presence of a periodic structure of nano- steps in the substrate surface) of the tilted substrates.

Therefore the anisotropy of the electrical parameters of $YBa_2Cu_3O_{7-x}$ (YBCO) thin films grown on tilted (to angles 0-26° from the (110) plane) $NdGaO_3$ substrates was investigated. Resistance of the films measured at 295 K in directions parallel and perpendicular to the steps of the surface were different. Resistivity of the films in *c*-direction was determined from the experimental data as well and it exceeded by more than one order the resistivity of the film in *ab* plane. At greater values (>3°) of the substrate tilt angle an increase of the film resistivity in *ab* plane was observed due to an increase of the number of irregularly distributed defects in the film.

Microwave surface resistance of YBCO films measured at 77 K and 8 GHz was anisotropic as well and the resistance was greater for the direction perpendicular to the steps in the substrate surface. The obtained experimental data was used for evaluating of the complex conductivity of the superconducting films in *ab* plane and in *c*- axis direction, and the complex conductivity of the weak links formed at the edges of the substrate steps.

The films grown on the substrates with the optimal tilt angle demonstrated greater values of the critical temperature and the critical current density and smaller value of the microwave surface resistance, although the optimal value of tilt angle was not the same for different growing conditions.

**2. Deposition of HTS and magnetic manganite films of submicron thickness.**

The magnetron sputtering technology for growing of HTS YBCO and magnetic manganite $La_{0.7}Ca_{0.3}MnO_3$ (LCMO), $La_{0.7}Sr_{0.3}MnO_3$ (LSMO) films and layered structures of nano- thickness (i.e. containing only several tens elementary crystalline cells of the material across the film thickness) was optimized.

Such films are sensitive to the effect of the external factors - the elastic stress, the electric and magnetic fields. The films was used for investigation of some "fine" effects such as the effect of the crystalline structure of the substrate on the electrical characteristics of the films and the effect of diffusion of the spins and charges through the interface HTS/manganite on the superconducting characteristics of YBCO film in the layered structures.

**3. YSZ and Pd doped YSZ layers**

Yttria-stabilized zirconia (YSZ) is widely used for oxygen sensors. YSZ

films are successfully used as buffer layers for deposition of YBCO superconductors as well. A spray pyrolysis method for deposition of YSZ and YSZ-Pt composite films with thickness 0.1-30 μm using solution of citric complexes as starting material was proposed. The crystal structure, the morphology of the films and the state of Pt atoms were investigated. The method worked out permits the preparation of cracks-free thick films, more uniform compared to the films with similar thickness prepared by a plasma-spray method.

**4. HTS thin film microstrip resonators with a ferrite component.**

Approximate formulas for describing the transmission characteristics of HTS thin film microstrip resonator structures with a ferrite component were proposed. These formulas take into account the effect of the external magnetic field on the resonance frequency (magnetic tuneability of the resonator) and the microwave losses (decreasing of the quality factor) caused by excitation of surface spin waves in the ferrite layer. It was shown that the results of the calculations using the obtained approximate formulas describe correctly the main peculiarities of the experimental transmission characteristics.

**5. Characteristics of HTS/ferromagnetic structures.**

Thin film HTS/ferromagnetic (FM) structures are prospective for application in the devices of new generation – the devices of spintronics. Therefore HTS/FM and FM/HTS double layer structures, consisting of YBCO and manganite layers with the thickness of several tens nanometers, were fabricated and their main electrical parameters were investigated.

It was shown that i) the temperature dependence of the normal state resistivity of these HTS/FM structures is not described by a linear function as in the case of single YBCO films; ii) a presence of the manganite layer leads to worsening of the critical parameters of the YBCO film; iii) the manganite layer leads to a significant increase of the microwave surface resistance of the structure. The peculiarities of the YBCO film, observed in the superconducting state, were interpreted as a consequence of a diffusion of the spin-polarized electrons from the ferromagnetic layer to the superconducting one, which leads to destroying of the superconducting state at the interface.

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Properties of HTS YBCO thin films deposited on tilted $NdGaO_3$ substrates,
Physica C 2005;420:61-67.

2. Mozhaev PB, Kotelyanskii IM, Luzanov VA, Mozhaeva JE, Donchev T, Mateev E, Nurgaliev T, Bdikin IK, Narymbetov BZ,
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Physica C 2005;419:53-60.

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Electrical transport and glassy response in strained thin $La_{0.7}Ca_{0.3}MnO_3$ films,
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Academician Emil Djakov Institute of Electronics, Annual Report 2004;93-105.

8. Nurgaliev T, Miteva S,
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Solid state chemistry and modern micro- and nanotechnologies, V International conference, Kislovodsk – Stavropol, Nord-Caucas GTU, 2005: 368, (in Russian).

10. Pencheva V, Zubov P, Naboko V, Penchev S, Naboko S, Penchev A, Donchev T, Nenkova E,
Investigation of superconducting layers by not-destroying method,
Solid state chemistry and modern micro- and nanotechnologies, V International conference, Kislovodsk – Stavropol, Nord-Caucas GTU, 2005: 368, (in Russian).

11. Blagoev B, Neshkov L,
Optimization of $CeO_2$ buffer growing conditions on sapphire substrates for obtaining HTS YBCO films,
Proc Balkan Conf of young scientists, June 2005, Plovdiv, Bulgaria; Scientific Researches of the Union of Scientists, Series C, Technics and Technologies 2005;5:420-422.

**CONFERENCES:**

1. B. Blagoev, L. Neshkov,

Optimization of $CeO_2$ buffer growing conditions on sapphire substrates for obtaining HTS YBCO films,
Balkan Conference of young scientists, Plovdiv, Bulgaria, June 16-18, 2005.

2. B. Blagoev,
Preparation of layered structures including $YBa_2Cu_3O_7$ layers and investigation their electromagnetic characteristics,
6th SCENET School - "Superconducting Materials and Applications", Turku, Finland, July 18-30, 2005.

3. B. Blagoev, E. Mateev, T. Nurgaliev, L. Neshkov,
Sandwich structures of HTS and ferromagnetic perovskites,
14th International Summer School on Vacuum, Electron and Ion Technologies - VEIT 2005, Sept. 12 -16, 2005, Sunny Beach, Bulgaria.

4. T. Nurgaliev, B. Blagoev, T. Donchev, S. Miteva, P.B. Mozhaev, J.E. Mozhaeva, G.A. Ovsyannikov, I.M. Kotelyanskii, C. Jacobsen,
YBCO/manganite layered structures on $NdGaO_3$ substrates,
European Conference of Applied Superconductivity (EUCAS 2005), Sept. 11-15, 2005, Vienne, Austria.
5. E. Vlakhov, B. Blagoev, L. Neshkov, T. Nurgaliev, L. Lakov, K. Toncheva, Y. Marinov, K. Nenkov, K. Piotrowski, M. Baran, and R. Szymczak, Magnetron sputtering deposition and characterization of $GdMnO_3$ thin films,
14th International Summer School on Vacuum, Electron and Ion Technologies - VEIT 2005, Sept. 12 -16, 2005, Sunny Beach, Bulgaria.

6. T. Nurgaliev, S. Miteva,
Microstrip Resonators with a Ferrite Component: A simplified description,
European Microwave Week (EuMW 2005), October 03–07, 2005, Paris, France.

7. E. Mateev, T. Nurgaliev, B. Blagoev, L. Neshkov,
Investigation of contact-less harmonic generation in HTS nano-films,
7th Workshop Nanoscience & Nanotechnology", Nov. 24-25, 2005, Sofia, Bulgaria.

**ONGOING RESEARCH PROJECTS:**

Financed by the National Science Fund

F1503/05 Characteristics and application possibilities of sandwiches of HTS and magnetic oxides in spinotronics (2005-2007).
X-1210 Spray-pyrolysis deposition of thin-film nanocomposites of semiconductor in yttria-stabilized zirconia ceramics for sensing devices (2002-2005).
VUX05/05 Fotoluminescent 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 (2004-2006).
MUF-08/05 Syntesis, modification and characterization of YBCO thin films for IR detectors.

Financed by the Medical University, Sofia

Laser stimulated bleaching of teeth.

Financed by EU Science Program

INTAS-2001-0249 Metal-oxide thin film heterostructures on tilted-axes substrates.

Financed by NATO Science for Peace Program

SfP973718 Damage free submicron structures of high temperature superconductor thin films.
SfP977986 Fabrication and properties of porous electro and photo-catalytic films.

**COLLABORATIONS:**

Electromagnetic characteristic of thin layered structures HTS/metal and HTS/magnetic prepared on conventional and unconventional substrates,
Institute of Radio Engineering and Electronics, Russian Academy of Sciences, Moscow, Russia.

Sandwich structures based on cuprates, dielectrics and manganites: physical properties and application possibilities,
Institute of Electrical Engineering, Slovak Academy of Sciences, Bratislava, Slovak Republic.

**LABORATORY VISITS:**

Dr. T. Nurgaliev,
Technical University of Denmark, Copenhagen, Denmark, Jan. 24 – Feb. 04, 2005.
Dr. E. Mateev,
Institute of Electrical Engineering, SAS, Bratislava, Slovak republic, October 24 – 30, 2005.
Dr. S. Miteva,
Institute of Radio Engineering and Electronics, RAS, Moscow, Russia, Aug.26 - Sept. 01, 2005.

**GUESTS:**

Prof. G. Ovsyannikov,
Institute of Radio Engineering and Electronics, RAS, Moscow, Russia – 14 days.

LABORATORY

## GAS LASERS AND LASER TECHNOLOGIES

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

TOTAL STAFF: **14**
RESEARCH SCIENTISTS: **13**
M.E. Koleva, Ph.D.; N.N. Nedialkov, Ph.D.; S.D. Donchev Ph.D., T.R. Stoyanchov; S.E. Imamova; T.J. Stanimirova; A.O. Dikovska; E.L. Pavlov; G.I. Furlinski; N.E. Stankova; I.G. Dimitrov; D.R. Milev, St.K. Yordanov.

**RESEARCH ACTIVITES:**

### 1. Pulsed laser deposition of thin films

*1.1. Rare-earth doped active thin films*

Nd:$KGd(WO_4)_2$ films have been grown using the nozzle-gas-assisted pulsed-laser deposition (NGA-PLD) method. A KrF excimer laser was used for the ablation of K-rich ceramic targets and films were deposited on r-cut sapphire substrates. The dependences of the oxygen nozzle gas on the film optical and crystallographic properties were investigated. The Nd:KGW film was coloured if the mass flow is not sufficient. The origin of the colour was attributed to the oxygen deficiency phase which was confirmed by the optical absorption and x-ray diffraction (XRD) measurements. Highly crystallized Nd:KGW films were grown by NGA-PLD under the optimized conditions. Comparing the films grown by conventional PLD (C-PLD) method, a dramatic improvement in the film surface morphology was achieved with NGA-PLD.

Ultraviolet (UV)-assisted annealing of thin $Y_2O_3$ films produced by pulsed laser deposition was applied. An excimer XeCl laser was used for ablation of $Y_2O_3$ ceramic target. The films were grown on (001) $SiO_2$ substrates at 500 °C and oxygen pressure of 0.05 mbar. The effect of UV–assisted laser annealing on the structure, morphology, and optical properties was investigated. The UV-assisted annealing was performed by the same laser. The beam was directed parallel or toward the surface of the as–deposited films. The influence of the ambient gas ($O_2$ or $N_2O$) is explored. The ambient atmosphere has an influence on the preferential (cubic or monoclinic) phase of growth while it has no significant effect on the surface morphology. The absorption coefficient in the VIS range has a lower value for the films annealed with laser directed parallel to the surface independently on the gas environment. Annealing of the films with laser beam directed at the film surface slightly increases the refractive index, independently of the gas ambient.

*1.2. Thin semiconductor metal oxide films for gas sensors*

Thin ZnO films have been produced by pulsed laser deposition on (001) $SiO_2$ substrates. The influence of the substrate temperature and oxygen pressure applied on the structural, morphological, and optical properties of the films were investigated. All ZnO films are textured along (002) direction. The increase of the substrate temperature enhances the diffraction peak intensity for all oxygen pressures applied. Highest intensity peak for a fixed temperature was obtained at pressure in the range 0.05 – 0.1 mbar. The increase of the substrate temperature at 0.1 mbar leads to deposition of smoother

films with an average RMS value of 9 – 11 nm. The film morphology changes with the increase of oxygen pressure at fixed temperature. Highest optical transmission was achieved at room temperature. The increase of the oxygen pressure reduces the film transmission in the visible range of the spectra. The value of the waveguide losses measured strongly depends on the crystalline quality and surface roughness of the films. The optical losses decrease to a value about 1.3 dB/cm. Films deposited at oxygen pressure between 0.05 and 0.1 mbar and at 150 or 300$^{o}$C have excellent mode properties and they are excellent candidate for optical sensors.

Thin tin oxide ($SnO_2$) films have been grown on (001) $SiO_2$ substrate by pulsed laser deposition (PLD) technique. XeCl laser was used for ablation of $SnO_2$ ceramic targets at substrate temperatures ranging from room temperature to 500 $^{o}$C and oxygen pressure in the range of 5 – 30 Pa. The structural and optical parameters of the layers have been studied as function of the deposition conditions. The oxygen pressure of 20 Pa was determined as an optimum one while the structural and optical properties vary with the substrate temperatures applied. The film deposited at 500 $^{o}$C and 20 Pa oxygen pressure has best crystalline properties, i.e. optimum growth conditions. However, film grown at 20 Pa and 200 $^{o}$C has maximum transmission in the visible region. The refractive index of the film deposited at optimum growth conditions is 1.93, which is close to this of the bulk material (1.96). Moreover, film grown at 20 Pa and 400 $^{o}$C has lowest (7 dB/cm) optical waveguide loss.

Thin $TiO_2$ films were grown on (001) $SiO_2$ substrates using excimer KrF laser ablation of ceramic targets. The influence of deposition temperatures at fixed oxygen pressure of 10 Pa on the crystal and optical properties of the films was investigated. Structural characterisation by X-ray diffraction and Raman spectroscopy shows preferential crystallization of the anatase $TiO_2$ phases. High crystalline anatase $TiO_2$ films were obtained at temperature of 600 °C. Optical transmission as high as 92 % in the visible spectral region was measured for films grown at temperatures higher than 400 °C. The refractive index and the thickness of the films measured by m-line spectroscopy shows the highest values of 2.41 and 250 nm, respectively, at deposition temperature of 600 °C. Films deposited at $P(O_2)$ = 0.1 mbar and $T_s$ = 500$^{o}$C have excellent mode properties and they are excellent candidate for optical sensors.

## 2. Interaction of laser radiation with matter and laser technologies

The time-gated optical emission spectroscopy has been used to investigate the characteristics of aluminum plumes and their vacuum expansion after femtosecond laser ablation at different fluences. The prominent feature is the presence of two main classes of species in the plume: very fast Al atoms and ions preceding the plume bulk essentially constituted of much slower Al nanoparticles expanding with a ten times smaller average velocity. Atomic force microscopy of deposited Al nanoparticles evidenced an average size of about 10 nm with a pretty narrow size distribution. These results and the peculiar feature of nanoparticle formation during femtosecond laser irradiation of matter were very satisfactorily interpreted and reproduced by molecular-dynamics simulation of the process. Finally, the analysis of the dependence on laser fluence of the ablation process showed an initial logarithmic increase of ablation yield, up to about 500 mJ/cm$^2$, followed by a sudden and very steep increase at higher fluences. According to our numerical calculations, this latter feature can be ascribed to the increase of the overheated material volume due to electron heat diffusion.

Classical molecular dynamics simulation technique was applied for investigation of the iron ablation by ultrashort laser pulses at conditions of deep hole for the first time. Laser pulse duration of 0.1 ps at wavelength of 800 nm was considered. The evolution of the ablated material in deep hole geometry differs completely from the free expansion regime as two major mechanisms are important for the final hole shape. The first one is the deposition of the ablated material on the walls, which narrows the hole at a certain height above its bottom. The second mechanism is related to ablation of the material from the walls (secondary ablation) caused by its interaction with the primary ablated particles. Properties of the secondary ablated particles in terms of the velocity and the angular distribution were obtained. The material removal efficiency was estimated for vacuum or in Ar environment conditions. The processes observed affect significantly the material expulsion and can explain the decrease of the drilling rate with the hole depth increase, an effect observed experimentally. The interaction of the ablated material with the hole's wall affects its shape. At aspect ratio of the hole (hole depth/hole width) higher than 1 the number of re-deposited, reflected, and secondary ejected particles from the walls were estimated as a function of the laser fluence. Significant secondary ejection of material from the walls was observed at fluences above 5 J/cm$^2$.

Ablation of Fe, Al, Ni, and Cu by laser pulses at durations of 0.1, 1, and 5 ps has been investigated experimentally. The laser fluence used varies from below the ablation threshold up to 100 J/cm$^2$. The ablation rate depends on the laser pulse duration at laser fluences above several J/cm$^2$ as the shorter pulse produces higher ablation rate. A change of the ablation regime with the laser fluence increase was also observed. The presence of molten material is clearly expressed at fluences above 10 J/cm$^2$ for all pulse durations used. These effects can be refereed to the contribution of the electron heat diffusion in the distribution of the absorbed energy. The traces of solidified molten material suggest for realizations of melt ejection mechanism of ablation.

Laser drilling of aluminium nitride (AlN) ceramics by 6 ns SHG ($\lambda$ = 532 nm) Nd:YAG laser pulses was studied. The drilling rate, quality of the holes, and the effects related to plasma formation were investigated. Numerical model based on the heat-transfer equation was developed to describe the drilling process. Different mechanisms of material decomposition were found to be realized, which depend on the laser fluence. They determine the quality of the holes produced. Below 5 GW/cm$^2$ the material ejection is realized by decomposition of ceramics into sold or liquid Al and gaseous $N_2$. The letter blows away clusters and flakes from the irradiated area and the holes drilled have irregular shape. At higher laser intensities, the decomposition into gaseous Al and $N_2$ or direct evaporation of the ceramics results in good hole quality. A saturation of the ablation rate as a function of the laser intensity was observed above 15 GW/cm$^2$. The calculated depths of the holes drilled are in agreement with the experimental data when absorption of the laser radiation from the plasma plume was taken into account.

**PUBLICATIONS:**

1. Atanasov PA,
Optically active Nd-doped potassium gadolinium tungstate films produced by pulsed laser deposition,
Pulsed Laser Deposition of Optoelectronic films, Ser. Optoelectronic Materials and Devices,

INOE Bucharest, Popescu MA (Edt) 2005;2/6:173-206.

2. Amoruso S., Bruzzese R., Vitiello M., Nedialkov NN, Atanasov PA,
Experimental and theoretical investigation of femtosecond laser ablation of Al in vacuum,
J Appl Phys 2005;98/044907:1-6.

3. Nedialkov NN, Imamova SE, Atanasov PA, Berger P., Dausinger F,
Mechanism of ultrashort laser ablation of metals: molecular dynamics simulation,
Appl Surf Sci 2005;247/1-4:243-248.

4. Stankova NE, Atanasov PA, Stanimirova TJ, Dikovska AO, Eason RW,
Thin (001) tungsten trioxide films grown by laser deposition,
Appl Surf Sci 2005,247/1-4:401-405.

5. Nedialkov NN, Atanasov PA, Breitling D, Heusel G, Dausinger F,
Ablation of metals by ultrashort laser pulses,
Proc. SPIE 2005;5830:80-84.

6. Nedialkov NN, Imamova SE, Atanasov PA, Berger P, Dausinger F,
Deep hole drilling in Fe by ultrashort laser pulses: molecular dynamics simulation study,
Proc. SPIE 2005;5777:850-854.

7. Nedialkov NN, Atanasov PA, Sawczak M, Śliwiński G,
Laser drilling of AlN ceramics using nanosecond pulses,
Proc. SPIE 2005;5777:846-849.

8. Dikovska AO, Atanasov PA, Tomov RI, Dimitrov IG,
Ultraviolet annealing of thin $Y_2O_3$ films grown by pulsed laser deposition,
Proc. SPIE 2005;5830:75-79.

9. Stanimirova TJ, Atanasov PA, Dikovska AO, Stankova NE, Tonchev SH,
Structural and optical properties of thin indium oxide films produced by pulsed laser deposition,
Proc. SPIE 2005;5830:55-59.

10. Stankova NE, Atanasov PA, Dikovska AO, Dimitrov IG, Socol G, Mihailescu I,
Growth of anatase $TiO_2$ thin films by laser ablation,
Proc. SPIE 2005;5830:60-64.

11. Okato T, Obara M, Atanasov PA,
Fabrication of Nd:KGW waveguides by use of nozzle-gas-assisted PLD method,
Proc. SPIE 2005;5830:70-74.

12. Kuneva MK, Tonchev SH, Atanasov PA,
Infrared spectra of proton-exchanged waveguides in $LiNbO_3$ and $LiTaO_3$,
Mater Sci Engng B 2005;118:301–305.

13. Stanimirova TJ, Atanasov PA, Dimitrov IG, Dikovska AO,
Investigation of the structural and optical properties of tin oxide films grown by pulsed laser deposition,

J Optoelectr Adv Mater 2005;7/3 1335-1340.

14. Dikovska AO, Atanasov PA, Vasilev C, Dimitrov IG, Stoyanchov TR,
Thin ZnO films produced by pulsed laser deposition,
J Optoelectr Adv Mater 2005;7/3:1329-1334.

15. Atanasov PA,
Thin films photonic gas sensors,
J. Bulg Acad of Sci 2005;5:25-30 (in Bulgarian).

**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.

Financed by other funds

IST-2001-39112 Project, NANOPHOS, Nanostructured Photonic Sensors, 5$^{th}$ FP, EU.

**COLLABORATIONS:**

Etude des processus d'ablation laser au cours de la deposition de couches minces pour des applications dans le domaine de l'optique,
CNRS, Universités Paris VI et Paris VII, Paris, France.
Ultrashort laser ablation of metals,
Coherentia-INFM, Istituto Nazionale per la Fisica della Materia, Naples, Italy.
Rare-earth doped thin sesquioxides films for optical application,
Institute de Optica, CSIC, Madrid, Spain.
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:**

Laser ablation of metals by ultrashort laser pulses,
Institute de Optica, CSIC, Madrid, Spain.

**GUESTS:**

Mr. S. Grigorescu,
Institute of Lasers, Plasma and Radiation Physics, Romanian Academy of Sciences, Bucharest, Romania, 1 week, 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, project Pulsed laser deposition of thin oxide films.

**LABORATORY VISITS:**

Prof. DSc P.A. Atanasov,
CNRS, Universités Paris VI et Paris VII, Paris, France.
Mrs. A.Og. Dikovska,
CNRS, Universités Paris VI et Paris VII, Paris, France.
Prof. DSc P.A. Atanasov,
Coherentia-INFM, Istituto Nazionale per la Fisica della Materia, Naples, Italy.
Mr. N.N. Nedialkov,
Coherentia-INFM, Istituto Nazionale per la Fisica della Materia, Naples, Italy.
Prof. DSc P.A. Atanasov,
Institute de Optica, CSIC, Madrid, Spain.
Dr. S.D. Donchev,
Institute of Lasers, Plasma and Radiation Physics, Romanian Academy of Sciences, Bucharest, Romania.
Ms. N.E. Stankova,
Institute of Lasers, Plasma and Radiation Physics, Romanian Academy of Sciences, Bucharest, Romania.
Mr. N.N. Nedialkov,
Institute of Fluid-Flow Machines, Polish Academy of Sciences, Gdansk, Poland.

**DISSERTATIONS**

N.N. Nedialkov,
Laser ablation of metals by ultrashort laser pulses: molecular dynamics study 2005, 117 pgs.

**AWARDS RECEIVED**

A.Og. Dikovska, P.A. Atanasov, I.G. Dimitrov, T. Kocuorek, M. Jelinek,
Structural and optical properties of Er, Yb co-doped $Y_2O_3$ thin films,
EMRS, J-PII.09, 8/19, Strasbourg, May 31-June 03 2005 - **Best poster presented.**

LABORATORY

## CONDENSED MATTER LASERS

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

TOTAL STAFF: 13
RESEARCH SCIENTISTS: 7
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.; V. Arsov Ph.D; A.I. Gisbrecht; N. J. Momchilov; Z.S. Jordanova; D.S. Petkov; D.I. Hristov, I. G. Kocev.
Ph.D. students: L.P. Petrov; D.H. Dobrikov.

### RESEARCH ACTIVITIES:

### 1. Tunable lasers and amplification of laser information signals.

1.1. Part of the new results concern our work on the development of a novel technique, proposed earlier by us, for high factor amplification (~ $10^6$ - $10^8$) of weak (micro- and nanowatts) laser radiation periodically modulated with information signals. The underlying principle is based on the use of laser injection-locking control by the amplified signal under the conditions of second competitive injection. The latter allows to one to obtain linearity of the amplification. Previously, we have developed different schemes of realization of the principle – in injection and in linear resonator configurations. It was shown that the amplification of a sequence of rectangular information pulses (~ 0.1 - 0.4 GHz) is possible and the contrast is greater than 1/100. The last work concern a development of theoretical models for study the noise characteristics of the amplifiers proposed. The background emission of the laser at the modes outside the locked at the signal mode and at the counter injection wavelength is considered as a main sources of the noise. The model is based on the analysis of emission development at each possible resonator mode. The numerical investigations show that for suitably chosen conditions the intracavity noise is very low or acceptable (~ $10^{-2}$ with respect to the signal output). The essential dependencies of noise characteristics from the system parameters are determinated.

1.2. It is continued the development of an original device for light control by light and we have describe its application for formation of a rectangular laser pulses with precisely varied duration in nanosecond scale. The device employs an idea that given volume near the limits of the gap in the Fabry-Perot Interferometer (FPI) with high reflecting coatings (~ 92 - 97 %), can be illuminated by light in two essentially different ways – directly and through the mirrors. In combination with high sensitivity of the FPI transmission to the losses in the gap, this permits, using in the gap a saturable absorber, (SA), to obtain efficient control of the resonant beam that is incident through the mirror by the second beam, which directly illuminates the gap. We have shown that such devices can be successively built using as saturable absorber $Cr^{4+}$: YAG material. The variation of the controlled beam intensity, with variation of the controlling beam, increases more than of order of magnitude in comparison with a simple use only of a saturable absorber.

### 2. Coherent resonances in gas media and discharges

*2.1. CPT resonances and applications*

Based on a modified model we have derived a system of equations, which

describes an atomic ensemble, placed in an external magnetic field with an arbitrary orientation and irradiated by a linearly polarized light. This allows us to solve consistently some concrete problems. For example by using some new tools for numerical calculations we have modeled the influence of an extra, arbitrarily oriented magnetic field on the atomic system in order to study the conversion of the higher rank components (up to 4) of the statistical operator **ρ** into second rank components, which are observable. These results are important for the optimization of some magnetometer systems.

The variations of the Earth magnetic field were investigated with the CPT-magnetometer developed in the Institute as part of the Project "New Magnetometer" within the frames of the EU's Fifth Framework Programme. Three collaborators from our laboratory were involved. The obtained results highly correlate with those of the specialized geomagnetic observatories, which use other magnetometric techniques. A distinguishing feature of the CPT-magnetometer measurements is the possibility to detect fast variations of the Earth/laboratory magnetic field. A comparison of our results with those received by another European geomagnetic laboratory, give us good reasons to consider that the IE's CPT-magnetometer completely meets the requirements for geophysical investigations – accuracy better than or equal to 0.5 nT, resolution – 1 nT, response time > 1 Hz. The developed experimental set-up has a potential for application in the archeology and medicine.

The results from the stray magnetic field influence on the CPT-resonances and the conversion of the fourth rank polarization moments into observable (quadruple) moments are reported on ICONO LAT-, May11-15, 2005 – St Peterburg-and LTL Plovdiv 2005.

*2.2. Magneto-optical and magneto-galvanic resonances in gas media*

Systematic theoretical and experimental investigations on the relation between the Hertzien atomic system coherence and the magneto-galvanic/ opto-galvanic resonances in gas media and discharges were carried out in a close collaboration with the Laboratory of Coherent Spectroscopy of NIIP of the St.-Petersburg University (Russia).

The detection method of Hanle resonances in absorption, which had been earlier optimized, has been applied in the investigation of a laser-induced alignment of rotational and hyperfine sub-states of the $NO_2$ ground (electron) state. For $Ar^+$ laser irradiation of a cell filled with $NO_2$, a qualitative explanation of the observed absorption resonance in a magnetic field has been given. According to the model and the estimations this resonance is due to the alignment of the hf- F-components, which are resonant with the laser radiation (transitions N", J" → N', J'). This is an additional confirmation of the M. P. Chaika's hypothesis, concerning the self-alignment of the $NO_2$ ground (electron) state in a molecular beam. The results are published in [1, 13].

Developed earlier theoretically idea about the relation between magneto-galvanic (MG) resonances and self-alignment of resonant (and metastable) states of noble (buffer for hollow cathode devices) gases was investigated experimentally. The main goal of these studies was to clarify the different opto-galvanic detectors parameters and the excitation conditions needed for optimization of the MG signals registration. We have implemented a new approach in the investigation of the MG signals in HCL, which is based on the observation of the immediate influence of the laser radiation, resonant with a given atomic transition, on the MG signal. The obtained experimental results confirm our previous hypothesis, that the source of the MG signal in neon HCL is the self-

alignment of the $1s_5$ neon state. These new results were reported on XIV Summer School VEIT and on XXIII Spectroscopy Congress in Russia. Some conclusions for dynamic optogalvanic effects and their application possibilities were discussed in [2].

We have developed a new flexible and multi-functional automated control- and detection system for magneto-optical and magneto-galvanic experiments. Together with the recent promising experimental results, obtained with the new system, we and our colleagues from the St. Petersburg University are on our way of creating a model of the MG effect, which should clarify the formation of alignment and self-alignment of the neon $1s_5$ state.

## 3. Laser medical and bio-medical research and applications

*3.1. Laser- and light-induced fluorescence spectroscopy of the human skin*

As results from the recent projects M1422/04 "Improvement of optical biopsy applications in the diagnostics of skin cancer" and MU-F-03/05 "Development of apparatus and methods for optical biopsy of human skin" were developed and tested spectral diagnostic methods for early differentiation of malignant melanoma vs. normal skin and benign melanin-pigmented cutaneous lesions. The methods of laser-and light induced fluorescence spectroscopy were applied using endogenous and exogenous chromophores.

Naturally existing chromophores' fluorescence of normal skin and of its melanin-pigmented pathological changes was investigated, including cancer lesions. The autofluorescence spectra in blue-green spectral region were obtained. Special investigation was carried out for the blood and melanin content influence over the spectral shape of the fluorescence spectra obtained in vivo. For melanin-pigmented lesions were not observed significant spectral shape changes, just rapid decrease of the fluorescence intensity. However, the intensity level changes between different lesion types were enough to develop a differentiation algorithm. These investigations were carried out in vivo in the frames of a common project with National oncological center in Sofia.

The light-induced fluorescence spectra were obtained from different skin anatomic areas and different skin phototypes (phototype I, II and III – typical for Bulgarian region). The results obtained were significantly different depend on the skin phototype. Good reproducibility in the frames of one skin type was also obtained which allowed using light-induced fluorescence (excitation in region 360-450 nm) for determination of skin phototypes of the patients with good objectivity and in real time without skin damage (as in some of the recently used methods).

*3.2. Phthalocyanines as photosensitizers for photodiagnosis and photodynamic therapy*

The method of exogenous fluorescence spectroscopy because of the low intensity levels obtained in autofluorescence spectroscopy of the melanin-pigmented cutaneous lesions, as well as to obtain better differentiation between benign and malignant lesions and to improve the contrast in early stages of the tumor growth was applied. The phthalocyanines which are photosensitizers with improved spectral properties in near-infrared spectral region, where the human tissues have lowest internal absorption were applied for these experiments. They absorb in the region around 660-700 nm and fluoresce in 680-760 nm and could be used for detection of big volumes of tissue.

Under cooperation between the Institute of Electronics and the Institute of Organic Chemistry of the Bulgarian Academy of Sciences, we carried out a series of experiments on studying the photophysical properties of this family of newly synthesized photosensitizers for

photodiagnosis and photodynamic therapy of malignant cutaneous lesions.

The absorption and fluorescence spectra were obtained in different transport systems DMF, DMSO, liposomes and cremophores.

The accumulation dynamics of these photosensitizers in the tumour models (mice, tumor – B16 – MM) in vivo were investigated to assess the applicability of the photosensitizers studied for photodiagnosis and photodynamic therapy of malignant cutaneous tumours. Contrast between 2,4 and 3,6 was obtained for tumor lesion against surrounding normal skin and early detection – on the first week after tumor model of MM implantation was also achieved. The photosensitizers used could be applied for photodiagnosis and photodynamic therapy of the skin lesions.

*3.3. Laser-induced fluorescence studies and laser scattering detection of the interaction of zinc phthalocyanine and serum albumins*

The labelling of the biological macromolecules as proteins, lipoproteins, membranes, DNA with red dyes has been considered as an advantageous approach in biophysical and clinical studies**.** Fluorescent labelling offers the ability for detection of non-fluorescent objects (analytes) in the VIS spectral region by very sensitive laser-induced fluorescence (LIF). Thus, their limits of detection are enhanced by several orders of magnitude. Fluorescent labels are specific to the analytes and can be chosen so that the fluorescent signals do not interfere with those of the other objects. However we may suggest that the process of labelling could also be attended from some changes in space structure or conformation changes of macromolecules.

In the present study the interactions of selected proteins - human serum albumin (HSA) and bovine serum albumin (BSA) with zinc phthalocyanine were investigated. The kinetics of protein-ZnPc complex formation was followed by the laser-induced fluorescence and scattering equipment. The binding parameters of the complex formed, as binding constants and binding stecheometry, were determined.

The binding of zinc phthalocyanine (ZnPc) to plasma proteins has been studied by using a laser-induced fluorescence technique. The kinetics of fluorescent intensity at emission maximum of ZnPc (690 nm) of the protein/ZnPc complex was measured. Fluorescent emission data show the solubility and monomerization of the hydrophobic ZnPc in aqueous buffered solutions of studied proteins at 37 °C. The solubility of ZnPc increases in order BSA>HSA. The dynamics of formation of protein-phthalocyanine complexes were detected by changes in fluorescence intensity of the system. It was proposed that the formation of the protein/ZnPc complex results in substantial fluorescent changes and slightly to photochemical reactions. The impact of the photophysical processes in the protein-phthalocyanine complexes was evaluated. The experimental studies demonstrate the capacity of the fluorescent interaction measurements as a promising approach for probing proteins with phthalocyanine.

The interaction process of zinc phthalocyanine (ZnPc) binding to plasma proteins - HSA and BSA at physiological temperature 37 °C has been studied by using a laser-induced dynamic scattering technique. The kinetics of scattered intensity by direct dye excitation (635 nm) of the protein/ZnPc complex was measured. The data of scattered signal of studied complex protein/ZnPc show that the dynamics of formation of protein-phthalocyanine complexes was accompanied by changes in scattering intensity of the system. It was proposed that the formation of the protein/ZnPc complex have as a result conformation changes in proteins. The experimental studies demonstrate the capacity of the measurements in scattered signal from protein/dye complex to give information

for protein structure by probing macromolecules with phthalocyanine.

Interaction of hydrophobic zinc phthalocyanine and two physiologically important plasma proteins, as studied by an experimental laser system, indicate the common features. The trends of complex formation are differently depends on the protein/ZnPc ration and scattered signal show tendency of changes of space parameters of macromolecules. In both cases the hydrophobic origin of the binding seems to play major role. The fluorescence emission data suggest one non-cooperative interaction of ZnPc with serum albumins in 1:1 molar complex.

*3.4.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 is developed. Due to the original method of data processing, the accuracy of measurements is 3-4 times higher compared with similar traditional systems. As a result, the registration of small changes of arterial blood saturation is reached with accuracy higher than 0.5 %.

A novel method of direct control of tissue local oxygen concentration based on laser-induced photodissociation of $HbO_2$ is proposed. It is shown that the local concentration of free oxygen in tissue under laser irradiation significantly increases at higher temperature of the body. The efficiency of releasing bonded oxygen from haemoglobin increases with increase in the local temperature of tissue and at temperature around $42^0$C reaches saturation 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 cell metabolism.

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

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Optics and Spectroscopy 2005;99: 5 – 7.

2. Petrov L, Arsov V, Polischuk V, Todorov G, Zhechev D,
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A new approach for tunable subnanosecond pulse generation using an active mirror & theoretical and experimental study,
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13. Polischuk V, Todorov G, Petrov L, Rashev S,
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Proc SPIE 2005;5830:201-205.

14. Borisova E, Angelov I, Mantareva V, Petrova D, Townsend P, Valberg L, Avramov L,
Tumor detection by exogenous fluorescent dyes using new generation photo-multiplier tubes,
Proc SPIE 2005;5830:399-403.

15. Borisova E, Troyanova P, Stoyanova V, Avramov L,
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Proc SPIE 2005;5830:394-399.

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Comparative study on the effect of He-Ne laser radiation and polarized monochromatic light on the changes of the cornea after chemical burning,
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Reflectance measurements of skin lesions – non-invasive method for diagnostic evaluation of pigmented neoplasia,
Proc SPIE 2005;5862/20A:1-11.

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Ultra-short laser ablation of biological tissue
Proc SPIE 2005;5830:473 – 478.

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New approach to carbon monoxide poisoning treatment by laser-induced photodissociation of carboxyhemoglobin of cutaneous blood vessels,
Proc SPIE 2005;5830:414-419.

22. Asimov M, Gisbrecht A, Mamilov S, Plaksiy Y,
Investigation of the influence of laser irradiation on the relative concentration of oxyhemoglobin in the blood,
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Proc Int Conf Advanced Optoelectronics and Lasers (CAOL'2005) 2005, pp 279-282.

24. Deneva M, Todorova P, Nenchev M,
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Proc Int Conf Electronics'2004, pp 45-50.

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Development and application of a new device for light control by light (optical transistor),
Proc Int Con. Electronics'2004 2005, p. 181-185, Bulg.

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A simple new technique for laser spectrum locking at atomic absorption line
Proc Int Conf Electronics'2004 2005, p. 39-44, Bulg.

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Optical biopsy of non-melanin pigmented cutaneous benign and malignant lesions,
Int Conf Coherent and Nonlinear Optics/Int Conf Lasers, Applications, and Technologies (ICONO/LAT 2005), May 2005, St. Petersburg, Russia.

2. P. Troyanova, E. Borisova, V. Stoyanova, L. Avramov,
Laser-induced autofluorescence spectroscopy of benign and dysplastic nevi and malignant melanoma,
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3. E. Borisova, P. Troyanova, L. Avramov,
Laser-induced autofluorescence properties of base-cell lesions – analysis and algorithms for diagnosis and differentiation,
Int Conf Coherent and Nonlinear Optics/Int Conf Lasers, Applications, and Technologies (ICONO/LAT 2005), May 2005, St. Petersburg, Russia.

4. E. Borisova, P. Trojanova, L. Avramov,
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European Conference of Biomedical Optics (ECBO'2005), June 2005, Munich, Germany.

5. E. Borisova, I. Angelov, V. Mantareva, L. Avramov,
Fluorescent spectroscopy of cutaneous pigmented malignant melanoma using endogenous and exogenous chromophores emission,
International School on Bio-photonics'05, June 2005, Ven, Sweden.

6. E. Borisova, L. Avramov,
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3rd Int Summer Student School Nuclear Physics Methods and Accelerators in Biology and Medicine, July 2005, Dubna, Russia.

7. L. Avramov,
From tissue optics study to smart laser therapy,
3rd Int Summer Student School Nuclear Physics Methods and Accelerators in Biology and Medicine, July 2005, Dubna, Russia.

8. T. Tsvetkova, S. Balabanov, E. Borisova, L. Avramov,
Photoluminescence properties of $Si^+$ and $C^+$ implanted polymer surfaces,
14th Int Summer School Vacuum, Electron and Ion Technologies VEIT'05, September 2005, Sunny Beach, Bulgaria.

9. T. Tsvetkova, S. Balabanov, G. Hadjichristov, L. Avramov, E. Borisova, S. Sinning, L. Bischoff,
Photoluminescence properties of PMMA ion implanted with silicon,
14th Int Summer School Vacuum, Electron and Ion Technologies VEIT'05, September 2005, Sunny Beach, Bulgaria.

10. D. Slavov, L. Petrov, V. Arsov, V. Polischuk, N.Mihailov, G. Todorov,
Magneto-Galvanic effect ia Hollow Cathode Lamp - new experimental investigation,
14th Int Summer School Vacuum, Electron and Ion Technologies VEIT'05, September 2005, Sunny Beach, Bulgaria.

11. V. Stoyanova, P. Troyanova, E. Borisova, L. Avramov,
Multispectral discriminant analysis of cutaneous tumor fluorescence and reflectance spectra,
4th Int Symp Laser Technologies and Lasers (LTL'05), October 2005, Plovdiv, Bulgaria.

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Reflectance properties of carious lesions,
4th Int Symp Laser Technologies and Lasers (LTL'05), October 2005, Plovdiv, Bulgaria.

13. E. Borisova, V. Stoyanova, P. Troyanova, L. Avramov,
Laser-induced autofluorescence spectroscopy of cutaneous lesions,
4th Int Symp Laser Technologies and Lasers (LTL'05), October 2005, Plovdiv, Bulgaria.

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Simplified experimental set-up for fluorescence and reflectance spectroscopy of normal skin and neoplasia,
4th Int Symp Laser Technologies and Lasers (LTL'05), October 2005, Plovdiv, Bulgaria.

15. V. Mantareva, I. Angelov, I. Goshev, E. Borisova, L. Avramov,
Laser-induced fluorescence investigations of protein-longwavelength dye interactions,
4th Int Symp Laser Technologies and Lasers (LTL'05), October 2005, Plovdiv, Bulgaria.

16. I. Angelov, V. Mantareva, E. Borisova, L. Avramov,
Laser scattering detection of protein conformation changes,
4th Int Symp Laser Technologies and Lasers (LTL'05), October 2005, Plovdiv, Bulgaria.

17. N. Momchilov, S. Tabakov, K. Koev, L. Avramov,
Low-level laser system microcontroller,
4th Int Symp Laser Technologies and Lasers (LTL'05), October 2005, Plovdiv, Bulgaria.

18. L. Avramov, E. Borisova,
Medical Laser Technologies,
4th Int Symp Laser Technologies and Lasers (LTL'05), October 2005, Plovdiv, Bulgaria.

19. D. Slavov, K. Nasirov, N.Petrov, T.Karaulanov, S.Cartaleva,
Coherent resonances in Rb radiated by frequency modulated light,
4th Int Symp Laser Technologies and Lasers (LTL'05), October 2005, Plovdiv, Bulgaria.

20. D. Slavov, T.Karaulanov, N.Petrov, S.Cartaleva, G. Todorov, Y. Dancheva, V. Biancalana, L. Moi,
All optical magnetometer,
4th Int Symp Laser Technologies and Lasers (LTL'05), October 2005, Plovdiv, Bulgaria.

21.D. Slavov, L. Petrov ,V.Arsov , V. Polischuk , V. Domelunksen, G. Todorov,
Observation of Stray Magnetic Field Influence on the High Rank Polarization Moments

4th Int Symp Laser Technologies and Lasers (LTL'05), October 2005, Plovdiv, Bulgaria.

22. E. Borisova, P. Trojanova, L. Avramov,
LIAFS for diagnosis and differentiation of malignant melanoma – results and perspectives,
8th Winter Seminar for Young Scientists, December 2005, Sofia, Bulgaria.

23. N. Momchilov, S. Tabakov, K. Koev, L. Avramov,
Microcontroller device for low-level laser system,
8th Winter Seminar for Young Scientists, December 2005, Sofia, Bulgaria.

24. L. Avramov,
Bulgarian dimensions of European science,
8th Winter Seminar for Young Scientists, December 2005, Sofia, Bulgaria.

**ONGOING RESEARCH PROJECTS:**

Financed by the National Council for Scientific Research

F-1006/00 Magnetic resonances in laser induced galvanic signals and possibilities for application.
F-1305/03 Creation of new methods for development of lasers with non-conventional generation characteristics.
F-1203/02 Emergent structures and collective behaviors in extended and distributed chaotic systems.
M-1422/04 Improvement of optical biopsy applications in the diagnostics of skin cancer.
MU-F-03/05 Development of apparatus and methods for optical biopsy of human skin.
VUL-01/05 Optical biopsy of dysplasia and tumors in upper part of gastrointestinal tract.
F-1404/04 Coherent effects in gas media nano-layers.

Financed by International Atomic Energy Agency

No CRP F-12016 Ion Beam Modification of Polymer Surfaces

Financed by ministries, departments, and companies

Optella Ltd: Photophysics characteristics investigation of newly synthesized photosensitizers for photodiagnosis and photodynamic therapy of malignant cutaneous lesions.
Laserproduct Ltd: Scientific-applied project for development of laser system.
Dentistry Department of Medical University-Sofia: Light-activated chemical bleaching of teeth – medico-clinical investigation.

**COLLABORATIONS:**

Specialized laser systems for spectral analysis and applications in metrology,
Conservatoire National des Arts et Metiers, INM, Paris, France.
Investigation of optical and galvanic properties of low-temperature plasma by the methods of laser spectroscopy,
University of Sankt Petersburg, Sankt Petersburg, Russia.

Development of new tunable lasers sources,

Institute of Physics, National Academy of Sciences of Belarus, Minsk, Belarus.

f new methods for laser diagnostics and therapy of dermatological and oncological diseases,
Institute of Physics, National Academy of Sciences of Belarus, Minsk, Belarus.

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**.**

**LECTURE COURSES:**

Quantum electronics and laser technique; Technological and medical laser devices; Selected topics of applied physics,
Technical University of Sofia, Plovdiv Branch, Plovdiv, Bulgaria.

**Ph.D. THESES:**

Ekaterina Borisova,
Laser-induced fluorescence and reflectance spectroscopy of the human tissues.

**SCIENTIFIC EVENTS:**

Prof. D.Sc. M. Nenchev, co-chair of the Programme Committee of the IV International Symposium Laser Technologies and Lasers, October 2005, Plovdiv, Bulgaria.
Assoc. Prof. Dr. L. Avramov, member of the Programme Committee of the IV International Symposium Laser Technologies and Lasers, October 2005, Plovdiv, Bulgaria.
Dr. E. Borisova, Secretary of the Organizing Committee of the VIII Winter Seminar for Young Scientists, December 2005, Sofia, Bulgaria.
Dr. D. Slavov, member of the Organizing Committee of the XIV International School on Quantum Electronics Laser physics and applications 2006.
L. Petrov-PhD student, member of the Organizing Committee of the XIV International School on Quantum Electronics Laser physics and applications 2006.

**LABORATORY VISITS:**

1. Dr. L. Avramov,
SIEMENS Department of Medical Solutions, Erlangen, Germany,
Work meeting to discuss the perspectives for development of optical tomography system.
2. A. Gisbreht,
Ukrainian Academy of Sciences, Kiev, Ukraine,
Work meeting.

**GUESTS:**

1. Prof. Mustafo Asimov, Institute of Physics, Belarus Academy of Sciences, October 2005.
2. Prof. Peter Townsend, University of Sussex, UK, October 2005.

LABORATORY

**LASER SYSTEMS**

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

TOTAL STAFF: **12**
RESEARCH SCIENTIST: **9**
Assoc. Prof. S. Cartaleva, Ph.D.; Assoc. Prof. E. Alipieva, Ph.D.; Assoc. Prof. S. Gateva, Ph.D.; C. Andreeva, Ph.D.; T. Karaulanov,PhD; O. Vankov; V. Sarova; E. Taskova; K. Gulieva. P.Todorov.
Ph.D. student:. N. Petrov

**RESEARCH ACTIVITIES:**

The research activities of the group working in the field of high-resolution laser spectroscopy were mainly related to the investigation of the potential of the Coherent Population Trapping (CPT) effect for precise magnetic field measurement. CPT resonances are obtained in alkali atoms when irradiated by coherent laser fields. Three approaches for magnetic field (MF) measurement were developed and three experimental set-ups were built in the Institute of Electronics: 1) CPT obtained by coupling the non-degenerate Zeeman sublevels of the two ground-state hyperfine (hf) levels of Rb and Cs by laser modulation in the GHz region; 2) CPT obtained by coupling degenerate Zeeman sublevels of a single hf ground-state level single-frequency light; and 3) CPT obtained by coupling non-degenerate Zeeman sublevels belonginf to a single ground-state hf level by means of laser light modulated in the kHz region.

Concerning the first approach, we have developed a methodology and a portable setup connected to a PC, for automatic MF measurements. The sensitivity of the device to MF variations is 50 nT for 10 s measurement time. It finds applications in metrology for measurement of the absolute value of the MFs in the range 0,1 ÷ 1000 μT with a sensitivity of 50 nT.

As a result of the second approach, an experimental setup and methodology for measurement of the three components of the MF with a sensitivity of 0,1 nT. The methodology is appropriate for application in geomagnetic stations.

As a result of the work on the third approach, a portable device and methodology have been developed, for measurement of MF in the interval 2 ÷ 200 μT with a sensitivity of 1 nT, with potential for application in geomagnetism, archaeology and material sciences.

Beside this, coherent resonances in Hanle configuration have been investigated at different polarizations and intensities of the exciting laser field. The sensitivity of the Hanle resonances to stray MFs at linear, circular and elliptical polarizations of the light. It has been shown that the resonance has a complex shape – a narrow structure (arond 1 mG wide) is superimposed on a broader one (several tens of mG). The dependenceo of the width and amplitude of both structures in absorption and in fluorescence have been studied depending on the light intensity. It has been shown that the width of the narrow resonance does not change under the conditions of our experiment, while the width of the broader structure depends in a complex way on the intensity. This dependence is different for the resonance in absorption and in fluorescence. The reason for this behaviour has been investigated [4].

CPT effects have also been investigated by application of additional ac

MF parallel to the dc MF. It has been shown that the ac MF leads to observation of additional resonances separated at frequencies multiple to the frequency of the ac MF. These sideband resonances are extremely narrow and can be resolved even at frequencies of the ac MFs lower than kHz, this making them very attractive for spectroscopic applications. A theoretical model is also developed, which describes well the obtained experimental results [2].

We perform experimental and theoretical study of sub-Doppler spectrum observed at the hyperfine (hf) transitions of Cs confined in an Extremely Thin Cell (ETC). The width of this cell is from 100 to 1500 nm. We use a cw extended cavity diode laser operating in single-frequency mode and with line-width of about 3 MHz. Very good contrast sub-Doppler resonances in absorption are obtained and their behaviour at $L = \lambda/2$ and $L = \lambda$ are examined. Moreover, at $L = \lambda$, new narrow dips are observed in the fluorescence. At $L = \lambda$, the sub-Doppler resonance formation is attributed to the velocity selective optical pumping taking place for atoms which velocity is mainly parallel to the cell windows that provides sufficiently long time for optical pumping to build up. An explanation is proposed also for the fluorescence behaviour of the 4-5 cycling transition.

In addition to the investigation of the absorption and fluorescence spectra, an experimental evidence of nonlinear, ground-state Hanle resonances in ETC has been performed. Cs atoms, confined in ETC are irradiated by mono-mode diode-laser light which is successively frequency tuned in resonance with each of the three allowed hf transitions starting from the ground-state hf levels $Fg = 3,4$ of $D_2$ line of Cs. The transmitted through the cell beam is registered in dependence on a perpendicular to the laser beam magnetic field *B*, scanned around B = 0. Despite the expectation of EIA resonance for $Fg = 4 \rightarrow Fe = 5$ transition, the EIT resonances of similar behaviour are observed for all hf transitions at cell thickness $L = \lambda$. The nonlinear Hanle effect in NTC was analyzed by means of Zeeman coherence rate equations. Assumptions of redistribution of atoms among the magnetic sublevels of the excited state and atomic coherence relaxation are incorporated in a form similar to one used in [2]. We believe that reason for atom redistribution among Zeeman sublevels of the excited state is a long-range interaction of atoms with the walls of the ETC. Theoretical and experimental resonance profiles comparison shows a qualitative agreement.

**PUBLICATIONS:**

1. Affolderbach C, Andreeva C, Cartaleva S, Karaulanov T, Mileti G, Slavov D,
Light shift suppression in laser optically pumped vapour-cell atomic frequency standards,
Appl Phys B: Lasers and Optics, 2005;80/7:841.

2. Bevilacqua G, Biancalana V, Breschi E, Dancheva Y, Moi L, Andreeva C, Cartaleva S, Karaulanov T,
Coherent population trapping spectra in presence of ac magnetic fields
Phys Rev Lett 2005;95:123601.

3. Alipieva E, Gateva S, Taskova E,
Potential of the single-frequency resonances for magnetic field measurement,
IEEE Trans Instrum Meas 2005;54/2:738-741.

4**.** Gateva S, Alipieva E, Taskova E,
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Phys Rev 2005;A72:025805.

5. Cartaleva S, Yanev A, Alipieva E, Gateva S, Todorov G, Slavov D, Andreeva C, Karaulanov T, Taskova E, Petrov L., Sarova V, Vaseva K, Petrov N,
Coherent effects in magnetometry,
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6. Alzetta G, Cartaleva S, Gozzini S, Karaulanov T, Lucchesini A, Marinelli C, Moi L, Nasyrov K, Sarova V, Vaseva K,
Magnetic Coherence Resonance Profiles in Na and K,
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Proc SPIE 2005;5830:196-200.

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Proc SPIE 2005;5830:170-175.

9. Bevilacqua G, Biancalana V, Breschi E, Dancheva Y, Marinelli C, Mariotti E, Moi L, Andreeva C, Karaulanov T, Cartaleva S,
Towards a simple and performing CPT based magnetometer: optimization of experimental parameters,
Proc SPIE 2005;5830:150-158.

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Power dependence of the coherent population trapping resonances at different registration,
Proc SPIE 2005;5830: 191-195.

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High sensitive in-line fiber-optic structure for refractometric measurements,
Proc SPIE 2005;5830: 546-550.

**ONGOING RESEARCH PROJECTS:**

Financed by the National Council for Scientific Research:

F-1404/04, Coherent effects in gas-phase nano-layers.
F-1009/04, Nonlinear magneto-optical effects in a resonance medium.
F-1005/00, Изследване на кохерентни ефекти при оптическо напомпване в рубидий.

**COLLABORATIONS:**

Coherent population trapping effect in alkali atoms,
CNR, Italy.

Spectral characteristics of lasers and laser spectroscopy,
Institute of Solid-State Physics and Optics, Hungarian Academy of Sciences.

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

High resolution spectroscopy in quantum optics and metrology
Institute of Physics, Belgrade, Serbia and Montenegro.

**PhD THESES DEFENDED:**

Todor Karaulanov,
Coherent population trapping effect in alkali atoms and application for magnetic field measurtements.

**LABORATORY VISITS:**

T. Karaulanov, S. Cartaleva - IPCF – CNR, Pisa, Italy, 15 days.
S. Gateva, Institute of Physics, Warsaw, Poland, 50 days.

**GUESTS:**

Ms. Marina Mijailovic, Mr. Zoran Gruijc, Mr. Alexander Krmpot,
Institute of Physics, Belgrade, Serbia and Montenegro.

LABORATORY

## FIBER AND NONLINEAR OPTICS

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

TOTAL STAFF: **4**
RESEARCH SCIENTIST: **3**
Assoc. Prof. I. M. Uzunov, Dr. Sc., Assoc. Prof. L. Kovachev, Ph.D.; T. Arabadziev, Ph.D.

**RESEARCH ACTIVITIES:**

### 1. New nonlinear and linear equations for ultra-short optical pulses. Relative linear stability of light bullets

We have investigated the application of the nonlinear amplitude equation, in linear and also in some special kind of nonlinear regime of propagations. Different generalizations of the paraxial equation are obtained, depending from the spectral zones, the material constants, and the initial shape of the pulses (long pulses or light bullets). From the provided analysis of the linear equations and theirs solutions in k-space, and also from the investigation of the dynamics of the Gaussian pulses in the real space under the dynamics of these equations, we find new relatively stable dynamics of the light bullets in linear regime of propagation. We come to the next important conclusion for the linear dynamics of light bullets. The light bullets with high number of harmonics in the pulse are relatively stable in respect to long pulses (paraxial approximation), or in respect to light bullets with small number of harmonics in the pulse. We also investigate more precisely experimental conditions and media, suitable to observing 3D+1 optical vortices. It was found large spectral region near the plasma frequency in cold plasma for fs and few picosecond pulses and also in high UV and Ro region of semiconductors and dielectrics, where the temporal effects of the second order in the amplitude equations can be neglected. In these spectral zones the propagation of optical pulses is governed by the amplitude vector nonlinear Schrodinger equation and, as it was predicted, stable 3D optical vortices can be observed. They look like a Fraunhofer distribution in the space. The internal vortex structures can be seen after the passing of the vortices through the linear polarizer.

### 2. Femtosecond magnetization dynamics

A growing trend in magneto-optics research in recent years has been towards studies of high-speed phenomena, driven by both scientific and technological interest in a broad variety of systems. Among the most significant developments in this area has been the realization that it is possible observation of transient phenomena on unprecedented scales, corresponding to femtosecond relaxation times or terahertz frequencies. In the experiments, provided in leading laboratories on magneto-optics, the electronic system is heated by a femtosecond laser pulse. The successive relaxation between electron, spin and lattice is explored measuring the reflectance and magneto-optical Kerr effect experienced by second-delayed probe pulse. In this way was observed longitudinal magnetic relaxation times of order of $T_1 \sim 200$ fs. These experiments request new treatment of the equations describing the propagation of ultra short fs optical pulses in such media. It must be

taken into account also the non-stationarity of the magnetic response of the media. We suggest a theoretical model in the case of magneto-optical media with different relaxation times of magnetization $t_1$ and polarization $t_2$. It is obtained slowly-warring amplitude equation of the amplitude of the electrical field $\vec{A}(x,y,z,t)$ in the case of linear non-stationary electronic and magnetic response.

The amplitude equation is the same slowly-warring amplitude equation, as in the case of dielectrics, when the magnetic response is constant ($\mu = const$), but governed more interesting dynamics: When the magnetic response is non-stationary, magnetization depend from frequency, ($\mu(\omega)$), and we define new dispersions relation for the wave vector $k(\omega)$, linear refractive index $n(\omega)$, the group velocity v and the high - order dispersions. The relation for the group velocity give unexpected new dynamics of localized optical pulses, when $\mu(\omega)$. The group velocity can be positive, negative and to reach values higher than velocity of vacuum, when $\mu(\omega)$ is symmetric function. This situation is possible to reach near to paramagnetic resonance of free electrons or other media with free half-spin moments.

## 3. Nonlinear dynamical systems (NDS) in fiber optics

We analysed the possibility of existence and stability of multiple soliton-bound states (or "vector solitons") in nonlinear optical fibers with and without optical amplification. This question is of great importance because of the undesirable effect of Kerr nonlinearity on the performance of fiber optical communication systems. As is well known the effect of Kerr nonlinearity causes the mutual interaction between the pulses, which in turn leads to a drastic limitation of the optical fiber communication system's bandwidth.

Dynamics of two modes with equal polarizations and different frequencies as well as the interaction of two optical modes, with different polarizations and equal frequencies have been theoretically studied. Dynamics in directional coupler with weak intermodal coupling was theoretically described. Raman scattering in the birefringent fibers was also treated. The corresponding systems of two coupled nonlinear Schrödinger equations have been transformed to nonlinear dynamical system (NDS) with two degrees of freedom. For some of the models, Lie group method has been applied for obtaining the symmetries of the differential equations. This approach of analysis allows not only properly to identify the possible invariant solutions but also to classify them. For the other proper trial functions were applied. Using a Lie group technique, the most general Lie algebra have been derived for the cases of parallel and orthogonal Raman gain. The associated optimal sets of reduced systems of ordinary diffrerential equations were obtained. Next the possibility of existence of coupled soliton states was studied. We looked for an approximate vector solitary wave solutions by a perturbative approach. The perturbation has been applied to the soliton solution of a given polarization in the decoupled case. We discovered the existence of two families of vector solitary wave solutions. Symmetry reduction method has been applied also to the analysis of nonlinear media with negative cross-phase modulation and different group-velocity dispersion regions for the two polarization modes. The most general Lie algebra and the corresponding Lie group of point symmetries permitted by the considered equations have been derived.

The obtained NDS with finite number of degrees of freedom have been then further analyzed with the specific methods of nonlinear dynamic theory. Following

numerical approaches have been applied: a) phase plane analysis; and b) solution of two-point boundary value problem for identifying the solitary stationary solutions. The phase plane analysis of the NDS associated with the integrable by the inverse scattering method Manakov system was performed by the usage of the second additional integral of motion besides Hamiltonian. The topological structures of the phase space as well as the fixed points were studied through Poincare surface section. As is well known the hyperbolic fixed points are connected with a solitary type of stationary solutions. The stability of the fixed points were analyzed by means of determination of the eigenvalues of the corresponding Jacobian matrix and application of Liapunov's theory.

Two different analytical approaches were applied for the analysis of the NDS. Analytical approach for integration of coupled nonlinear systems of ODE, describing two-degree of freedom NDS was studied, which utilizes the mechanical approach based on the application of the Hamilton-Jacoby equation. Separation of variables has been performed through transformation to the elliptic coordinates. Using this approach the formation of multiple soliton-bound states in circular optical fiber was analyzed. Some specific analytical solutions of this problem expressed in terms of elementary functions were found. They represent the shapes of "vector" soliton solutions. Numerical solution of the corresponding two-point boundary value problem has been also performed. Obtained analytical and numerical results were compared. Further application of this approach will include the solution of Jacobi inversion problem for hyperelliptic integrals that can be expressed in terms of Riemann theta functions.

We performed analytical investigation of branching bifurcations of polarized soliton states in nonlinear couplers and as well as similar bifurcations that appear in the study of dynamics of two modes with equal polarizations and different frequencies in nonlinear optical fibres. The expressions of bifurcating soliton states in terms of hyper-geometric functions were identified. The obtained results were compared with the results from numerical solution of the corresponding two-point boundary value problem.

Finally, dissipative NDS, derived from the theoretical model describing the periodical amplification with semiconductor optical amplifiers (SOA) of optical pulses propagating in optical fibers have been numerically analysed. Important issue for such dynamical system is the question of existence and classifications of the possible type's stationary wave solutions. Special attention has been paid to the dissipative solitons and multi-hump solutions. In particular, the so-called "accelerating" stationary waves has been studied and compared with the "non-accelerating" ones. The functional shape of dissipative solitons has been obtained by means of numerical solution of the corresponding two-point boundary value problem of the NDS.

## 4. The amplification of the solitary optical waves in the fibers with positive group velocity dispersion

The investigation of the generation and the stable propagation regime of the solitary optical waves in all-optical transmission lines are of importance for the development of the high-speed optical communication systems. The stationary solitary optical waves as the averaged and dissipative optical solitons can be generated in dissipative nonlinear media with group velocity dispersion (GVD) and periodical amplification. Its preservation in such media can be explained on one hand with the presence of strong balance between the group velocity dispersion and nonlinearity and on the other hand with the presence of the delicate balance between

looses and nonlinear amplification. We investigate numerically a cascaded fiber optical communication system with in-line semiconductor laser amplifiers (SLA). The gain saturation and the small gain exceeding in SLA at negative GVD region can lead to generation of the dissipative optical solitons. We determine numerically that in the positive GVD region at above conditions the solitary optical wave's generation with similar properties is possible too.

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1. Kovachev LM, Ivanov LM,
Vortex solitons in dispersive nonlinear Kerr type media,
Proc SPIE, Nonlinear Optics Applications, 2005;5949/07:1-12.

2. Pulov V, Uzunov IM, Chakarov E,
Two light modes propagation in nonlinear media with negative cross-phase modulation via Lie group analysis,
Proc SPIE, Laser Physics and Applications, 2005;5830:100-104.

3. Pulov V, Uzunov IM, Chakarov E,
Symmetry properties of nonlinear pulse propagation in nonlinear birefringent optical fibers with Stimulated Raman scattering,
Proc SPIE, Laser Physics and Applications;2005;5830:105-109.

4. Kovachev LM, Ivanov LM,
Vortex solitons,
Los Allamos E-mail Lab., 2005; 1: Paper arXin:nlin.PS/0504020.

5. Kovachev LM, Ivanov LM,
Propagation of ultra short optical pulses in dispersive Kerr type media with no-stationary response,
Proc First Int Conf FMNS, Blagoevgrad, Bulgaria, 2005, pp 198-205.

6. Uzunov IM, Pulov V,
Vector solitary wave solutions to coupled nonlinerar Schrodinger equations with Raman terms,
Proc Second Int Congress Mechanical and Electrical Engineering and Marine Industry (MEEMI-2005), 2005;3:187-190.

7. Pulov V, Uzunov IM, Chakarov E, Lyutskanov V,
Lie group symmetry reduction of two coupled nonlinear Schrodinger equations,
Proc Second Int Congress Mechanical and Electrical Engineering and Marine Industry (MEEMI-2005), 2005;3:191-195.

8. Uzunov IM,
Optical fiber communication systems,
Proc XXXIII National Conf Physics and Information and Communication Technologies, Varna, Bulgaria, 2005, pp 18-25 (in Bulgarian).

**CONFERENCES:**

1. Kovachev LM, Ivanov LM,
Vortex solitons in dispersive nonlinear Kerr type media,
International Congress on Optics and Optoeletronics, SPIE Europe, 28 August -2 September 2005, Warsaw, Poland.

2. Kovachev LM, Ivanov LM,
Propagation of ultra short optical pulses in dispersive Kerr type media with no-stationary response,
First International Conference of Faculty of Mathematics and Natural Sciences, Blagoevgrad, Bulgaria, 12-15 June 2005.

**LECTURE COURSES:**

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

General Physics,
Technical University, Sofia, Bulgaria.

**Ph.D THESES:**

T. Arabadzhiev,
The propagation of soliton waves in nonlinear media and fiber optic transmission lines with periodical amplification.

LABORATORY

## OPTICAL RADIOMETRY

HEAD: **Prof. E. Ferdinandov, Dr.Sc.**

TOTAL STAFF: **5**
RESEARCH SCIENTISTS: **3**
Assoc. Prof. V. Tsanev, Ph.D.; P. Pavlova, Ph.D; E. Angelova; M. Danov

### RESEARCH ACTIVITIES:

The main research topics of the laboratory continue the work done during the previous year.

1. Theoretical investigation of the influence of atmospheric turbulence on the quantitative features of different type optical systems was performed. A full analytical description of the energy balance of a free space laser communications system was developed in case of fixed BER (Bit – Error Rate). The results were achieved using a specially crafted technique. This algorithm was also applied to analyse the coherent images created from far situated objects (including cosmic objects).

2. The second area of investigations concerned various applications of the radiometric and colorimetric analysis:

- Special software for colorimetric estimation of the spectrum had been developed and used to collect database of features of different types of rocks. This classification was carried out on the base of spectra measured in the "Remote Sensing" Department of the Solar-Terrestrial Laboratory of BAS. Another rocks' classification was based on the infrared radiometric signals acquired with the existing improved experimental set-up for hemispherical emission measurements. Another system for infrared spectral emission measurements is currently in process of assembling.
- Spectral reflectance features were used for estimation the vital condition of agricultural plants. This investigation was provided also in cooperation with Solar-Terrestrial Laboratory of BAS. The software mentioned above has been adapted to find differences in colorimetrical features of the plants under stress.
- The liquid crystals phase state was studied preparing new liquid crystals mixtures and testing of their parameters in dependence on temperature using spectral measurements and colorimetrical analyses. This was a joint work of the team with members from the Institute of Solid-State Physics and the laboratories "Optical Radiometry" and "Condensed Matter Lasers" of the Institute of Electronics.
- The development of an expert system based on the color characteristics of the reflected spectra obtained from skin cancer was continued with preparing a special software for processing the images acquired from the same lesions. The study was done in cooperation with "Condensed Matter Lasers" laboratory.

3. One member of the laboratory's staff currently participates in a team of Cambridge University, which carries out spectral investigation in the optical wavelengths range of the gases and aerosols resulting from volcanic eruptions and burning of agricultural plants.

We consider the dissemination of our scientific knowledge and experience in the educational process as a very important part of our work. The laboratory members taught several courses for the students of the Technical University of Sofia, and its branch in Plovdiv, and the University of Sofia.

**PUBLICATIONS:**

1. Ferdinandov E, Pachedjieva B, Saparev S, Mitsev T,
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2. Pachedjieva B, Ferdinandov E, Saparev S, Mitsev T,
Radiometric determination of the size of cosmic objects detected by photon counting,
Electrotechnica & Electronica, 2005;9-10:9-12.

3. Pavlova P,
Machine Vision and Metrological System Based on Non-linear Signals,
Electrotechnica & Electronica, 2005;1-2:78-80.

4. Pavlova P, Staneva K,
Colour Attributes and Reproducing Signals Discrete Presentation,
Electrotechnica & Electronica, 2005;3-4:3-6.

5. Krezhova D, Yanev T, Lukov S, Pavlova P, Aleksieva V, Hristova D, Ivanov D,
Method for detecting stress induced changes in leaf spectral reflectance,
Compt Rend Acad Bulg Sci, 2005;58/5:517-522.

6. Pavlova P, Avramov L, Naradikian H, Angelov T, Petrov A,
Temperature Dependence of Chromaticity in Polimer-dispersed Cholesteric Liquid Crystal: Reflection and Transmission Characteristics,
J Optoelectr Adv Mat 2005;7/1:285-288.

7. Danov M, Tzanev V,
Emissivity of combination of two types of rocks,
Proc SPIE 2005;5830:120-124.

8. Borisova D, Nikolov H, Danov M,
Spectral mixture analysis for remote sensing data interpretation,
Proc 2nd Int Conf Resent Advances in Space Technologies, Istanbul 2005, Turkey, pp 69-72.

9. Nikolov H, Borisova D, Danov M,
Classification of open pit mines and dump areas based on land cover mapping,
Proc Sci Conf SES'2005, Sofia, Bulgaria, 2005;1:209-214.

10. Nikolov H, Borisova D, Danov M,
Detection of open pit mines and dump areas based on land cover thermal mapping,
Annual St Ivan Rilski Univ of Minning and Geology, Sofia 2005;48/1:231-233.

11. Pavlova P, Iliev I, Danov M, Angelova E,
Investigation of the Colorimetrical Changes of the Light,
Proc 11th Int Sci Conf Solar-Terrestrial Influences**,** November 2005, Sofia, pp 239-241.

12. Krezhova D, Pavlova P, Yanev T,
Remote sensing of natural objects by means of color transforms,

Proc 11th Int Sci Conf Solar-Terrestrial Influences**,** November 2005, Sofia, pp 113-116.

13. Nikolov H, Borisova D, Danov M,
Sub-pixel mapping of open pit dumps,
Proc 11th Int Sci Conf Solar-Terrestrial Influences**,** November 2005, Sofia, pp 119-121.

14. Ferdinandov E, Pachedjieva P,
Probabilistic and statistic methods in communications,
Parts I and II, Textbook, Ciela Publ House, Sofia, 2005.

15. Pavlova P,
Digital image processing (handbook)
E-issue – *http://marvil-books.com/main/kartoteka.html* - section "Nauka", Sofia, 2005.

16. Pavlova P,
Digital image processing (handbook),
Foundation Physics, engineering, medicine – XXI Plovdiv, 2005.

**CONFERENCES:**

1. Danov M, Tzanev V,
Investigation of thermal infrared emissivity spectra of rock samples,
LTL 2005 Plovdiv, Bulgaria.

2. Pavlova P,
Computer vision and colorimetry,
Nat Conf Contemporary Aspect of Colorimetry", November 2005, Sofia, Bulgaria.

3. Nikolov H, Borisova D, Danov M,
Sub-pixel mapping of open pit dumps,
11th Int Sci Conf Solar-Terrestrial Influences, November 2005, Sofia, Bulgaria.

4. Nikolov H, Borisova D, Danov M,
Detection of open pit mines and dump areas based on land cover thermal mapping,
Int Sci Session, St. Ivan Rilski Univ of Mining and Geology, October 2005, Sofia, Bulgaria.

5. Nikolov H, Borisova D, Danov M,
Classification of open pit mines and dump areas based on land cover mapping,
Scientific Conference SES'2005, Sofia, Bulgaria.

6. Borisova D, Nikolov H, Danov M,
Spectral mixture analysis for remote sensing data interpretation,
2nd Int Conf Resent Advances in Space Technologies, 2005, Istanbul, Turkey.

**ONGOING RESEARCH PROJECTS:**

Financed by the National Council for Scientific Research

TN–1523/05 Influence of the atmospheric turbulence on the quantitative characteristics of the optical systems used in: free- space laser communications, optical remote control and

radiometric systems for environment eco-monitoring, system for investigation of optical images of natural objects.
MU-NZ-1502/05 Investigation of emission and reflection characteristics of spectral mixtures of rocks and minerals.

**LECTURE COURSES:**

Probability and statistical methods in telecommunications; Fundamentals of optoelectronics; Signals and systems.
Technical University of Sofia, Sofia, Bulgaria.

Radio-waves and radio-relay links; Theory of optoelectronic systems; Computer vision; System for optical data processing.
Technical University of Sofia, Plovdiv Branch, Plovdiv, Bulgaria.

LABORATORY

**LASER RADARS**

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

TOTAL STAFF: **23**
RESEARCH SCIENTISTS: **14**
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.l. Mitev, Ph.D.; S. Penchev, Ph.D.; V. Pencheva, Ph.D.; A. Deleva, Ph.D.; Z. Peshev, Ph.D.; G. Kolarov; R. Avramova; B. Kaprielov; V. Naboko; I. Grigorov.

## RESEARCH ACTIVITIES:

### 1. Lidar monitoring of the atmosphere

Systematic measurements in frame of EARLINET program was made by the lidar, supplied with a CuBr laser ($\lambda$=510 nm) with pulse duration 10 ns and pulse repetition 13 kHz. The studies were conducted in about 65 hours, during 17 days of 2005 (G. Kolarov, I. Grigorov).

Systematic investigations were carried out according the EARLINET and other projects using a lidar with a Nd-YAG laser. Yearly round lidar studies were performed; a part of them were accompanied by ground level ozone concentration (IE) and radiometric observation (Institute of Geophysics). Preliminary results on height and structure of the PBL were obtained. The extinction coefficient and aerosol optical depth in the PBL were determined from lidar data. The total aerosol optical depth in the entire atmosphere between the Earth and the Sun were determined from the optical radiometer data. The results reveal the necessity of more detailed study since the subject is new for the team. The ground level ozone concentration was followed during ML development over an urban area. The data obtained by the three devices, namely, the lidar, optical radiometer and ozonbemeter are to be harmonized (N. Kolev, R. Nenchev, V. Grigorieva, I. Kolev).

An analysis was made on the periodic structure of gravitational waves (GW), registered through remote lidar measurements. GW of orographic origin arises as a result of dragging the ground air flow when overcoming a mountainous obstacle. The object of our research was to register GW of orographic origin at altitudes up to 10 km, using high spatial resolution (30m) in the area above Sofia city both at day- and nighttime. The orographic situation around Sofia fosters formation of GW in the atmosphere. Vitosha Mountain is located 6 km southwards from the city center, the ridge reaching a height of more than 1500 m above the plain (peak Cherni Vrah – 2390 m), and having longitudinal dimensions of about 15 km. Its proximity and significant dimensions and height often result in GW when winds are coming from the south, southwest and southeast. The studies were conducted in 14 days in the months October 2004 – February 2005, when the sky was cloudless. The total duration of lidar profile records for this period is 48 hours, and in 39 hours or 77% of the total sounding time, presence of waves was registered. The duration of one experiment for atmosphere sounding was 1.5 hours. The lidar parameters determined registration of discrete temporal series (realizations) of 90 numerical values each, distant by time intervals of $\Delta$t=1 min. Each realization represents the time distribution of a lidar backscatter from an atmospheric

layer of 30-m thickness, located at a certain height. Each lidar signal record contained 360 realizations. After filtering, the spectra of these realizations were constructed using Fourrier transformation and the respective GW periods were determined. Often in one spectrogram 2 or 3 significant spectral lines were observed, which shows that the waves registered represent superposition of waves with different wavelengths. At altitudes of about 2-2.5 km, fading to insignificant amplitude values was observed in the temporal series, which testified to the decomposition of the periodic structures studied. Such behavior is characteristic for waves of orographic origin (G. Kolarov, I. Grigorov).

Some characteristics of different sub-layers of the planetary boundary layer have been studied in more detail, namely, the stable layer (SBL), the residual layer (RL), and the mixing layer (ML). Their courses of development during the different seasons have been determined R. Nenchev, N. Kolev, I. Kolev).

Systematic studies were carried out on determination of the optical characteristics of the atmospheric aerosol in the planetary boundary layer (PBL). The relationship between the processes in the PBL and the optical characteristics of the atmospheric aerosol was followed (R. Nenchev, N. Kolev, I. Kolev).

As a result of those lidar–radiometric investigations within the PBL, the significant effect of the processes taking place in the ML was determined. During the RL destruction (when the ML rises up to its height, in the period between 10:30 and 12:30 LST in summer) the aerosol optical depth reaches its maximum value approximately 1-2 hours before the complete development of the ML. The main process which plays the significant role in that of the turbulent mixing during the ML formation (N. Kolev, R. Nenchev, B. Kaprielov, I. Kolev, I. Iliev).

The influence of the processes in the PBL on the ground level ozone concentration was studied. The effect of the mixing of the elevated layers with the atmospheric aerosol and ozone in the ML was observed. An increase in the ground level ozone concentration was determined during the RL destruction by the processes of advection and mixing (V. Grigorieva, N. Kolev, R. Nenchev, I. Kolev).

The elaborated technique for measuring the velocity of inhomogeneities drifting in the atmosphere by capturing and processing their images have been suggested. Properly selected data records of imaged clouds are used for building time variations of in-plane moving dots, related to different parts of the area of measurement and also corresponding to the image detector pixel resolution. The precision of obtaining the velocity is provided by adjusting the time between two successive image registrations (Vl Mitev).

An important result favoring the further work with Raman lidar is the accomplished reconstruction and reorganization of the laboratory. After the reconstruction completion, both the laser and whole lidar were readjusted and the initial condition of the system was restored. The lidar's laser became a part of the worldwide light performance activities "The physics enlightens the world" for celebration of the international year of physics. In accordance with F-1408 project program, two algorithms for processing lidar data were developed. The first algorithm will be applied for retrieval of the atmospheric extinction coefficient by using Raman lidar data. The second one is intended for determination of molecular constituents of the atmosphere by the Raman lidar. Development of corresponding software is forthcoming. (A. Deleva, Z. Peshev).

**2. Lidar signal processing**

On the basis of an approach developed by us for measuring precisely the shape of randomly

arriving pulses shorter than the acquisition step of the analog-to-digital converters, a new method for precise range measurement has been proposed and experimentally verified (precise laser rangefinder). This method is based on appropriate conversion of the input signals before their acquisition (sampling). It is shown experimentally that, by using nanosecond pulses and sampling step of 10 ns (100 MHz/12 bits ADC), this technique allows one to determine the range to some object with an accuracy of the order of 1.5 mm. Some final experimental investigations with the system developed are being conducted and the results obtained will be published (D. Stoyanov, T. Dreischuh, O. Vankov).

A generalized concluding statistical modeling has been performed of a high-range resolution technique developed by us for coherent lidar sensing, with arbitrary shaped laser pulses, of Doppler velocity profiles in the atmosphere. The main sources of fluctuations of the coherent lidar signal have been taken into account. The results from the simulations confirm the theoretical estimates we have done formerly and, as a whole, the applicability of the method developed for estimation of Doppler-velocity profiles with high range resolution and accuracy, in the case of strong signal fluctuations. Preparing the results for publication is in the final stage (L. Gurdev, T. Dreischuh).

Some lidar-principle-based approaches have been developed for single-side gamma-ray in-depth sensing and tomography of optically opaque dense media. The conditions have been investigated under which the detected return signal can be considered as a result of single backscattering. The delta-pulse single-scattering return signal equation, which is the basis for quantitative analysis and data processing, has been formulated by analogy with the lidar equation, taking into account the inelastic character of the gamma-photon scattering and the natural photon-counting mode of detection of the signal photons. This equation describes the relation between the known experimental parameters, the measured time-to-range resolved return signal profiles, and the unknown line-of-sight distribution of specific material characteristics such as the volume extinction and backscattering coefficients. At given mass density, these coefficients are specific for the different substances and the knowledge of their spatial distributions in case of gamma sensing provides the opportunity to find simultaneously the distribution, inside an object, of various material components and their mass density as well as of the electron density. Some methods have been developed (by using some lidar approaches) for recognition of different ingredients within a probed medium and determination of their disposition and mass density as well as for determination of the mass-density distribution inside one-material objects. The methods are based on solving the return-signal equation with respect to the profiles of the extinction and backscattering coefficients. The approach developed can be widely applied, e.g., for nondestructive material examination in industry and aviation, detection of landmines and explosives, investigating the constitution of archeological artifacts, etc. (L. Gurdev, T. Dreischuh, D. Stoyanov, H. Protochristov.

A new additional receiving channel was constructed for registration of the optical background sky radiation of the atmophere. It uses the same elements – telescope, filters, photomultiplier, as the principal channel for registration of the backscattered laser light. Both channels use same start-pulse and sample-durations. The changes of background sky radiation perturbe daily lidar soudings of the atmosphere. Performing registration of

these noise light by the additional lidar channel and substracting it from the registered backscatter laser light, rises the precision of lidar measurements. New optical-fiber connection between the laser and the pin-diode, which generates a start pulse of the registration electronics, is in train to be constructed. It will make more stable the all system beyond electrical pulse-perturbations. (G. Kolarov, I. Grigorov).

A modification was made of the system "LIDAR", designated to computing and storing data of lidar measurements. Data is now stored in so called structure-areas during the full cycle of computations and analyses. This also permits simultaneous data importing from many measurements (reading of many data-files) for inter-comparisons and investigations. The algorithm for calculations of atmospheric extinction profiles was modified and the method of Fernald is now used. It refers a model of the atmospheric molecular backscattering, conformably to the model used by lidar groups in Minsk (Belarus) and Belsk (Poland), both participants in EARLINET program. The possibilities of the system "LIDAR" for multi-traces lidar data analyses are functionally developed. Addition of Raman channel data analysis is foreseen (I. Grigorov).

## 3. Lidar hardware & software

Laser modulated techniques including laser heterodyne method for remote sensing of material media are developed, designed for nondestructive analysis in contemporary material science and nanotechnology. The principle of detection is based on the photothermal interaction (propagating thermal wave) on the surface of the investigated media. This includes:

- Detection of photothermally - modulated reflection;
- Laser heterodyne method of detection of photothermal displacement in the focus of the laser beam;
- Double laser heterodyne method employing two- wavelength scheme for modulation and sounding of the characteristic physical properties of the investigated medium;
- Development of highly sensitive optical schemes with square- wave thermal modulation combined with lock-in amplifier, optimized by laser diodes and elements of fiber optics.

The following achievements of the referred experimental and theoretical research are gained:

- Measurement of photothermal displacement of metallic and nonmetallic media accomplished by laser diode of 30mW power and laser double heterodyne method of record high sensitivity ($<10^{-12}$m);
- Contribution to the theory of photothermal displacement experimentally validated in the case of transparent media (like GaP and Si); analytical expressions were derived applicable for analysis of prospective optical materials and optical waveguides design (V. Pencheva, S. Penchev, V. Naboko);
- A system for tuning and thermal regulation of powerful laser diodes (PLD) was developed and experimentally tested;
- A photodetector incorporating APD (avalanche photodiode) was constructed and .tested at low temperatures (optimized for $-10C^0$);
- A specialized device for programming of digital thermo- sensors was constructed, mastering the relevant d software, with indication of the working temperature on PC monitor;
-The developed Dual- wavelength lidar system based on PLD was reconstructed for reduction of excessive noise according to the accumulated experimental results including open- path atmospheric application;

According to the developed technique, PLD of wavelength 850-900nm and 150W power are employed, which match the relevant absorption bands of water vapor. PLD frequency and power stabilization is

accomplished by stabilization of the driving pulse current (25-30A) and the bulk temperature in the range of 10-50C$^0$. Spectral analysis conducted to determine the error of DIAL measurement according to wavelength fluctuations demonstrated high thermal stability (by this feature the method considerably overcomes the conventional methods of spectroscopy using tunable laser diodes). Due to the considerable dissipated thermal power (~40W), the efficiency of PLD thermal stabilization is a demanding task. Schematically, the volume confining the laser diode and the thermo- regulator Peltier cooler is miniaturized and thermally isolated (respectively evacuated) to prevent ambient thermal flow. A Peltier cooler of considerable power and current of 7-10A is needed, so the driver was developed and realized in an energy-saving pulse operation mode. A thermo-sensor of digital type was used in the thermostat with a programmable memory for operation in a set temperature interval of thermal stabilization (±1C$^0$). An option for reprogramming is introduced by the use of a specialized programmer operated by PC of the lidar. The thermo stabilizing scheme is validated for real operational conditions, where high energetic efficiency was achieved (S. Penchev, V. Naboko, V. Pencheva, S. Naboko).

The lidar's spectrum analyzing module is completed by supplying it with three interference filters having peak transmission at 532 nm, 607 nm, and 660 nm, respectively.

The aerosol channel of the Raman lidar was entirely equipped and activated. Initial series of aerosol backscattered lidar signals were obtained (A. Deleva, Z. Peshev).

It was developed specialized experimental set-up for measuring and restoration of highly dynamic optical fluxes. The experimental set-up provides the opportunity to analyze to three regimes of photodetection – analog, photon counting and overlapping by a single photon detector. This system was developed for testing the behavior of the lidar photon detector on dynamic fluxes from the atmosphere and the correct retrieving of lidar signal from clouds (A. Masheva, O. Vankov, D. Stoyanov).

**4. International colaboration**

In the framework of the joint project of the Indo - Bulgarian inter-governmental program of cooperation in Science & Technology, Grant № INT/Bulgaria " Optical remote sensing studies of the atmospheric boundary layer characteristics using laser radar", Institute of Tropical Meteorology, Pune, India we performed a series of regular lidar measurements. The results were processed and presented at 5$^{th}$ UAQC (I. Kolev, B. Kaprielov, N. Kolev, R. Nenchev).

In accordance with the joint research project "Investigation of the aerosol fields transformations in industrial centres by lidar", with the Institute of Physics, National Academy of Science, Minsk, Belarus we received their novel lidar photoreceiving block and software for data transmission and processing. This block is now incorporated in the upgraded Raman lidar system. A lot of joint testing results have been performed in Sofia. It was proposed before BAS and NANB to extend the joint project for the next 2 years. (D. Stoyanov, A. Deleva, Z. Peshev).

It was developed novel method for enhancing the spatial resolution of digital cameras in the framework of the joint project "Optical, gamma and MW remote characterization of Dynamic small-size submicron structured systems in life-sciences and industry," with the University of Liege, Liege, Belgium. (D. Stoyanov).

**PUBLICATIONS:**

1. Kolev I, Tatarov B, Savov PI, Trifonov T, Kaprielov B,
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**ONGOING RESEARCH PROJECTS:**

Financed by the National Science Fund (NSF) of the Republic of Bulgaria:

Ph-1408 Development of powerful Raman lidar for sounding the molecular components in the low and middle atmosphere.
ES-1406 Peculiarities of ozone variations and investigation of processes, responsible for their excistence.
YS_Ph-1406 Lidar determination of microphysical characteristics of natural and anthropogenic atmospheric objects.

**NOVEL RESEARCH PROJECTS, WINNED IN 2005:**

European Aerosol Research Lidar Network: Advanced Sustainable Observation System, EARLINET – ASOS, financed through the V-FP of EU.
Ph-1511 with NSF Lidar methods for high resolution probing of inhomogeneities objects by optical and gamma radiation.
YS Ph-1510 Simulated and experimental investigations on retrieving of time-resolved profiles at dynamic photon fluxes in laser radars.

**COLLABORATIONS:**

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).

Optical, gamma and MW remote characterization of Dynamic small-size submicron structured systems in life-sciences and industry,
University of Liege, Liege, Belgium.

Investigation of the aerosol fields transformations in industrial centres by lidar,
Institute of Physics, National Academy of Science, Minsk, Belarus.

Earlinet Foundation, founded in 2004 by the research teams from 14 European countries, creating the European Lidar Network by development of the EARLINET project, financed through the V-FP of EU.

LABORATORY

**MICROWAVE REMOTE SENSING**

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

TOTAL STAFF: **16**
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, Ph.D.; E. Krasteva, Ph.D.; I. Sirkova, Ph.D.; K. Kostov; L. Mladenov; L. Vulkova; N. Kitova, Ph.D.; I. Atanasov; G. Dimitrova.

**RESEARCH ACTIVITIES:**

**1. Microwave radiometers for remote sensing applications**

Significant part of the radiometric research activities was devoted to the Bulgarian-Vietnamese contract "Design and development of a C-band microwave radiometer and its applications for remote sensing of vegetation cover and sea surface environment in Vietnam" concluded for the period 2004-2006.

The principal diagram of a C-band total power microwave radiometer – type CRM (central frequency from 3.5 to 3.7 GHz) was proposed and implemented. The CRM-radiometer was developed jointly with ES com, Ltd. Special attention was paid to: (i) step tuning of the central frequency of the radiometer for reducing the effects of man-made interference; (ii) two systems for controlling the temperatures of the tuner and the low-noise block-converter for improving short-term and long-term stability of the radiometer. A microcontroller unit was developed for radiometer control and data acquisition, incl. displaying various types of data on liquid-crystal display and data transfer to a personal computer via USB port.

The testing of the radiometer developed in field conditions showed that it could be a valuable tool for ecosystem monitoring, especially for remote sensing of surface soil moisture, vegetation and sea surface environment in Vietnam [1].

**2. Microwave propagation modeling under complicated terrain and meteorological conditions**

When studying microwave propagation in open areas, it is important to account for underlying terrain and tropospheric characteristics. The difficulties in the immediate collection of terrain data for a particular place make the accessible and convenient in use world wide available standardized datasets of Digital Terrain Elevation Data (DTED) attractive for application in numerical calculations related to microwave propagation prediction. The reliability of DTED Level 0 (provided by USA National Imagery and Mapping Agency) as for microwave path loss calculations over a specific region - the plateau of Sofia, is studied using the Parabolic Equation (PE) method in conjunction with the Fourier split-step numerical technique. The ability of the PE method to provide quantitative accounting for microwave field changes due to tropospheric refraction and diffraction around terrain elevations was shown. Due to its precision, the PE method allows assessment of the influence of the accuracy of the used digital terrain data on microwave field changes. This assessment is particularly important when predicting

radio networks coverage in shadowed zones [2,3].

**3. Scattering of electromagnetic waves from natural media**

Hybrid model of electromagnetic scattering from rough surfaces is developed for the purposes of the active microwave remote sensing. The developed method encompasses the perturbation method and the fixed-point method. On this basis the scattered in the atmosphere electric field of first and second order is evaluated, along with the scattering matrix F in the far zone of the atmosphere. The scattering matrix F is needed for the purposes of environmental SAR scenes interpretation. The model takes into account the depolarization effects of the natural rough surfaces. Using the obtained matrix F the expressions of polarimetric radar cross sections of rough surfaces were derived.

**4. Emergent structures and collective behavior in extended and distributed chaotic systems**

Several statistical methods for rough surface morphology characterization were implemented and assessed. They can largely be divided into two classes. The first class is based on estimation of two-point, quadratic statistical functions and includes: estimates of the sample autocovariance function, sample height-height correlation (also, structure) function, and periodogram estimate of the surface power spectrum. The second class incorporates estimation of up to the fourth statistical moments of the local curvature on a fixed scale.

We applied these methods first on computer simulated epitaxial surfaces, which permits the characterization using large sets of "data" and rich statistics. Then we dealt with real surfaces, whose roughness profiles are measured using atomic force microscopy (AFM). In both cases we inferred and discussed scaling properties, degree of anisotropy and deviation from Gaussian distribution of surface heights [4].

**5. Propagation of nonlinear electro-magnetic waves**

The reductions of the multi-component nonlinear Schrodinger (MNLS) type models related to **C.I** and **D.III** type symmetric spaces are studied [5-8]. We pay special attention to the MNLS related to the sp(4), so(8) Lie algebras. The MNLS related to sp(4) is a three-component system which could be applied to Bose-Einstein condensates. The MNLS related to so(8) Lie algebra after convenient $\mathbf{Z_2}$, $\mathbf{Z_4}$ reductions reduce to multi-component MNLS showing new types of $\chi^3$-interactions that are integrable. We briefly explain how these new types of MNLS can be integrated by the inverse scattering method. The spectral properties of the Lax operators **L** and the corresponding recursion operator **Λ** are outlined. Applications to spinor model of Bose-Einstein condensates (BEC's) are discussed. When spinor BEC's are trapped in the magnetic potential, the spin degree of freedom is frozen. However, in the condensate held by an optical potential, the spin is free. We consider BEC's of alkali atoms in the **F=1** hyperfine state, elongated in **x** direction and confined in the transverse directions **y,z** by purely optical means. In the absence of external magnetic fields, their three internal states $\mathbf{m_F=1,0,-1}$, where $\mathbf{m_F}$ is the magnetic quantum number, are realized. The assembly of atoms in the **F=1** hyperfine state is characterized by normalized spinor wave function. The dynamics of the spinor condensates is described by three-component model, based on a system of three nonlinearly coupled Gross-Pitaevskii (GP) equations (matrix nonlinear Schrodinger equation (NLS)) in one-dimensional (1D) **x**-space. Matter-wave solitons are expected to be useful in atom

laser, atom interferometry and coherent atom transport. It could contribute to the realization of quantum information processing or computation, as a part of new field of atom optics.

**6. Investigation of the attenuated internal light reflection: excitation of evanescent waves in metals with nonflat boundary using the method of prism coupling in the Otto configuration**

We investigated the link between the curvature of bulk metal sample and the spatial distribution of the reflected (scattered) field in the far zone in the case of prism coupling where attenuated total reflection occurs. The reduced integral Reyleigh equation for the configuration "dielectric prism-air gap-metal" was solved approximately in [9,10] and experimental measurements for tantalum have also being reported there. In the absence of a protrusion i.e. for three-layer planar structure an analysis was made of the reflectivity coefficient for the practically important case of almost perfectly conducting samples. We show that a single minimum exists corresponding to resonant excitation of surface plasmon-polariton modes and an analytical formula for the characteristics of the observed Lorentz dip was also given.

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**ONGOING RESEARCH PROJECTS:**

Financed by the National Scientific Research Council

F-1203/02 Emergent structures and collective behavior in extended and distributed chaotic systems.
TN-1314/04 Design and development of a C-band microwave radiometer and its applications for remote sensing of vegetation cover and sea surface environment in Vietnam.
F-1410/04 Soliton models and applications in nonlinear optics.

**COLLABORATIONS:**

Statistical studies of meteorological time series,
University of Liege, Belgium.

Design and development of a C-band microwave radiometer and its applications for remote sensing of vegetation cover and sea surface environment in Vietnam,
Space Technology Application Center - Institute of Physics & Electronics - Vietnamese Academy of Science & Technology, Hanoi, Vietnam.

LABORATORY

**MICROWAVE MAGNETICS**

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

TOTAL STAFF: **11**

RESEARCH SCIENTISTS: **5**

Assoc. Prof. K.G. Grigorov, Ph.D.; T. Koutzarova, Ph.D.;
T. Merodiiska; T. Beneva; Ch. Ghelev.
Ph.D. students: S. Kolev; L. Slavov; P. Lukanov.
WFS guest scholarship students: M. Milanova, Ph.D.; E. Daykova.

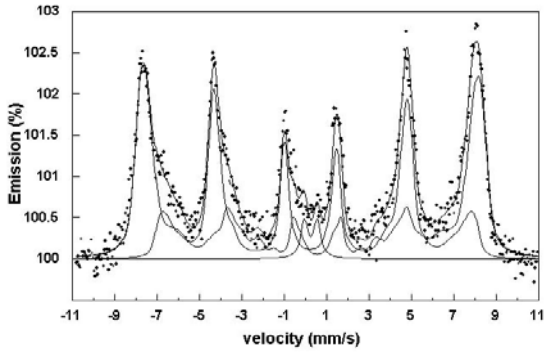
## RESEARCH ACTIVITIES:

### 1. Phase and structural particularities of nanosized magnetic materials

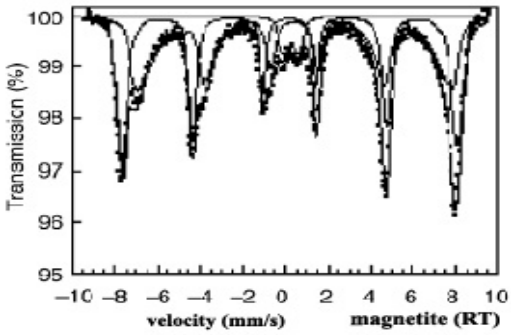
The object of the work was spinel ferroxide nanoparticles of $Fe_3O_4$. The particles were obtained via a soft chemical process. The Institute of Electronics has technological capabilities for fabrication by coprecipitation from water solutions of $Fe_3O_4$ powders with particle within wide ranges. The crystalline structure and shape evolution of the magnetite particles were investigated by XRD and TEM (HRTEM and JOEL JEM-4000 EX microscopy). The particle shape changed from spherical to ellipsoidal to cubic when the amount of oxidizing solution was increased. The Oswalt ripening process worsened the particles' dispersity. The results demonstrated that the crystal cell constant for spherical particles is smaller than that for edged particles, the voids related to the higher symmetry (octahedral) are filled with priority, and the diameter of the spherical spinel particles is smaller. As we were able to show, the above is most probably related to the Laplace pressure acting on the particles surface. The particles size was calculated by means of two techniques – statistical determination of the average grain size as seen on the TEM micrographs and applying the Sherrer formula to the Lorentz-broadened XRD spectra.

The experiments further demonstrated that spherical monodispersed magnetite with size below 15 nm can be produced at $FeCl_2.4H_2O:NaNO_2 = 10:1$ or by coprecipitating $Fe^{2+}$ and $Fe^{3+}$ cations in stoichiometric ratio 1:2, filtered for 30 min following the coprecipitation process. Monodispersed magnetite particles with cubic shape and size below 15 nm can be produced at a ratio $FeCl_2.4H_2O:NaNO_2 = 1:1$ without Oswalt ripening.

In order to find the degree of oxidation and establish the possible existence of a second magnetic phase in the powders studied, we applied low-energy Mössbauer spectroscopy (ILEEMS). This technique was developed and described in detail by the scientific group at the University of Gent, Belgium, with which we have a long-term collaboration, and was applied in practice for the first time to investigate the ferroxides produced in the Microwave Magnetics Laboratory. In contrast with the conventional MöS, this technique allows one to study the nanosized particle's surface to a depth of several nanometers.




a)




b)

Fig. 1. Mössbauer spectra at room temperature of magnetite particles with grain size 10 ± 2 nm a) by means of ILEEMS and b) obtained following the conventional transmission technique.

Fig. 1 presents a comparison of the MöS spectra of particles with size 10 ± 2 nm obtained by means of the two techniques cited above. The analysis of the two spectra indicates the presence of more than 10 % of superparamagnetic phase. The ILEEMS spectrum interpretation points to the existence of a maghemite-like defective magnetic structure on the particles surface, where one can assume oxidation of $Fe^{2+}$ to $Fe^{3+}$ and formation of vacancies in the spinel. Since the energy of the detected electrons is essentially related to the depth, then obviously by selecting a specific energy one can obtain information on a specific layer below the surface. The depth resolution of a few nanometers is achieved by using high-sensitivity electrostatic and magnetic electron spectrometers. Weight functions that were calculated before were used to describe the probable depth distribution of the electrons with various energies, as well as to account for the angular distribution of the electrons detected.

ILEEMS spectrum (Fig. 1a) points to a small contribution of the $Fe^{2+}$ sextet, thus proving that the surface is more strongly oxidized. The spectra assessment shows that the depth of oxidation reaches 3 nm below the surface, while the spectral data processing yielded a composition following the formula $(Fe^{3+})_A[Fe^{3+}_{5x}Fe^{2.5+}_{2-6x}\ \square_x]_BO_4$, where $x$ varies from 0 to 0.2. The strong overlapping of the $Fe^{2.5+}$ sextet and a possibly broader $Fe^{3+}$ of maghemite (a phase of lower size) makes it difficult to obtain the exact composition from the respective spectral zones. Figure 2 presents a model of the surface oxidation level observed. The surface chemical composition can be described by the formulas below Fig. 2.

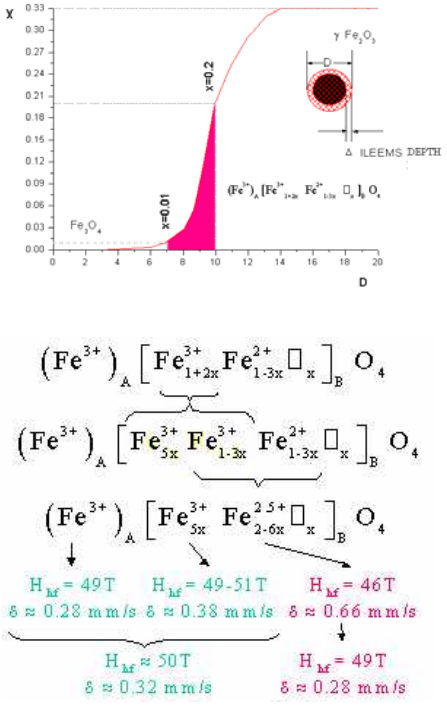



Fig. 2. Model representation of the surface oxidation variation of magnetite particles with grain size 10 ± 2 nm.

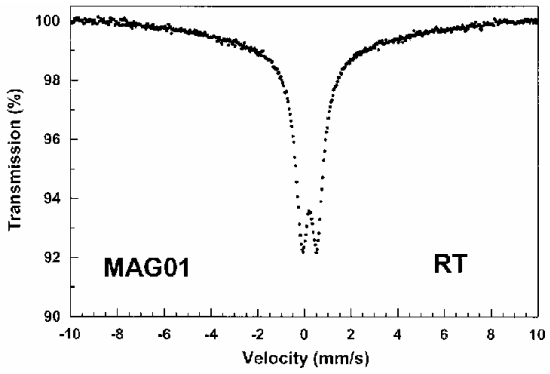


Fig. 3. Mössbauer spectrum at room temperature.

The MöS spectra at room temperature indicate unambiguously 100 % superparamagnetic powders (Fig. 3).

## 2. Applied studies of nanostructured oxides at MW frequencies

The composite MW absorbers are a separate class of MW materials which find various applications, such as MW radiation protection, shielding of functional electronic components, etc. The object of our studies were composite materials containing nanostructured ferroxides fillers. The phenomenon responsible for the absorbing properties of such particles is their ferromagnetic resonance (FMR), which determines the frequency where absorption takes place. In contrast with micron-sized particles, the nanostructured particles are monodomain and may exhibit superparamagnetic properties (depending on the temperature and the external magnetic field applied). These facts determine their specific magnetic properties (exchange magnetic interactions, particle-particle interactions, etc.), which are still to be studied in detail.

The main loss mechanisms are: dielectric losses, conductance losses, hysteretic losses and resonant losses (FMR due to domain walls motion, in the MHz range, and spin FMR, in the GHZ range). The various mechanisms of electric and magnetic losses in such structures depend on the type and microstructure of the material, as well on the frequency and the temperature. The investigations of these phenomena in nanostructured oxides are still in their early stages, with the engineering sciences laying their hope on applications in magnetic recording, harmful radiation protection and new integral devices. It is expected that the comprehensive studies will open up new avenues for applications. In our work we placed the emphasis on clarifying the nanosized magnetic particle (magnetite) contribution to the formation of the MW properties of the MW absorbing material, making use of the equipment available in the Institute of Electronics. The dynamic characteristics of the samples studied were followed in the 1-20 GHz by using a scalar network analyzer Hewlett Packard 8756 A.

The frequency dependence of the complex magnetic permeability and dielectric permittivity of some of the samples are shown in Figs. 4 and 5.

Fig. 4 a) and b) present the values of $\varepsilon_r^{'}$ and $\varepsilon_r^{''}$ in the 1 - 13 GHz frequency range. The most probable loss mechanism there is the orientation polarization. The polarization mechanism in ferrites at MW frequencies depends on the presence of ions in the different sublattices; it is assumed that the orientation polarization in a ferrite is mainly the result of the electron transfer between ferro- ($Fe^{2+}$) and ferri- ($Fe^{3+}$) ions. The dielectric losses, however, are not constant within the entire frequency range.

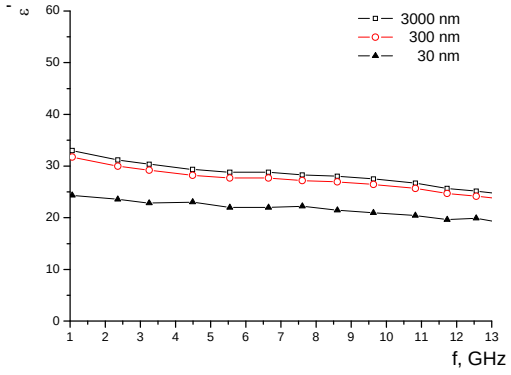
The dielectric losses in the sample can be understood as due to the ***dc*** and ***ac*** conductivities, or ion jumping and dipole relaxation, following the expression:

$$\varepsilon_r^{''} = \left[\sigma_{dc} / (\omega\varepsilon_0) + \varepsilon_{ac}^{''}\right],$$

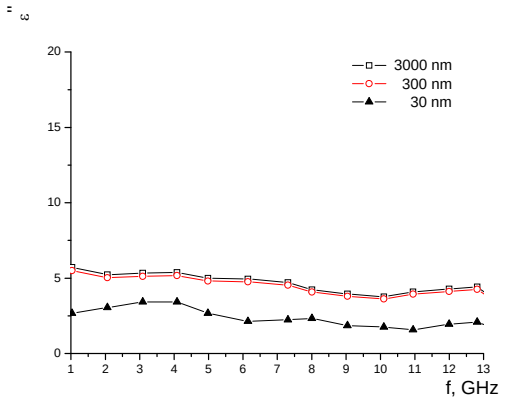
where $\sigma_{dc}$ is the ***dc*** conductivity, $\omega$ is the angular frequencyт, $\varepsilon_0$ is the dielectric constant of free space and $\varepsilon_{ac}^{''}$ ***ac*** are the high frequency losses. As can be seen, the term where the ***dc*** conductivity participates

is inversely proportional to the frequency; i.e., the ***dc*** conductivity is the reason why $\varepsilon_r''$ rises as the frequency decreases. Similar behavior has also been observed for a composite consisting of Mn–Zn ferrite in a polymer matrix.

The magnetic losses are related to the spin rotation resonance. It is observed in a filler with particle size 30 nm; it is shifted to the higher frequencies and occurs at 7 GHz. In fillers with particles size 300 and 3000 nm, the maximal magnetic losses are seen at about 4 GHz.



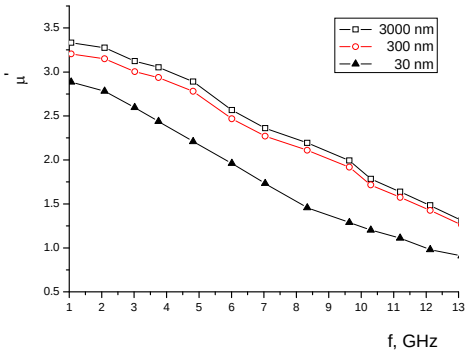

a)



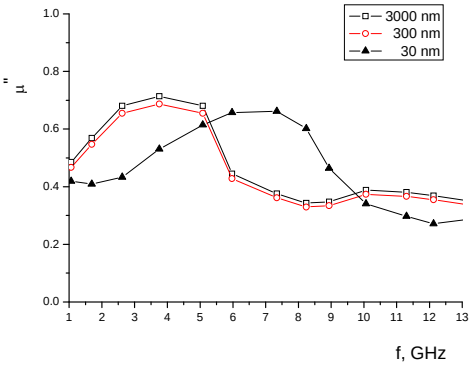

b)

Fig. 4. Frequency dependence of the real a) and the imaginary b) parts of the complex dielectric constant for samples with the same degree of filling.

The results presented above led us to the following conclusions: it was established that for a nanosized filler the FMR frequency is shifted to the shorter wavelengths; we also showed that the material's resonant characteristics can be varied in a controlled way by varying the filler size; using the FMR data, the values of the effective magnetic anisotropy of a nanostructured magnetite were calculated, which allows one to determine the contribution of the surface magneto-crystalline anisotropy to the formation of the particle's magnetic properties. Further, we observed a considerable increase of the effective anisotropy of the nanostructure material, which we related to changes in the cation distribution in the nanosized particle, to its defective surface, to the surface-volume interaction and to the particles aggregation.




a)




b)

Fig. 5. Frequency dependence of the real a) and the imaginary b) parts of the complex magnetic permeability for samples with the same degree of filling.

In summary, our MW studies demonstrated the potential of the techniques used for investigating nanostructured ferroxides; on the other hand, the results obtained point to possible practical applications when the FMR contribution to the MW absorber properties is established.

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Characterization of magnetic nanoparticles and their organization in magnetic fields", poster presentation,
Nanoscience&Nanotechnology - 7th Workshop on Nanostructured Materials Application and Innovation Transfer, November 2005, Sofia, Bulgaria.

5. L. Slavov, T. Merodiiska, M. Milanova, I. Nedkov,
FTIR- investigations on the contribution of different organic coating agents for downgrading the degree of surface oxidation of magnetite nanoparticles in time,
Nanoscience&Nanotechnology - 7th Workshop on Nanostructured Materials Application and Innovation Transfer, November 2005, Sofia, Bulgaria.

6. K. Grigorov,
Real-time YBCO phase transformations investigated by synchrotron radiation,
Invited lecture, XXVI Congress of the Brazilian Vacuum Society, July 2005, Londrina, Brazil.

**ONGOING RESEARCH PROJECTS:**

Financed by the National Council for Scientific Research

TH – 1-01/2003 Nano-structured for microwave and optical measurements.
MUF-1301 The effect of the ferro-magnetic resonance of nano-structured oxide fillers on the properties of MW absorbers.
Financed by other funds

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

**COLLABORATIONS:**

Nanostructure ferroxide powders for biomagnetic applications,
University of Gent, Gent, Belgium.
Optical, gamma and microwave remote characterization of dynamic small-size submicron-structured systems in life sciences and industry,
University of Liege, Liege, Belgium.

Magneto-optical and microwave characteristics of nano-structured magnetic oxide thin films, Institute of Radioelectronics, Russian Academy of Sciences, Moscow, Russia.

**GUESTS:**

Prof. R. Vandenberge from University of Gent, Belgium, Joint Research Project "Nanostructure ferroxide powders for biomagnetic applications" between IE-BAS and Gent University, Belgium, 14 days.
Prof. M. Ausloos from University of Liege, Belgium, Joint Research Project "Optical, gamma and microwave remote characterization of dynamic small-size submicron-structured systems in life sciences and industry", between IE-BAS and University of Liege, Belgium, 8 days.
Dr. P. Clippe from University of Liege, Belgium, Joint Research Project "Optical, gamma and microwave remote characterization of dynamic small-size submicron-structured systems in life sciences and industry", between IE-BAS and University of Liege, Belgium, 8 days.
Prof. Ph. Vanderemden from University of Liege, Belgium, Joint Research Project "Doping effects in magnetic ceramics" between IE-BAS and Liege University, Belgium, 5 days.

**LABORATORY VISITS:**

Prof. I. Nedkov - University of Gent, Belgium, Joint Research Project between IE-BAS and Gent University, Belgium, "Nano-structured ferroxide powders for biomagnetic applications"; 14 days.
Prof. I. Nedkov - University of Liege, Belgium, Joint Research Project between IE-BAS and Liege University, Belgium, "Optical, gamma and microwave remote characterization of dynamic small-size submicron-structured systems in life sciences and industry"; 7 days.
Assoc. Prof. K. Grigorov – Institute of Aeronautics, San Jose dos Campos, Brazil, one year, "Structural and chemical behavior of thin films in low-pressure plasma".

LABORATORY

## MICROWAVE SOLID STATE ELECTRONICS

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

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

### RESEARCH ACTIVITIES:

### I. Methodology for Calculating and Optimizing the Performance of a Multistage Wide-Frequency-Band Transistor Amplifier

The methodology applied by us for calculation and optimization of a single-stage transistor amplifier characteristics was extended to include the case of a multi-stage amplifier. The methodology developed is based on a model of a matching circuit, which includes ideal elements – a resistance transformer with constant transformation ratio over the entire frequency band and a negative reactive element (- *C*). This allows one to calculate the amplifier's optimal characteristics: minimal noise figure at a given gain coefficient and flatness.

The main problem arising in calculating multi-stage transistor amplifiers in a wide frequency range is the synthesis of circuits matching the complex impedance of the transistor's output with that of the next transistor's input. As a solution we proposed a model of an ideal matching circuit, so that the problem of matching a complex impedance with a complex impedance was reduced to matching two complex impedances with a real load.

The next step in the amplifier calculating procedure consisted in synthesizing matching circuits with lumped elements, the circuits' characteristics being close to the model's. The methodology was applied to the calculation of a two-stage low-noise transistor amplifier in the 4 – 8 GHz frequency band. The amplifier's characteristics – noise figure, gain coefficient and input-output matching are in very good agreement with the model values.

The work will be continued with the implementation of the amplifier by using quasi-lumped elements (segments of microstrip lines) and the experimental study of its performance.

### II.Signal Reception Suppression Device in Remote Activation of Radio-Electronic Equipment

In cooperation with *Electron-Progress* J.S. Co., we proposed a novel operating principle and design of a device for signal reception suppression in the case of remote activation of receiving equipment in the 20 – 2 000 MHz band. The principle of operation is based on emitting a high-power sweeping signal with amplitude modulation. This results in a manifold increase of the distance of effective equipment operation, as compared with noise signal generation at the same emitted power. The device offers the possibility for communications within the operating area and frequency band. The rate of frequency sweeping and the power emitted can be varied, which results in more efficient operation in the case of digital receiving systems.

The 20 – 2 000 MHz frequency band is divided into six channels with identical structure and emission band of one and more octaves. Each channel comprises the following elements: frequency sweeping master oscillator, fixed attenuator, low-frequency filter, electronically tunable rejection filter, variable electronic attenuator, electronic switch, output power control detectors, and power amplifiers. All electronic components, with the exception of the power amplifiers, were implemented in the Institute of Electronics.

The device passed successfully the functional tests. The work will be continued with replacing the power amplifiers with similar units developed in the Institute of Electronics.

## III.Spectroscopic monitoring of atmospheric compounds

The application of a pulse distributed feedback (DFB) quantum cascade laser (QCL) for a multi-pass open path spectroscopic monitoring of atmospheric compounds is demonstrated. To increase the sensitivity and to decrease the lowest detection limit of the system, spatially at relatively short atmospheric open paths a multiple passes are performed. An usual "monostatic" experimental setup is used. At this setup transmitter (QCL) and receiver are displaced on the one side of the open path. The passive device – in most cases mirror retroreflector is installed on the other side of the path. The successful experiments were performed using up to four double passes (transmitter – retroreflector – receiver). The distance between transceiver and retroreflector is 220 m, corresponding to 440 m double pass and 1760 m unfolded optical path (four double passes). This increase the sensitivity and decrease the lowest detection limit approximately 4 times, compare with usually used one double pass (440 m).

These results are obtained using a QCL with pulse power of 50 mW. Preliminary calculations shows that the number of double passes using the same low power QCL can be multiply to 10 and more by optimization of the reflective surfaces placed on the both sides of the open path. Increasing the pulse QCL power to 6 W (state of the art QCL's) will increase the number of passes in addition. So the lowest detection limit can be improved more than 10 times.

The proposed method will be very useful in the case when the length of the open path is topographically or technically limited. Other important application will be the high sensitivity open path measurement over limited distances – for example over high ways, factories or farms. Using a pulse laser source (pulsed QCL) has an important advantage, compare to CW light source, that the signals received after different number of passes can be easily separated in the time. The used pulse duration of 200 ns limits the minimum distance between the transceiver and retroreflector to 30 m. Decreasing the pulse length to 100 ns will aloud to shorten the distance to 15 m. The maximum useful distance is limited from the beam devergency and loses and can exceed 500 m.

## IV.Qualitative conversion of electric energy by means of power electronic converters

The theoretical models of the consumed current from a single phase AC choppers with PWM of two and three pulses for a half-period of line voltage in case of active load are supposed. On the base of the developed method for a estimation of those converters power efficiency are made optimization researches for elimination or reduction of some significant high harmonics in input current curve in all control range with the same power factors.

The estimated results showed, that for the models with two pulses for a half-period of line voltage, the first high harmonic wth significant amplitude is fifth and with three pulses- seventh with the same power factors. This results give a considerable benefit with the use of those methods for alternating voltage control into the practice.

**PUBLICATIONS:**

1. Hasquin S, Meneses L, Cupido L, Cruz N, Kokonchev L, Prentice R, Gowers C,
Upgrade of the X-mode reflectometry diagnostic for radial correlation measurements in the Joint European Torus,
Rev Sci Instr 2004;75/10:3834-3836.

2. Карталева С, Янев А, Алипиева Е, Гатева С, Тодоров Г, Славов Д, Андреева С, Карауланов Т, Таскова Е, Петров Л, Сарова В, Васева К, Петров Н,
Кохерентни ефекти в магнитометрията,
Списание на БАН 2005;5:31-62.

3. Kolev S, Nedkov I, Yanev A,
Absorption properties of microwave absorbers with different nanostructured fillers.
Proc 6th Workshop on Nanostructured Materials: Application and Innovation Transfer, 2005, pp. 65-66.

4. Taslakov M, Simeonov V, van den Bergh H,
Open path trace gas measurements using pulse quantum cascade laser,
Proc SPIE 2005;5830:347-351.

5. Taslakov M, Simeonov V, van den Bergh H,
Quantum cascade laser based system for line-of-sight data transmission in the mid IR
Laser physics and applications,
Proc SPIE 2005;5830:541-545.

6. Ristori P, Simeonov V, Taslakov M, Molina L, Molina M, van den Bergh H,
Ozone and aerosol distribution measured above Mexico City with a differential absorption lidar during the MCMA 2003 field campaign,
Proc 22nd Int Laser Radar Conf (ILRC), Matera, Italy, July 2004, pp. 755-758.

**CONFERENCES:**

1. П. Зъбов, В. Пенчева, В. Набоко, С. Пенчев, С. Набоко, А. Пенчев, П. Дойчев, С. Ненкова,
Исследование YBCO сверхпроводниковых слоев неразрушающим методом,
V международная конференция "Химия твердого тела и современных микро и нано технологии, 18-23.IX.2005, Кисловодск, Русия.

2. В. Набоко, С. Набоко, С. Пенчев, С. Ненкова, , В. Пенчева П. Зъбов,
Лидарная система с мощным лазерным диодом и охлаждаемым фотоприемником,
V международная конференция "Химия твердого тела и современных микро и нано технологии, 18-23.IX.2005, Кисловодск, Русия.

3. М. Миланова, С. Атанасова, С. Кашчиева, Р. Тодоровска, Д. Тодоровски, П. Зъбов, Микрокомпозиты на основе кремния, содержащие Ru как оптические кислородные сенсоры,
V международная конференция "Химия твердого тела и современных микро и нано технологии, 18-23.IX. 2005, Кисловодск, Русия.

**ONGOING RESEARCH PROJECTS:**

Financed by Electron Progress LTD, Bulgaria
Signal Reception Suppression Device in Remote Activation of Radio-Electronic Equipment.

**AWARDS:**

A. Yanev, B. Todorov, V. Ranev,
Bulgarian Chamber of Commerce Award for the development and application of low noise MW amplifiers.

LABORATORY

## PHYSICAL TECHNOLOGIES

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

TOTAL STAFF: **4**
RESEARCH SCIENTISTS: **4**
Assoc. Prof. T. Uzunov, Ph.D.; D. Dechev; N. Ivanov; N. Lutakova.

## RESEARCH ACTIVITIES:

### Deposition and investigation of mechanical properties of single layer coatings of TiN, W and WN

Single layer coatings of TiN, W and WN on instrumental steel marks R18 and 5CrNiMo were deposited by DC magnetron sputtering. The adhesion of the coatings was investigated and its dependence on the variation of the process parameters was determined. These parameters are the substrate temperature, the nitrogen partial pressure and the duration of the cathode cleaning.

The values of the parameters for deposition of coatings with high adhesion were experimentally determined. The adhesion was measured by two methods: "normal strain" and "scratch test". It was established that the nitrogen partial pressure is the main factor determining the structure and the phase composition of the films, but the substrate temperature is also an important parameter, especially regarding the film/substrate interaction processes.

The Vickers hardness and the Young's modulus of 2μm thick single layer TiN coatings deposited on different steel substrates (R18, 5CrNiMo, 30CrMo and 40Cr) were investigated as a function of the nitrogen partial pressure. The hardness was measured by a FISCHERSCOPE – H100 nanotester with an indentor load of 100 mN and a penetration depth up to 1/3 of the film thickness. The hardness values from 20370 MPa to 22900 MPa, close to that of the bilk material, were measured.

The influence of the temperature and the duration of the additional thermal treatment on the adhesion and the friction coefficient, μ, were investigated for TiN coatings deposited on plates of instrumental steel 5CrNiMo. The results from this investigation show that after depositing the TiO coating the friction coefficient varies from 0.27 (at a deposition temperature of 500 $^{o}$C and treatment time of 2 hours) and 0.47 (at a deposition temperature of 600 $^{o}$C and treatment time of 4 hours.

## PUBLICATIONS:

1. Djakov B, Enikov R, Oliver D,
Production and diagnostics of plasma jets,
J Bulg Acad Sci 2005;5:18–25.

2. Dechev D, Uzunov T, Krastev P, Ivanov N,
AlN coatings deposited by reactive sputtering,
Proc Univ Sliven, Bulgaria 2005;9:51-54.

3. Jordanov M, Uzunov T,
Adhesion and cohesion tensions in magnetron sputtered coatings determined by the scratch test method,
Machine technique and technology 2004;2:24-28.

**ONGOING RESEARCH PROJECTS:**

Financed by the Technical University of Sofia

N 515 NI-16/2005 Mechanical characteristics of ion nitrided metal and metal-nitride coatings obtained in vacuum.

**LECTURE COURSES:**

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

Materials for Electronics, Sliven College of the Technical University of Sofia.

# SELECTED PROJECTS

- **Magnetic Nanocomposites for Microwave Applications**
- **Nanostructured Photonic Sensors - Nanophos**
- **Coherent Population Trapping in the Presence of Electromagnetic Fields**
- **Metal-Oxide Thin Film Heterostructures on Tilted-Axes Substrates**

# MAGNETIC NANOCOMPOSITES FOR MICROWAVE APPLICATIONS

*I. Nedkov, T. Koutzarova, S. Kolev, T. Merodiiska, T. Beneva, Ch. Ghelev, L. Slavov*

We present here the main results obtained in the research during the first year of the NATO Reintegration Grant Project (RIG 981472) "Nanocomposites - magnetic superconductors and ferroxides, for microwave applications" and two projects financed by the National Research Fund at the Ministry of Education and Sciences, namely, NT-1/01/2003 и MUF-1301/2003, the latter having been successfully completed in 2005.

## 1. Introduction

The polymer magnetic nanocomposites with ferromagnetic or superparamagnetic nano-particle fillers dispersed in polymers, which were the object of our research, are now being extensively studied as promising for different applications (high-capacity magnetic storage media, microwave absorbing devices, possible elements of nano-scale integral circuits). The magnetic nanocomposite materials exhibit novel macroscopic magnetic properties due to the combined action of quantum-sized effects, strain and surface effects, interface between nano-structures and the matrix, matrix properties and morphologies of nano-structures.

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.

According to our plan for the first year of the NATO Project, we focused our attention on adapting known "wet chemical" technologies to synthesizing nanoscale magnetite ($Fe_3O_4$) as a model structure for spinel ferroxides.

The most commonly used method for obtaining iron oxide nanoparticles is co-precipitation. Although by using the co-precipitation method one can vary the average size of the nanomagnetic particles by adjusting the pH and the temperature of the aqueous media, one has only limited control over the size distribution of the particles. To overcome this problem we adapted a reverse microemulsion process for synthesizing of nanoscale $Fe_3O_4$. One of the advantages of this technique is the preparation of very uniform particles - (< 10% variability).

## 2. Experimental

We used a water-in-oil reverse microemulsion system with n-hexadecil trimethylammonium bromide (CTAB) as a cationic surfactant, n-butanol as co-surfactant, n-hexanol as a continuous oil phase, and aqueous phase for synthesis of nanosized magnetite.

We studied the possibility to control the size of $Fe_3O_4$ nanoparticles by applying two varieties of the microemulsion techniques - single microemulsion and double microemulsion.

The double microemulsion technique is the well known microemulsion method used so far to obtain nanosized oxides. There, the synthesis process runs via the mixing of two microemulsion systems with identical compositions but different aqueous phase type – one containing metal ions, the other, a precipitating agent. The first one consisted of an aqueous solution of iron chloride salts ($Fe^{2+}/Fe^{3+}$ molar ratio 1:2) dispersed in the CTAB/n-butanol/n-hexanol. The second system comprised a precipitating agent (ammonium hydroxide) dispersed in the CTAB/n-butanol/n-hexanol. The two microemulsions were mixed together under continuous stirring.

The single microemulsion technique uses a microemulsion system

whose aqueous phase contains metal ions only ($Fe^{2+}$ and $Fe^{3+}$). The magnetite was precipitated by adding an aqueous solution of ammonia. To the best of our knowledge, ours was the first attempt to produce iron oxides by using this type of microemulsion.

### 3. Structural investigations.

The XRD data exhibited consistently a single-phase spinel structure for all types of samples. The unit cell parameters (0.8371 - 0.8374) for powders are in the range between that for standard values for $Fe_3O_4$ and $\gamma$-$Fe_2O_3$, regardless of the synthesis procedure. We found that the $Fe_3O_4$ powders produced had a strongly defective structure, which is typical for nanosized magnetite powders. The average nanoparticle size was estimated from the XRD spectrum by applying the Scherrer formula. The particle size decreased 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 the two methods of synthesis - double and single microemulsions. Magnetite with the lowest particles size - 14 nm, was produced for the lowest concentration of ferric and ferrous ions in the aqueous phase. The microscopic investigations showed that the particles were spherical with uniform particle size distribution. It could also be seen that the particles were strongly aggregated, which is typical for particles with a size less than 50 nm.

In the case of single microemulsion, we explored the influence of the amount of surfactant on the particle size. The amount of surfactant affected substantially the size of the particles obtained, when the ferric and ferrous ions concentration in the aqueous phase was high. As the CTAB concentration increased, the particles size decreased. The particle size was estimated to be about 15 nm for the highest CTAB concentration and around 36 nm for lowest one.

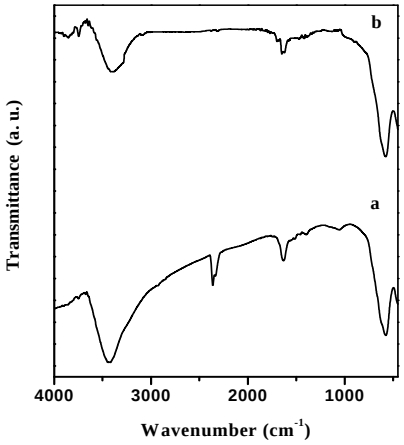



**Figure 1.** FTIR spectra of magnetite powders obtained by single (a) and double (b) microemulsion techniques with identical compositions.

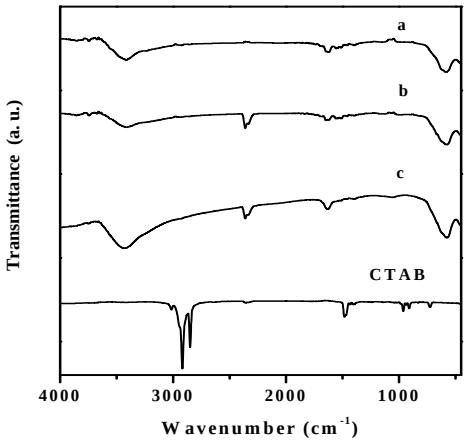



**Figure 2**. FTIR spectra of magnetite obtained by single microemulsion techniques and CTAB.

Infrared spectroscopy is an important tool in exploring various ordering phenomena and can yield information not only about the position of the ions in the crystal but also about their vibrational modes. FTIR spectra of magnetite obtained by double and single microemulsion techniques with identical compositions are shown in Fig. 1. Figure 2 presents FTIR spectra of magnetite obtained by single microemulsion. Figure 2 (a) is the spectrum of a sample obtained by microemulsion with low concentration of ferric and ferrous ions in the aqueous

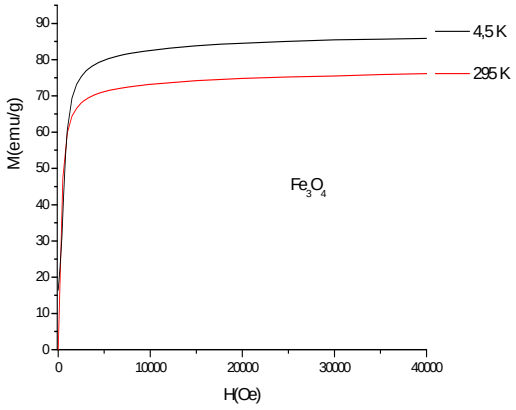
phase. Figure 2 (b, c) presents spectra of samples with high concentration of ferric and ferrous ions in the aqueous phase for $W_0 = 5$ and 20, respectively. Figure 2 (d) shows the infrared spectrum of CTAB. All samples exhibited absorption in the region 3400, 1620, 1050 and 574 $cm^{-1}$. The general range of 3600 - 3100 $cm^{-1}$ is related to antisymmetric and symmetric OH stretching. The IR bands in region 1670 - 1600 $cm^{-1}$ are due to bending vibrations of OH in the water molecule. The simultaneous presence of bands in these two ranges (3600 - 3100 $cm^{-1}$ and 1670 - 1600 $cm^{-1}$), which are associated with the lattice of water molecule, is indicative of water crystallization in the powders. The absorption in the range 800 to 1200 $cm^{-1}$ is characteristic of OH deformation in hydroxides. The absence of absorption in this range reveals the lack of iron hydroxides in the powders obtained. Based on the above, and on the presence of characteristic hydroxyl peaks of water at 3600 - 3100 $cm^{-1}$ and 1670 - 1600 $cm^{-1}$, we concluded that the water is absorbed on the nanoparticles surface.

Bands at 576 and 574 $cm^{-1}$ were also observed in the samples due to the metal-oxygen stretching vibration modes, which correspond to $Fe_3O_4$. These bands were sharp and of strong intensity, which demonstrated the high degree of crystallinity of the samples. Their position depended on the history of the sample and the particle size.

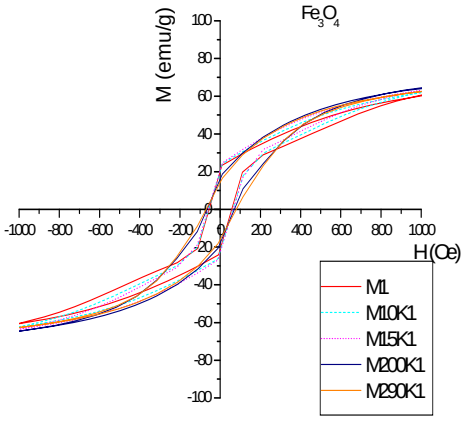
## 4. Magnetic properties.

The main results obtained in fulfillment of the projects financed by the Ministry of Education and Science had to do with acquiring new data on the magnetic properties of nanostructured ferroxides with cubic (magnetite) and hexagonal (barium hexaferrite) structure. Using the technology for fabrication of nanostructured ferroxides by co-precipitation, patented by us in 2005, we produced materials with unique properties.

The measurements of the saturation magnetization $M(H)$ showed that it decreases near He temperature, which is typical for spherical magnetite particles with diameter $10 \pm 2$ nm (Fig. 3a); this effect, related by some authors to the so-called "boundary" effect, has to do with spin moments disorder at the particle's surface.




a)

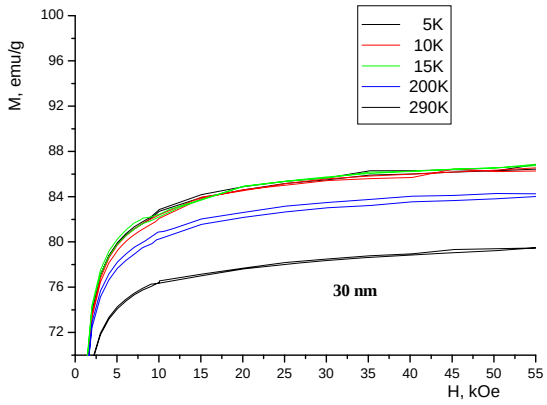



b)

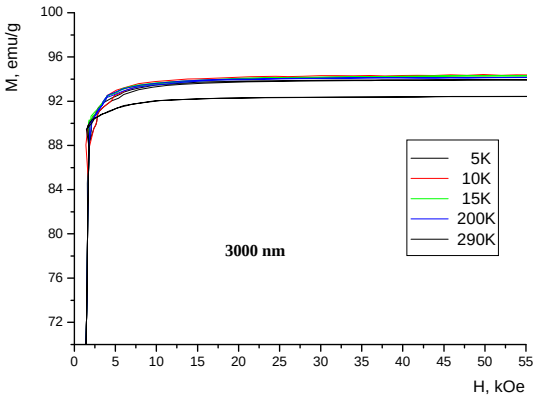
**Figure. 3.** a) SQUID measurement of the saturation magnetization at room temperature and at 4.5 K and b) change of the hysteresis loop shape as a function of the temperature of spherical magnetite particles with diameter in the order of $10 \pm 2$ nm.

The hysteretic losses in such particles change with the temperature; our measurements demonstrated that the hysteresis loop changes its shape in the 80 – 130 K interval, which is illustrated in Fig. 3 b. We believe that this is related to the Verwey transition.

To examine the monodomain particle phenomenon, we chose a sample with particles size of 30 nm, where no superparamagnetic contribution was observed at room temperature, while the partial oxidation is less (27 %) than that in smaller particles (10 nm, 84 %).




a)




б)

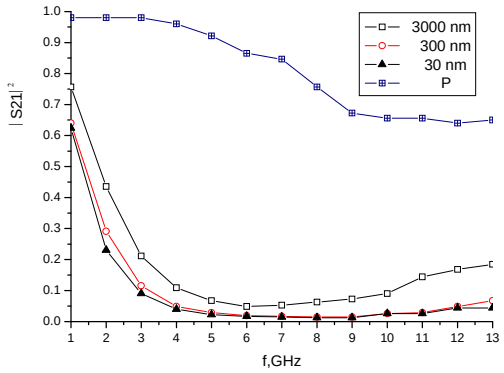
**Figure 4.** Saturation magnetization of $Fe_3O_4$ with grain size 30 nm a) ad 3000 nm b).

The sample with grain size 3000 nm is typical example of polycrystalline samples; this is why we chose it for comparison between the two types of particles. The static magnetic characteristics were measured by a SQUID in the temperature range 5 - 300 K in order to determine the inverse point of superparamagnetism and the anisotropy coefficient. The data on the coercive field and anisotropy coefficient for the commercial magnetite were supplied by the manufacturer. The results saturation magnetization measurements of the two samples ($M_s$) are presented in Fig. 4..

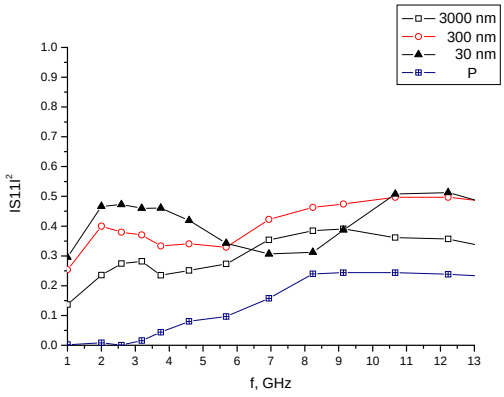
We observed a reduction of the saturation magnetization of the sample with average grain size of 30 nm by 17% as compared with the other sample (average grain size 3000 nm). In addition, the 30-nm sample could not be saturated even at very high magnetic fields (55 kOe). For the 3000-nm sample the $M_s$ values were similar to those of bulk material, with saturation being reached at moderately high fields. We relate the nanosized sample behavior to the existence of magnetic disorder and oxidation on the particles' surface. These effects result in a change in the surface properties of the particles, namely, appearance of anisotropy, which leads to a rise in the particles' overall anisotropy.

## 5. Applied studies magnetic nanocomposites in the MW region.

In view of applying nanosized ferroxides as absorbing structures in the MW range, we studied the scattering parameters (S-parameters) of composite materials with magnetic filler (magnetite). The measurements were performed in the 1 - 13 GHz range, with the aim of clarifying the role of the ferromagnetic resonance (FMR), the latter for bulk material being around 1 GHz. The S-parameters are used to express the electromagnetic wave energy reflected from and transmitted through the sampleand the. $S_{21}$ is the transmission coefficient representing the energy transmitted through the sample (Fig. 5 a), while $S_{11}$ is the reflection coefficient (Fig. 5 b).




a)




b)

**Fugure 5.** S-parameters of samples with the same degree of filling and of the polymer (P).

The energy absorbed is calculated by subtracting the reflected and transmitted energy from the incident energy (100%):

$$\text{Absorbed energy} = 1 - |S11|^2 - |S21|^2$$

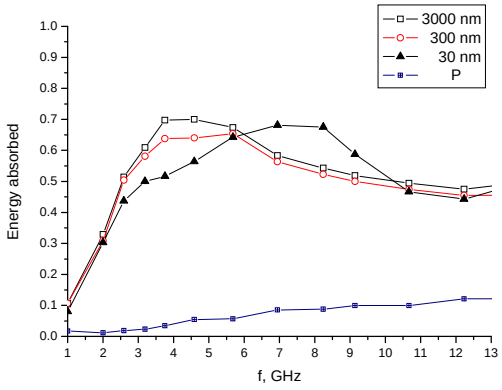



**Figure 6.** Energy absorbed in samples with the same degree of filling and in the polymer (P).

Fig. 6 presents the absorbed energy as calculated using $S_{11}$ and $S_{21}$ for samples with the same degree of filling of the polymer (P). It is seen that the maximum of the energy absorbed in the composite samples coincides with the magnetic losses maximum which gives us reason the claim that the FMR is the main loss mechanism in the frequency range considered.

## 4. Conclusion.

In conclusion, the powders' structural and composition characteristics show that there are no significant differences in the particle size and the particle size distribution between the single and the double microemulsion techniques. One of the advantages of the single microemulsion technique is that it is much less expensive than the double microemulsion methods. The magnetite nanoparticles were successfully synthesized by using the single microemulsion technique, where the aqueous phase of the microemulsion system contains only $Fe^{2+}$ and $Fe^{3+}$ ions. This method is an effective way of synthesizing magnetite nanoparticles with narrow size distribution.

New data were acquired on the order/disorder effects in the particles' core/surface on the particles' saturation magnetization. The studies at high

magnetic fields indicated the presence of paraprocess in the nanoparticle, this process being strongly dependent on the particle's anisotropy. New data were summarized on the surface anisotropy contribution in the nanosized state and on its relation to the superexchange interactions within the crystal cell. During the period reported, we carried out a series of studied geared at elucidating the role of a nanosized magnetite filler dispersed in a polymer matrix. The results thus obtained may form the basis of applied studies on creating functional microwave absorbers.

**Publications related to the projects:**

1. Koutzarova T, Kolev S, Ghelev Ch, Paneva D, Nedkov I,
Microstructural study and size control of iron oxides nanoparticles produced by microemulsion technique,
accepted for publication in **phys. stat. sol. (c) doi: 10.1002/pssc.200563115.**

2. Koutzarova T, Kolev S, Ghelev Ch, Paneva D, Nedkov I,
Iron oxides nanoparticles produced by microemulsion technique,
7th Workshop NANOSCIENCE & NANOTECHNOLOGY, Sofia, Bulgaria, November 24 - 25, 2005.

3. Nedkov I, Merodiiska T, Slavov L, Vandenberghe RE, Kusano Y, Takada J,
Surface oxidation, size and shape of nano-sized magnetite obtained by co-precipitation,
J. Magn. Magn. Mater., accepted for publication doi:10.1016.

4. Slavov L, Merodiiska T, Nedkov I, Vandenberghe RE,
Surface oxidation control of nanosized magnetite and Mössbauer measurements,
Hyperfine Interactions, accepted for publication.

5. Kolev S, Nedkov I, Yanev A,
Absorption properties of microwave absorbers with different nanostructured fillers, Nanoscience & Nanotechnology - Proc. of 6th Workshop on Nanostructured Materials Application and Innovation Transfer, ed. by Balabanova E., Dragieva I., Heron Press Ltd. 65-66, (2005).

6. Kolev S, Yanev A, Nedkov I,
Microwave absorption of ferrite powders in a polymer matrix,
accepted for publication in **phys. stat. sol. (c) doi:** 10.1002/pssc. 200563116.

7. Kolev S, Nedkov I, Yanev A,
Absorption properties of microwave absorbers with different nanostructured fillers,
Proc. of 6th Workshop on Nanostructured Materials Application and Innovation Transfer, ed. by Balabanova E., Dragieva I., Heron Press Ltd., (2005), 65-66.

# NANOSTRUCTURED PHOTONIC SENSORS – NANOPHOS
# IST-2001-39112 Project 5th FP, EU

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## 1. Introduction

Several types of gas sensors are currently available and intensively studied: solid electrochemical sensors, infrared spectroscopic sensors, metal oxide sensors, quartz microbalance (QMB) sensors and surface acoustic wave (SAW) sensors. The last three categories are characterized by an interaction between a sensitive material and the chemical agent. The physical properties of the material are modified under gas exposure.

The operation of metal oxide sensors is based on the electric conductivity variation of a thin layer of a semiconductor (typically $SnO_2$, ZnO, $WO_3$, $TiO_2$, ITO, and etc.) when exposed to the target gas. The presence of ambient oxygen near the material leads to the adsorption of oxygen by trapping of (usually) free electrons and creating ions such as $O^-_2$, $O^-$ and/or $O^{2-}$ which remain adsorbed. This effect results in the formation of a depletion zone near the grain boundary or the nanoparticle surface. The macroscopic effect consists in drop in the conductivity due to the reduced number of available carriers. This phenomenon is usually thermally activated. The sensitivity depends on the gas type and the working temperature.

The selectivity concerning gases of the same chemical family remains low. However, it can be improved by doping the films with a catalyst (Pd, Pt).

In the case of semiconductor oxides, a strong variation is observed of the surface conductivity of a thin film under gas exposure (several decades), which leads to a variation of the refractive index.

We made use of the pulsed laser deposition (PLD) technique to grow high optical quality films from the semiconductor oxides mentioned before and studied the films' sensitivity to various gases – mainly hydrocarbons.

## 2. Recent results and discussion

### *2.1. ITO thin films*

Thin indium tin oxide (ITO) films were grown on (001) $SiO_2$. The oxygen pressure during deposition varied from 5 to 20 Pa with substrates temperature in the range 200 to 460°°C. The ITO targets were composed of $In_2O_3$ (90 wt.%) : $SnO_2$ (10 wt.%), pressed at 6 MPa and sintered at 1100 °C for 4 hours to form ceramics. The structural and optical properties of the films investigated in dependence of the deposition conditions. The X-ray diffraction measurements showed that all films had preferential orientation in the (111) direction. Fig. 1 presents the XRD spectra of the films grown at oxygen pressure of 5 Pa at different temperatures. As is seen, the intensity of the peak (222) decreases with the substrate temperature and peaks of (211) and (400) appear. Similar behavior of the structure was observed when the oxygen pressure was raised from 5 to 20 Pa at a constant substrate temperature.

All films were transparent in the visible and near-infrared regions of the optical spectrum.

Fig. 2 shows the transmission spectra of the ITO oxide films prepared at 5 Pa and different temperatures. As is seen, the

transmission decreases slowly with the temperature. Films grown at increasing oxygen pressure at a fixed temperature exhibited a similar behavior.

The lowest optical waveguide losses measured were 2 $dBcm^{-1}$ for the film grown at $P(O_2)$ = 5 Pa and $T_s$ = 200 $^oC$, the optimum conditions.

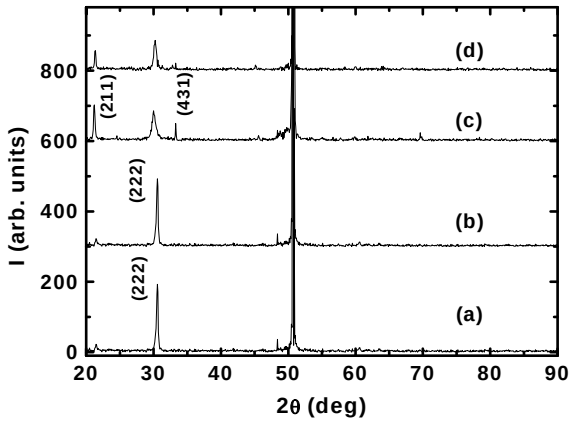



Fig. 1. XRD patterns of films grown at $P(O_2)$ = 5 Pa and substrate temperatures: a) 200 $^oC$; b) 300 $^oC$; c) 400 $^oC$; d) 460 $^oC$.

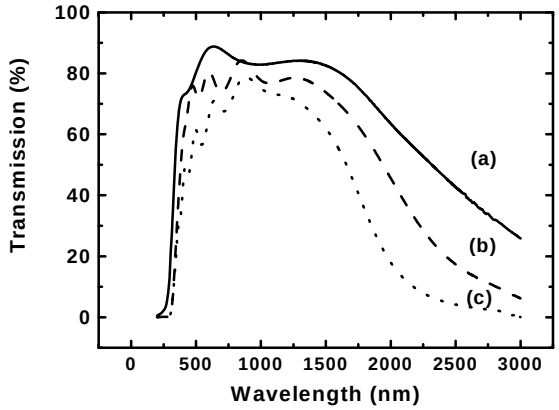



Fig. 2. Optical transmission spectra of indium tin oxide films grown at $P(O_2)$ = 20 Pa and temperatures: a) 200 °C; b) 400 °C; c) 450 °C.

### *2.2 Palladium doped ITO thin films*

Palladium doped ITO thin films were grown on $SiO_2$ (001) substrates at oxygen pressures of 10 and 15 Pa and substrate temperature ranging from 300 and 450 $^oC$. The ITO targets were composed of $In_2O_3$ (90 wt.%) : $SnO_2$ (10 wt.%), doped with palladium 1% or 3%, pressed at 6 MPa and sintered at 1100 $^oC$ for 4 hours to form ceramics. The films were polycrystalline and had structures similar to the non doped films, i.e. the palladium concentrations used did not affect the crystalline structure of the films.

The optical transmittance increased with the oxygen pressure and the substrate temperature. It had maximum values for the films grown at $T_s$ = 400 $^oC$ and $P(O_2)$ = 15 Pa and tended to decrease with temperature and oxygen pressure. The transmission of pure and palladium doped ITO films grown at the same deposition conditions varied between 85-91 % in the 400 - 900 nm wavelength region. The transmission and reflectance spectra of pure and palladium doped ITO films are shown in Fig. 3.

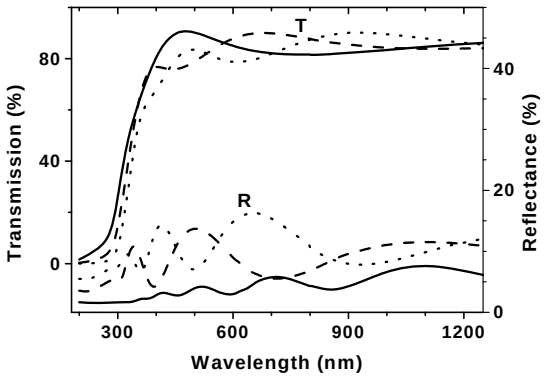



Fig. 3. Optical transmission and reflectance spectra for undoped and palladium doped ITO films grown at $P(O_2)$ = 15 Pa and $T_s$ = 400 $^oC$.

The refractive index of the films tended to decrease as the oxygen pressure, substrate temperature or doping concentration were raised. The optical band gap $E_g$ was in the range from 3.8 to 4.15 eV and decreased with the doping concentration. Fig. 4 presents the variation of the refractive index $n$ and the band gap $E_g$ as a function of the doping concentration.

The AFM studies of the same films showed that the roughness of the films increases significantly with the doping concentration. The ITO films with

1 wt.% Pd had higher transmittance, density and better surface morphology than those with 3 wt.% Pd. It is well known that 1 wt.% Pd improves the gas sensitivity, while the optical properties are still sufficiently good at this concentration.

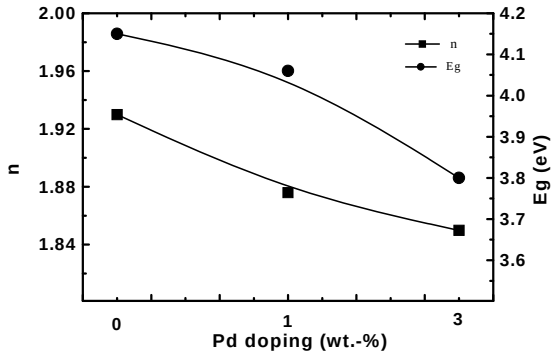



Fig. 4. Refractive index and band gap as a function of the doping concentration.

### *2.3. Thin films of $TiO_2$ and $WO_3$*

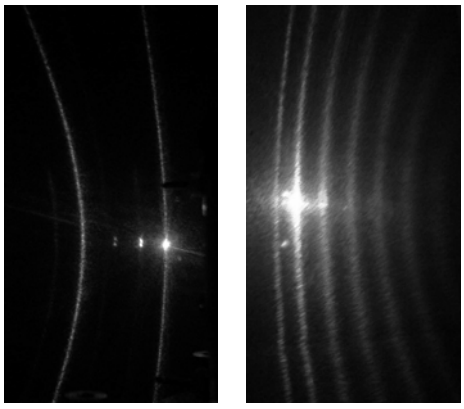
Thin films of $TiO_2$ and $WO_3$, were produced by laser ablation of ceramic targets. $TiO_2$ and $WO_3$ powders (Merck, Germany) with purity of 99 % and 99.9%, respectively, were pressed at pressures ranging from 2 - 10 MPa to form dense pellets of pure $TiO_2$ and $WO_3$. Subsequent sintering of the pellets was performed at 1100 °C for 8 hours in air to form ceramic targets. However, different stepwise sintering modes were performed for the different types of pellets. All films were grown on single crystal (001) $SiO_2$ substrates because of its low refractive index and high transparency in the visible and near-infrared spectral ranges. The substrate temperature was varied from 100 to 600 °C. Different oxygen pressures in the range of 1 to 20 Pa were applied. The laser fluence was varied from 1.2 to 3.2 $J.cm^{-2}$. The influence of the deposition time and the oxygen pressure on the film thickness was investigated for the films grown at 100 °C.

The X-ray diffractograms showed an amorphous structure for the films grown at temperatures lower than 400 °C at all oxygen pressures applied. However, an anatase $TiO_2$ phase, consisting of (101) and (001) lattice plane reflections, was formed when the temperature was raised from 400 to 600 °C. It is worth noting that better crystalline properties were observed for the film grown at 600 °C and pressure of 1 Pa, which crystallized preferentially in (001) anatase phase. In addition, a shallow peak of (110) rutile $TiO_2$ phase was observed at higher oxygen pressures.

AFM images of the films showed that the surface morphology is affected more strongly by the temperature than by the oxygen pressure. The RMS values measured were very low and remained nearly constant (1.5 – 3.9 nm) as the temperature was varied between 100 and 500 °C for films deposited at a fluence of 1.2 $J.cm^{-2}$. A sharp rise of the surface roughness up to 15.7 nm was observed at 600 °C, because of the formation of three-dimensional large islands resulting in the growth of large grains. The RMS values of the films grown at 100 °C and a higher fluence (3.2 $J.cm^{-2}$) at all pressures showed an increase from 4 to 9 nm.

The waveguide propagation mode structure, the refractive index, and the thickness of the films were determined by m-line spectroscopy using film-prism coupling at wavelength of 632.8 nm. High quality mode structure of the light was observed for the films grown at pressure of 0.10 mbar, fluence of 1.2 $J.cm^{-2}$ and temperatures of 400 and 500 °C. The thickness of the films varied between 300 and 500 nm. However, it was observed that the films grown at the lower temperature of 100 °C and higher fluence of 3.2 $J.cm^{-2}$ at all pressures also exhibited sharp and well defined narrow lines for TE and TM light polarization (Fig. 5a). The thickness of these films rose from 700 to 1400 nm when the pressure and the deposition time were raised simultaneously. The highest value was

measured for the film grown at the highest pressure of 20 Pa and the longest deposition time of 2.5 h. No difference was observed in the mode structure of the thick films as compared with the thinner ones. The refractive indices of the low temperature films for the TE and TM modes were measured to be significantly lower than those of the anatase $TiO_2$ phase (~2.5) and varied in the range 1.73 to 2.11. It is worth pointing out that the refractive index measured for the TE polarization increased gradually with the temperature from 2.17 to 2.53 for the films grown at 1.2 J.cm$^{-2}$.



a) b)

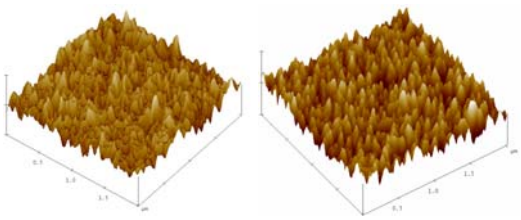
Fig. 5. Mode structure in the waveguide films grown at temperature of 100 °C, pressure of 15 Pa, fluence of 3.2 J.cm$^{-2}$, and deposition time 1.5 h: a) thin $TiO_2$ film with thickness of 600 nm; b) thin $WO_3$ film with thickness of 1700 nm.

Thin $WO_3$ films were grown at the low temperature of 100 °C, oxygen pressure of 15 Pa and fluence of 3.2 J.cm$^{-2}$. The AFM images showed smooth film surface with RMS values of 3 to 3.6 nm. The mode structure of the light propagating in the films consisted of a large number of narrow and bright TE and TM modes (Fig. 5b). The refractive index and the thickness were measured to be 2.06 and 1700 nm, respectively.

The optical transmission measured in VIS and NIR spectral regions was in correlation with the morphological properties of the films and showed a stronger dependence on the temperature than on the oxygen pressure. All films grown below 500 °C were highly transparent in the visible region with transmission varying in the range between 87 and 92 %. In addition, the smoother surface contributed to the higher transparency of the films.

*2.4. Al-doped ZnO films*

Highly textured thin Al-doped ZnO films were produced by pulsed laser deposition. All films deposited were textured along the (002) direction. It should be noted that the substrate temperature and the oxygen pressure applied had stronger influence on the film crystallinity than the presence of dopants. The grain size of the 2wt% $Al_2O_3$:ZnO films was approximately the same as in the undoped ZnO. Increase the dopant concentration to 5wt% $Al_2O_3$:ZnO in the films led to an increase in the grain size, which is well known to result in a decrease in the gas sensitivity. The use of doped targets increased the droplets on the film surface thus leading to deterioration of the optical detection of the gas sensing effect. The increase of the dopant concentration increased the RMS value to about 25 – 35 nm (Fig. 6), reduced the film transmission in the visible range and shifted the transmission cut-off edge to the shorter wavelengths (Fig. 7).



(a) (b)

Fig. 6. AFM images of the ZnO films prepared at 300 °C and 5 Pa from (a) undoped and (b) 2wt% $Al_2O_3$:ZnO targets.

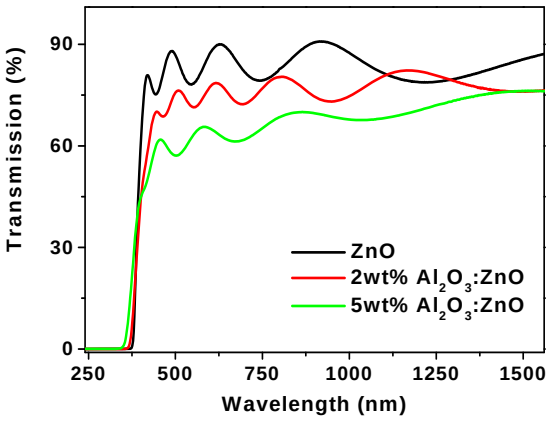



Fig. 7. Optical transmission spectra of doped and undoped ZnO films, deposited at 150 °C and 5 Pa.

The refractive indices of the doped films were higher than those of the undoped samples. The films deposited from the 2wt% $Al_2O_3$:ZnO target at oxygen pressures between 0.05 and 0.1 mbar and at 150 or 300$^o$C had good mode properties, which made them good candidates for optical sensors.

**Principal recent publications of the group, related to the topic of the Project**

1. Stankova NE, Atanasov PA, Stanimirova TJ, Dikovska AO, Eason RW,
Thin (001) tungsten trioxide films grown by laser deposition,
Appl Surf Sci 2005;247/1-4:401-405.

2. Dikovska AO, Atanasov PA, Tomov RI, Dimitrov IG,
Ultraviolet annealing of thin $Y_2O_3$ films grown by pulsed laser deposition,
Proc SPIE 2005;5830:75-79.

3. Stanimirova TJ, Atanasov PA, Dikovska AO, Stankova NE, Tonchev SH,
Structural and optical properties of thin indium oxide films produced by pulsed laser deposition,
Proc SPIE 2005;5830:55-59.

4. Stankova NE, Atanasov PA, Dikovska AO, Dimitrov IG, Socol G, Mihailescu I,
Growth of anatase $TiO_2$ thin films by laser ablation,
Proc SPIE 2005;5830:60-64.

5. Stanimirova TJ, Atanasov PA, Dimitrov IG, Dikovska AO,
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6. Dikovska AO, Atanasov PA, Vasilev C, Dimitrov IG, Stoyanchov TR,
Thin ZnO films produced by pulsed laser deposition,
J Optoelectr & Adv Mater 2005;7/3:1329-1334.

7. Atanasov PA,
Thin films optical gas sensors,
Proc Bulg Acad Sci 2005:19 pgs. (in Bulgarian, CSI-BAS).

# COHERENT POPULATION TRAPPING IN THE PRESENCE OF ELECTROMAGNETIC FIELDS

*C. Andreeva, G. Bevilacqua, V. Biancalana, E. Breschi, S. Cartaleva, Y. Dancheva, T. Karaulanov, L. Moi, N. Petrov, K. Vaseva*

## I. Introduction

Coherent coupling of ground-state atoms results in interesting effects with significant importance for fundamental physics and applications. Among others, Coherent Population Trapping (CPT) and the related effect of Electromagnetically Induced Transparency (EIT) are nowadays extensively studied and applied to laser cooling of atoms [1] slowing down the light [2], atomic clocks [3, 4] and very sensitive optical magnetometers [5, 6].

The CPT effect manifests itself as a dip in the fluorescence (Fig.1), or a peak in the laser light transmitted through (most frequently) alkali atoms, which is several orders of magnitude narrower than the width of the corresponding optical transitions. The resonance is observed when the two ground-state hyperfine (hf) levels are coupled to a common excited state by two coherent laser fields [7]. Using the sensitivity of the resonance parameters to magnetic fields, it is applied for weak magnetic field measurement [5]., While the effect of a static magnetic field (MF) on CPT has so far been studied extensively [5, 6], much less attention has been paid to the case of an alternating MF. Interesting results have recently been reported by Lukin *et al.* [8] and Yelin *et al.* [9]. In [8], the case of a coherent perturbation which couples the Λ system to a fourth state, giving rise to a doubling of the resonance, is discussed from a general point of view. In [9] the case of an alternating MF applied orthogonally to the laser beam is considered: such a field induces transitions between adjacent Zeeman ground sublevels which act as the fourth state needed to split the resonance.

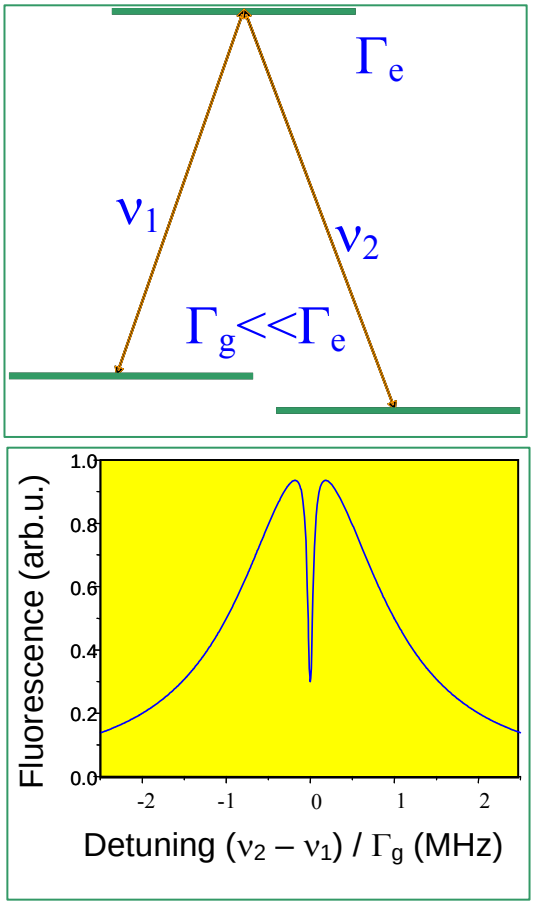



Fig.1. CPT formation in Λ system.

In the work presented we report the results from the and theoretical interpretation of experiments on the CPT effect produced in the presence of dc and ac magnetic fields, with potential for electromagnetic field (EMF) measurement. We consideed a different configuration, where the ac MF is parallel to the laser beam propagation direction and to a bias static field. The modified spectrum resembles the spectra obtained when a single Λ system is probed with the frequency modulation (FM)

technique in which the modulation frequency lies well outside the CPT linewidth. The FM spectroscopy [10, 11, 12] is a very sensitive technique where spectral structures are probed by a frequency modulated radiation. The spectrum of such radiation contains many components (sidebands) separated by the modulation frequency $\Omega_M$. In the present work similar features appear which can be explained in terms of "atomic level sidebands".

## 2. Experimental setup

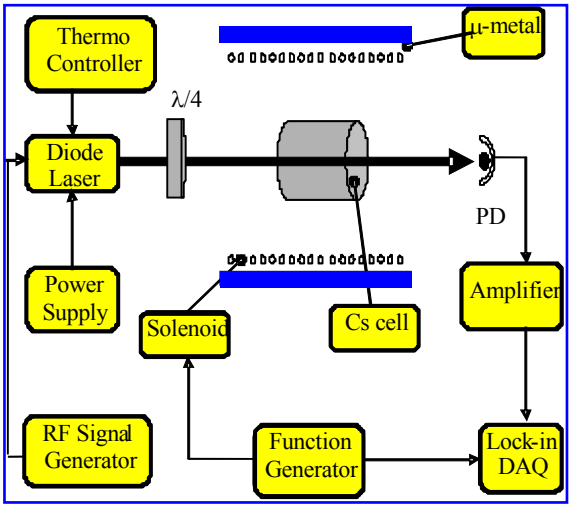
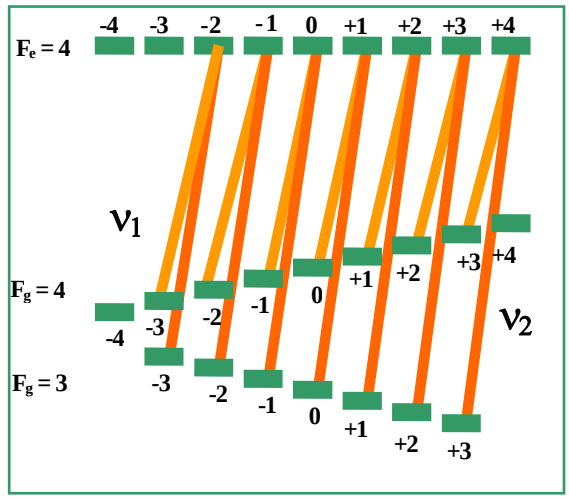



Fig.2. Experimental setup.

A schematic illustration of the experimental setup is shown in Fig.2. The light from a Vertical Cavity Surface Emitting Laser (VCSEL) is circularly polarized and irradiates a sealed cell with Cs and 50 Torr Ne added as a buffer gas. The experiment is performed on the $D_2$ line of Cs. The two required coherent light fields are provided by means of frequency modulation of the VCSEL at $\Omega_M$ around 4.6 GHz. Thus, the two first sidebands in the laser spectrum have frequency difference matching the ground-state hyperfine separation of Cs. The transmission is registered when scanning the frequency difference between the two light fields involved (i.e. the laser modulation frequency). A DC magnetic field parallel to the laser beam propagation direction is produced around the cell by means of a solenoid. The cell and the solenoid are situated inside a three-layer μ-metal shield to avoid the laboratory magnetic field. The CPT spectrum in the presence of a constant magnetic field is illustrated in Fig.3. The magnetic field removes the Zeeman degeneracy of the two ground states and thus, for the case of Cs 7, independent Λ systems are formed, giving rise to the registration of 7 resonances, each of them registered at a different modulation frequency. The frequency difference between two adjacent resonances is a measure of the constant magnetic field applied.



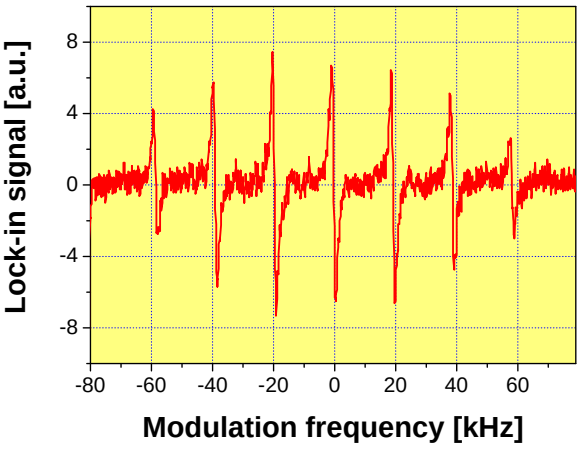




Fig.3. Formation of the CPT spectrum (PSD) on the $D_2$ line of Cs consisting of seven Λ systems.

## 3. Experimental results

In order to examine the effect under the influence of EMF, that field is additionally imposed using the same solenoid. Now, phase-sensitive detection (PSD) is performed at the EMF frequency $f_{ac}$. First, EMFs with frequencies of the

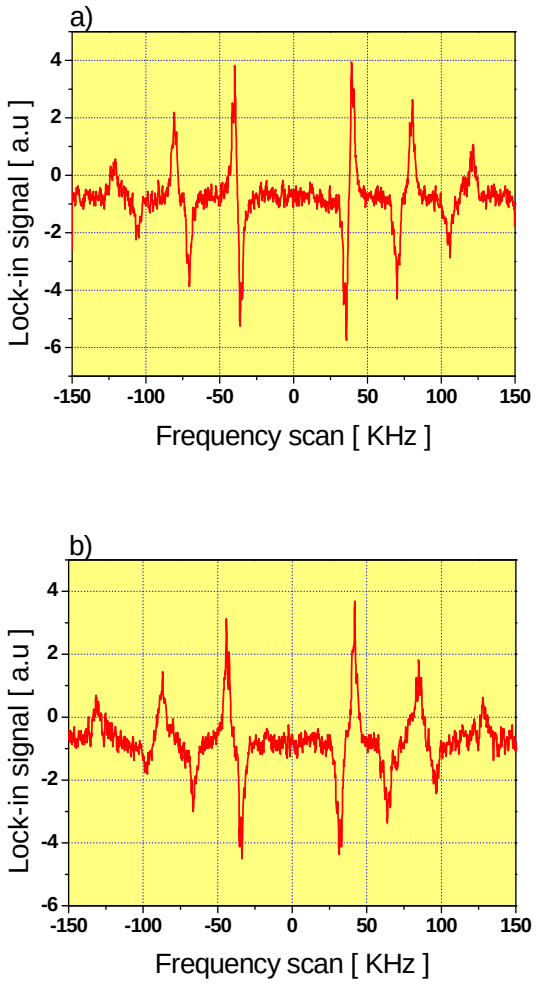



Fig.4. CPT spectrum with PSD at the EMF frequency ($f_{ac}$ = 1.734 kHz), for two different EMF amplitudes: (a) 1.1 mG; (b) 6.3 mG.

order of the CPT resonance FWHM or lower are applied. In this case, the EMF amplitude enhancement causes broadening of the resonances profile (Fig.4). At lower EMF amplitudes (about 1 mG peak-to-peak) only the (−3, −3) and (+3, +3) resonances exhibit notable broadening by the EMF, while at a field amplitude of about 6 mG already all resonances are influenced. It should be noted that when PSD at the EMF frequency is realized, the (0, 0) resonance is not observed due to the absence of a linear Zeeman shift for the $m_{Fg} = 0$ sublevels.

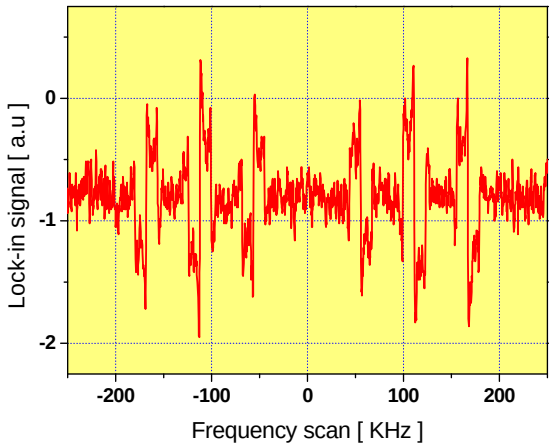



Fig.5. CPT spectrum for PSD at EMF frequency $f_{ac}$ = 11.739 kHz significantly higher than the FWHM of the CPT resonance.

When the EMF applied has a frequency significantly higher than the FWHM of the CPT resonance, the PSD signal shape (Fig.5) is similar to that of the resonances observed by applying frequency modulation spectroscopy [13]. In our case, though, instead of laser frequency modulation for PSD of the CPT resonance, the atomic sample levels are modulated.

To illustrate in a more clear way the modification of the separate resonances, we will zoom on one of them, namely the (−2, +2) resonance, and follow the appearance of atomic level sidebands with increasing the EMF amplitude. Again, PSD is performed at the EMF frequency $f_{ac}$, which is higher than the FWHM of the resonance itself. In Fig.6 the PSD signal is presented in dependence on the laser frequency modulation for different amplitudes of the EMF with $f_{ac}$ = 7.117 kHz. It can be seen that for low amplitude (about 1 mG, Fig.6a), the (−2, +2) resonance consists of three resonances separated at the EMF

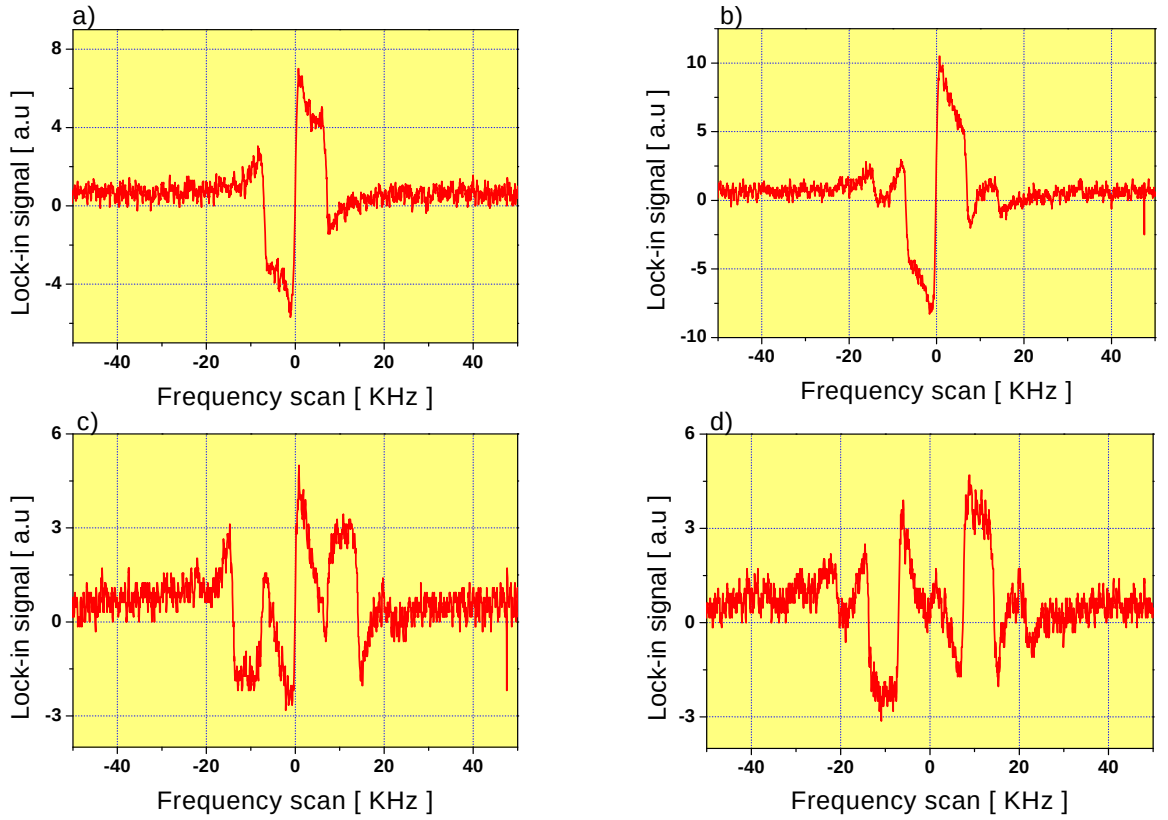



Fig.6. The (−2, +2) CPT resonance modification with EMF amplitude: (a) 1.4 mG; (b) 4.8 mG; (c) 7.7 mG; (d) 8.9 mG. The EMF frequency is $f_{ac}$ = 7.117 kHz and is higher than the FWHM of the CPT resonance.

frequency. When the EMF amplitude is slightly increased (Fig.6b), two additional components appear, which increase in amplitude (Fig.6c). With further EMF amplitude increase, two more components appear, while the central component almost vanishes (Fig.6d). The separation between the adjacent resonances is equal to $f_{ac}$.

## 4. Theoretical description

For a theoretical analysis of the phenomenon observed, we propose a model based on a simplified three-level structure. In our conditions, due to the presence of dc MF, we have a set of Λ systems of the form $|1\rangle = |F_e = 3,\ m_F - 1\rangle$, $|2\rangle = |F_g = 4,\ m_F\rangle$, and $|3\rangle = |F_g = 3,\ m_F\rangle$ giving resonances at different Raman detunings corresponding to the different $m_F$ values. The various parameters used in the model and their meaning are shown in Fig. 7.

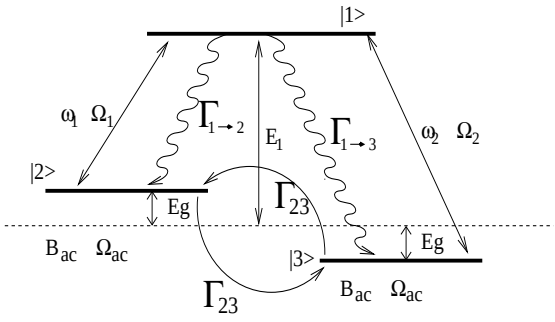



Fig.7. Description of the model parameters used in the calculations. The states are $|1\rangle = |F_e = 3,\ m_F - 1\rangle$, $|2\rangle = |F_g = 4,\ m_F\rangle$, and $|3\rangle = |F_e = 3,\ m_F\rangle$. The laser polarization is $\sigma^-$.

The physics of the system can be understood by transforming the initial Hamiltonian, for which the following expression is obtained [14]:

$$H_t = \begin{pmatrix} E_1 & \Omega_1 e^{iM_2 \sin \Omega_{ac} t} & \Omega_2 e^{iM_3 \sin \Omega_{ac} t} \\ \Omega_1 e^{-iM_2 \sin \Omega_{ac} t} & E_g + \omega_1 & 0 \\ \Omega_2 e^{-iM_3 \sin \Omega_{ac} t} & 0 & -E_g + \omega_2 \end{pmatrix} \quad (1)$$

where $\omega_1$ and $\omega_2$ are the optical frequencies between the excited state $|1\rangle$ and the ground levels $|2\rangle$ and $|3\rangle$, respectively; $\Omega_1$, $\Omega_2$ are the corresponding Rabi frequencies; $B_{ac}$ is the amplitude and $\Omega_{ac}$ – the frequency of the AC magnetic field. The quantity $E_1$ is the energy separation from the excited state $|1\rangle$ to the ground state taken as the middle between the levels $|2\rangle$ and $|3\rangle$. It should be noted that in our experiment $E_1/\hbar$ equals the diode laser carrier frequency. Finally, the term $E_g$ denotes half the ground-state separation energy. Thus, the energy separation between the excited state $|1\rangle$ and the ground states $|2\rangle$ and $|3\rangle$ is $E_1 - E_g$ and $E_1 + E_g$, respectively.

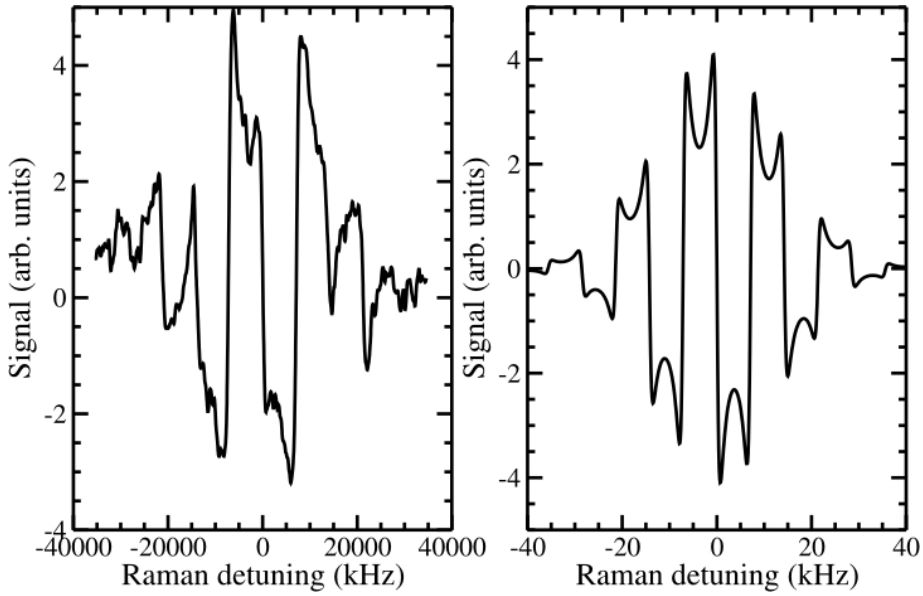



Fig.8. The PSD signal obtained experimentally (a) and from the simulation (b). The DC magnetic field is $B_{dc}$ = 138.4 mG. The amplitude of the AC field is $B_{ac}$ = 10.9 mG and its frequency is $\Omega_{ac} = 2\pi$x7.117 kHz. The recorded signal comes from the Λ system involving $m_{Fg} = 2$, $m_{Fe} = 1$.

Equation (1) gives the Hamiltonian of a three-level system under the irradiation of two optical frequencies, each of which is frequency modulated with modulation index equal to

$$M_i = S_i - S_1 = (m_1 g_1 - m_i g_i) \frac{\mu_B B_{ac}}{\Omega_{ac}} \quad (2)$$

and modulation frequency $\Omega_{ac}$. The Hamiltonian (1) is similar to that of the three levels irradiated with two polychromatic fields with frequencies $\omega_{1,n} = \omega_1 + n\Omega_{ac}$, $\omega_{2,m} = \omega_2 + m\Omega_{ac}$ and Rabi frequencies $\Omega_1 J_n(M_2)$, $\Omega_2 J_m(M_3)$, respectively, where $J_m(M_i)$ are the first-kind Bessel functions. In this sense (1) presents analogy with the Hamiltonian describing atomic samples in FM spectroscopy experiments. The main difference between the two cases consists in the fact that according to (2) in our case the modulation indices attributed to the two optical fields are in general different and may have opposite signs.

For the case of AC MF, the condition of zero Raman detuning for the (n,m) pairs of fields can be written as:

$$\Delta_{n,m} = \omega_{1,n} - \omega_{2,n} - 2E_g = \Delta_{0,0} + (n - m)\Omega_{ac} = 0$$

and thus a number of CPT lines can be expected, separated by $\Omega_{ac}$ from both sides of the main line obtained with the pair of carriers (0,0). In this way it can also be shown that, inversely, a frequency modulation of the lasers can be described

to some extent as an effective ac MF on the levels.

In spite of the simplified level system considered in the model, a good correspondence is evident for most of the spectral features, and, in particular, the same number of side peaks is observed. In general, both in the experiment and in the model each new pair of side peaks appears at approximately the same $M_i$ ratio. The frequency positions of the experimental components coincide with the theoretical ones. In Fig.8, the signal is plotted versus the Raman detuning for a particular value of $B_{ac}$. As can be seen, the theoretical results (Fig.8b) are in very good agreement with the experiment (Fig.8a). Of course, a quantitative analysis would demand the use a more complex model, including the whole set of levels, but this may turn profitable by accounting for example for the sign reversal that appears for some components, which can be seen for the third order peaks in the case of Fig.8.

## 5. Conclusion

As a general conclusion from the experimental examination of the EMF influence on a single CPT resonance, it can be seen that CPT resonances can be used for EMF measurement. The resonance spectrum is sensitive to a magnetic field change in the mG region. Still a complete theoretical description of the experimentally observed effect of a single CPT resonance splitting in EMF is not developed. A related result was observed recently in [9] but at different geometry and experimental conditions. Work is in progress for the elaboration of exact relation between the applied EMF and the observed single CPT resonance spectrum. EMF measurement is important in many applications connected with monitoring of EM pollution. Besides for measurement, this method can be also used for DC magnetic field and coils current stabilization.

**Acknowledgements:**

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Reference Number INTAS - 01- 0249

# METAL-OXIDE THIN FILM HETEROSTRUCTURES ON TILTED-AXES SUBSTRATES

*T. Nurgaliev, E. Mateev, S. Miteva, B. Blagoev,*

## 1. Introduction

The metal-oxide materials are widely used in electronics as superconducting (HTS), ferroelectric and ferromagnetic materials. One possible way to improve the crystal quality of the metal-oxide thin films is application of specially cut substrates with surface inclined with respect to the small-index crystallographic planes – the tilted-axes substrates. Small inclination angles (vicinal substrates) change the thin film growth mechanism to the "layer-by-layer" mode and can provide thin films with higher crystal quality and improved superconducting properties. Such films are obvious candidates for fabrication of passive microwave elements, because defects in the crystal structure are the main limiting factors for high-frequency superconductor applications. The tasks of the Project are preparation of the HTS thin films and layered HTS/ferromagnetic structures on tilted substrates and investigation of their structure and superconducting properties. Here we present some results obtained by the IE team in the framework of the Project INTAS - 01- 0249.

## 2. Deposition and characterization of HTS YBCO films on tilted $NdGaO_3$ substrates

The perovskite material $NdGaO_3$ is characterized by relatively good electrical parameters (the permittivity and the loss tangent are $\varepsilon$~23, tg($\delta$)~0.0003 at 77 K and 10 GHz) and its (110) small-index plane has a good match with the plane (001) of YBCO (lattice mismatch < 1%) providing appropriate conditions for growth of epitaxial YBCO films.

The surface of the $NdGaO_3$ substrates used in the experiments was tilted around the [001] axis from the (110) crystalline plane of the material. The tilt angles $\theta$ were 0°, 1.5°, 3°, 5°, 7°, 18.2° and 26°.

The YBCO films were deposited on $NdGaO_3$ substrates using two-opposed DC magnetron sputtering technique. The thickness of the films was about 100 nm. The YBCO films on the tilted substrates had a smooth step-like surface morphology.

AFM surface images of YBCO films grown on $NdGaO_3$ substrates with the tilt angles $\theta$ = 3°, 5° are shown in Fig 1. As a rule, the films deposited on standard

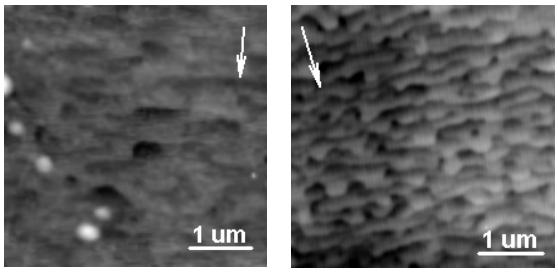


Fig. 1. AFM images of surface of YBCO films on 3° (a) and 5° (b) tilted $NdGaO_3$ substrates. The arrows indicate the direction perpendicular to the step edges. The height difference between the white and dark areas is 93 nm (a) and 44 nm (b).

oriented substrate ($\theta$ = 0°) demonstrate a great number of imperfections, irregularly distributed on the surface, while the surface of the film grown on the substrates with $\theta$ = 3° is smooth (Fig.1a). A regular elongated grain structure with a period of ~250 nm in *T*- (perpendicular to the steps of the surface) direction was observed in YBCO films with tilt angle $\theta$ = 5° (Fig.1b).

Dependences of the film normal resistivity $\rho_L$, $\rho_T$ on the tilt angle $\theta$ of the

substrate, measured at 295 K in directions parallel and perpendicular to the

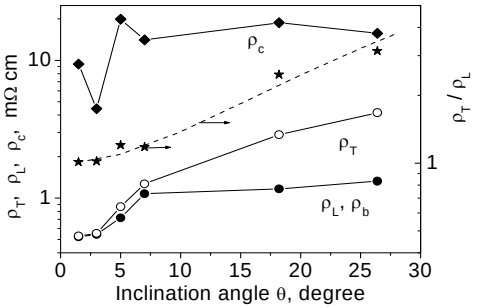


Fig.2. Dependences of YBCO film resistivity $\rho_L$, (solid circles), $\rho_T$ (open circles) and the anisotropy parameter $\rho_T/\rho_L$ (asterisks) on the tilt angle $\theta$ of the $NdGaO_3$ substrate (295 K). Calculation results of $\rho_c$ (solid diamonds) and of the anisotropy parameter $\rho_T/\rho_L$ ($K$= $\rho_c/\rho_b$ =13.5, dashed curve) are represented as well.

step edges of the substrate, are shown in Fig.2. Both components $\rho_L$, $\rho_T$ increase with $\theta$. The resistivity of the YBCO films depends significantly on the defect microstructure induced by the substrate. We assume that the number of defects rapidly increases with the tilt angle $\theta$ from ~3° to ~7°. This causes an increase of the film resistivity in dependence on $\theta$ not only in $T$- direction, but in $L$- (or $b$-) direction as well (see Fig.2). The film's in-plane $\rho_b$ and out-of-plane $\rho_c$ resistivities determined from the experimental data $\rho_L$, $\rho_T$ using the formulas $\rho_L = \rho_b$, $\rho_T = \rho_b[\cos^2(\theta) + K\sin^2(\theta)]$, where $K = \rho_c / \rho_b$ (Fig.2).

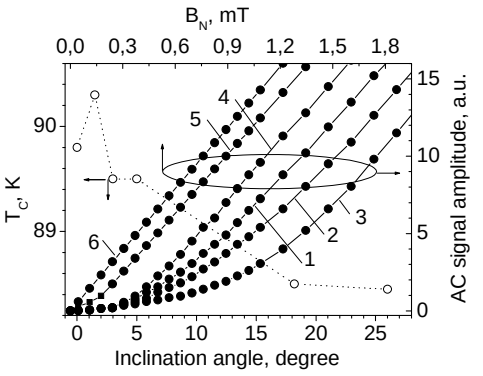


Fig. 3. Dependence of $T_C$ on the tilt angle $\theta$ (open circles) and dependences of the receive coil voltage on the perpendicular component $B_N$ of AC magnetic field (closed circles). Tilt angles are $\theta$= 0°, 1.5°, 3°, 7°, 26° (curves 1-5, respectively). Curve 6 – film is in the normal state.

The dependence of $T_C$ of YBCO films on the substrate tilt angle $\theta$ and the dependences reflecting the screening properties of the films are shown in Fig.3. The best film parameters are observed ar small values of the tilt angles (~1.5° and ~3°, respectively) when the density of the irregularly distributed defects in the film is still small.

The effective microwave surface resistance measured at ~ 8 GHz and 77 K exhibits anisotropy in the plane of the film and $R_{ST}$ is greater than $R_{SL}$ (Fig.4). Minimum of $R_{SL}$ and $R_{ST}$ was observed for films deposited on the tilted substrates with $\theta$ ~1.5°. This minimum $R_{SL}$ ~4.3 mΩ corresponds to characteristic resistance $R_{SC}$ < 1mΩ.

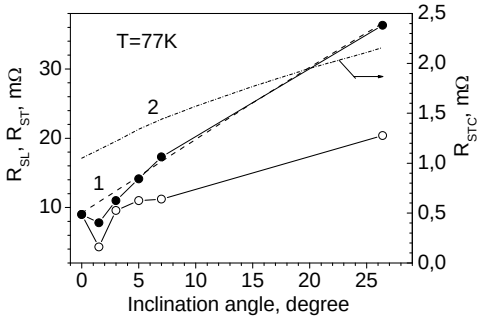


Fig. 4. Dependences of $R_{SL}$ (open circles) and $R_{ST}$ (closed circles) components of the effective surface resistance of YBCO films on the tilt angle $\theta$ of the substrate. Curves 1 and 2 represent the results of modeling the $T$- component of the effective ($R_{ST}$) and the characteristic ($R_{STC}$) surface resistances.

The components of the complex microwave conductivity of the film were determined from the complete microwave conductivity $\sigma_{1t}$-$i\sigma_{2t}$ using the effective medium approach for the direction perpendicular to the steps of the substrate:

$$(\sigma_{1t} - i\sigma_{2t})^{-1} = (\sigma_{1b} - i\sigma_{2b})^{-1}\cos^2(\theta) + (\sigma_{1c} - i\sigma_{2c})^{-1}\sin^2(\theta) + (\sigma_{1j} - i\sigma_{2j})^{-1}\sin(\theta).$$

It was found that the results of the calculation of $R_{ST}$ vs $\theta$ dependence at $\theta >$ 3° fit appropriately the experimental data if the components of the microwave conductivity are the following: $\sigma_{1b}$=6.16 $10^6$ $(\Omega\ m)^{-1}$, $\sigma_{2b}$=8.14 $10^7$ $(\Omega\ m)^{-1}$, $\sigma_{1c}$=4.8

$10^6$ $(\Omega\ m)^{-1}$, $\sigma_{2c}$=6.3 $10^7$ $(\Omega\ m)^{-1}$, $\sigma_{1j}$=1.05 $10^6$ $(\Omega\ m)^{-1}$, $\sigma_{2j}$=1.3 $10^7$ $(\Omega\ m)^{-1}$.

## 3. HTS/Ferromagnetic structures deposited on tilted substrates

Due to the possibilities of applying superconductor/ferromagnetic (SC/FM) structures in micro- and nanoelectronics, the investigations of such structures were one of the challenging goals of the research presented.

Layered SC/FM structures containing superconducting YBCO and magnetic $La_{0.7}Sr_{0.3}MnO_3$ (LSMO) or $La_{0.7}Ca_{0.3}MnO_3$ (LCMO) films were grown on standard ($\theta$ = 0) and tilted ($\theta$ = 8°) $NdGaO_3$ (NGO) substrates. The LSMO and LCMO films were deposited using RF magnetron sputtering. The 50-150-nm-thick $CeO_2$ buffer layers were deposited on the top of the manganite films and YBCO films with the thickness $d_{YBCO}$ = 230 – 560 nm were grown on theses buffers by laser ablation.

The electrical parameters measured of such layered structures are summarized in Table I. It is seen that the YBCO films in structures containing LSMO are characterized by lower critical temperature $T_C$, and critical current density $J_C$. The normal resistance $R_{L,T}$ (measured in *L*- and *T*- directions, respectively) of YBCO films

| | YBCO/ LCMO $\theta$=0 | YBCO/ LSMO $\theta$=8° | YBCO/ LCMO $\theta$=8° |
|---|---|---|---|
| $d_{YBCO}$, nm | 230 | 560 | 560 |
| $R_L$, Ω<br>$R_T$, Ω | 13 | 6.95<br>7.94 | 4.1<br>4.9 |
| $T_K$, K | 88.6 | ~89.1 | 89.8 |
| $J_C$, MA/cm$^2$ | 0.98 | 0.1 | 1.1 |
| $R_{SL}$, Ω<br>$R_{ST}$, Ω | 0.1 | ~<br>~ | 0.061<br>0.069 |

TABLE 1. Parameters of SC/FM structures NGO substrate.

in such structures is higher in comparison with that of the films in YBCO/LCMO structures. The parameters of YBCO films in YBCO/LCMO structures do not differ significantly from those of typical HTS YBCO films except for their surface resistance. In fact, the surface resistance characterizes the complete microwave losses of the SC/FM structure considered. They include the losses not only of the YBCO film but the losses of the LSMO or LCMO layers as well. Therefore, the layered structures considered are characterized by a substantially higher microwave surface resistance in comparison with single YBCO films.

## 4. Tunable SC/FM structures

Superconducting thin film structures, containing magnetic components, are promising for microwave applications because of the magnetic tunability of their resonance frequency. We studied the microwave characteristics of HTS YBCO)/yttrium-iron-garnet (YIG) structures of several configurations at 77 K. The YIG slab or the YIG film with its substrate served as a spacer between the YBCO electrode and the Cu ground plane in the structures of A-type. The LAO substrate of the YBCO electrode was used as a spacer in the structures of B-type and a YIG component was placed on top of the YBCO electrode. The DC magnetic field *H* was applied parallel to the microwave current direction in the structure. Fig.5 shows the field dependence of the resonance frequency $f_1$ of the YBCO ring structures and the modified ferromagnetic

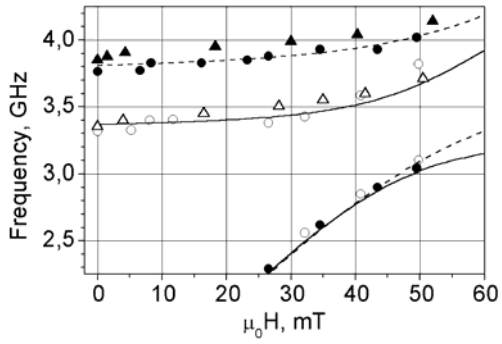


Fig.5. Field dependence of the modified frequency $f_1$ of YBCO ring microstrip structures of A (closed symbols) and B (open symbols) types with an YIG film (circles) and a bulk (triangles) YIG components. The modified FMR frequency $f_2$ of the YIG film is shown by circles (bottom-right). Solid and dashed curves were calculated theoretically with $\mu_0 M$=235 mT, $f_0$=3.73 GHz, $k$=0.014 and $f_0$=3.316 GHz, $k$=0.008 for the structures with YIG film component of A and B types, respectively.

resonance (FMR) frequency $f_2$ of the YIG film component. The above dependences were used for determining the unperturbed resonance frequency $f_0$ and the coefficient $k$, which takes into account the coupling efficiency of the ferrite with the structure. The coupling is more efficient ($k$ is greater, see the caption) for the A-type structure, and the magnetic tunability of such structures is greater.

## 5. Conclusions

Superconducting YBCO thin films and YBCO/ferromagnetic layered structures were prepared and their electrical and microwave properties were investigated in detail. The structures demonstrate original electromagnetic characteristics (i.e. anisotropy of the parameters and magnetic tunability) and are promising for device applications.

## Publications related the project

1. Nurgaliev T, Donchev T, Mateev E, .Miteva S, Mozhaev PB, Mozhaeva JE,
Properties of HTS YBCO thin films deposited on tilted $NdGaO_3$ substrates,
Physica C 2005;420:61-67.

2. Mozhaev PB, Kotelyanskii IM, Luzanov VA, Mozhaeva JE, Donchev T, Mateev E, Nurgaliev T, Bdikin IK, Narymbetov BZ,
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Physica C 2005;419:53-60.

2. Nurgaliev T, Blagoev B, Mozhaeva JE, Mozhaev PB, Miteva S, Mateev E, Donchev T, Stribik V, Benacka S,
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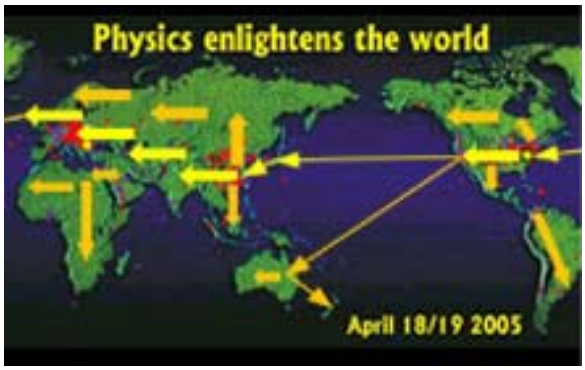
# SCIENTIFIC EVENTS

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

## Participation in the Word Year of Physics under the *Physics Enlightens the Word Program*

One of the main international events dedicated to the World Year of Physics 2005 (WYP 2005) was the Light Relay *Physics Enlightens the World*. The International Organizing Committee chose the night of April 18, 2005, for carrying out the relay, thus commemorating the 50-th anniversary of Albert Einstein's death. The idea was to start from Princeton, where Einstein died, to illuminate the night by a firework of light sources and generate waves of light to the west, north and south, which then would be relayed through borders, ocean depths, and over all continents across the world. Thus, the light from million sources would unite the peoples of the world under the motto *Physics Enlightens the World.*




The Light Relay route around the globe celebrating the World Year of Physics. The red dots denote the cities taking part in the event.

Nine Bulgarian cities took part in the Light Relay, namely, Varna, Silistra, Shoumen, Veliko Turnovo, Gabrovo, Stara Zagora, Plovdiv, Panagyurishte and Sofia.


The Bulgarian cities participating in the Light Relay dedicated to the World Year of Physics..

The three lidar system at the Institute of Electronics that took place in the International Light Relay *Physics Enlightens the World*: A) Copper vapor aerosol lidar; B) Solid-state laser aerosol lidar; C) Raman lidar.

The Laser Radars Laboratory of the Institute of Electronics was the national organizer of the Light Relay for Bulgaria and coordinated our country's participation in the international event. We should mention here

that the International Organizing Committee placed Bulgaria at the 6-th place of all participating countries in terms of the number of participants per capita.

A laser beam lights up the night sky over Sofia, starting Bulgaria's participation in the World Light Relay on April 19, 2005.

Moments of the laser show.

Laser radiation reflection from nearby objects.

A close-up of the laser beam. The naked eye can discern a large number of aerosol particles floating freely in the air, which glimmer brightly scattering the laser radiation.

In Sofia, besides the Laser Radars Laboratory, co-organizers were the Metal Vapors Lasers Laboratory of the Institute of Solid State Physics, Bulgarian Academy of Sciences, and the Union of Physicists in Bulgaria. A spectacular laser show was performed, using the three main lidars of the Institute of Electronics, as well as the high-power (40 W) copper bromide laser developed in the Metal Vapors Lasers Laboratory of the Institute of Solid State Physics.

The event was widely reported in all Bulgarian mass media, including interviews and live broadcasts by some of the most popular TV networks. In order to popularize the World Light Relay, the Institute of Electronics opened a specialized website, which can still be accessed at http://www.ie-bas.dir.bg/WorldYearPhys/WYP.htm.

Academician N. Sabotinov, Vice-Chairman of the Bulgarian Academy of Sciences, was among the guests.

Preeminent members of the Bulgarian physical community, as well as Representatives of the Bulgarian Academy of Sciences' leadership attended the World Year of Physics celebration, which took place in the Institute of Electronics building during the Light Relay.

The team of physicists, which organized the event, comprised a large number of researchers. The Institute of Electronics' team included R. Enikov, D. Stoyanov, I. Grigorov, G. Kolarov, D. Slavov, B. Kaprielov, A. Deleva, Z. Peshev, N. Kolev, R. Nenchev.

Members of the Bulgarian physical community attending the event.

The organizers of the International Light Relay *Physics Enlightens the World*, from left to right, Assoc. Prof. Dr. R. Enikov, Director of the Institute of Electronics, and Prof. Dr.Sci. D. Stoyanov, Head of the Laser Radars Laboratory.

# 14th International Summer School on Vacuum, Electron and Ion Technologies (VEIT)

The Fourteenth edition of VEIT was organized by the Institute of Electronics, Bulgarian Academy of Sciences, the Institute for Ion Beam Physics and Materials Research, Research Centre Rossendorf, Germany, and Evrika Foundation, Bulgaria. The meeting was held in the Black See resort Sunny Beach, Bulgaria, on 12-16 September 2005. 120 participants from 18 European and American countries presented at 11 oral and 3 poster sessions more then 140 contributions with emphasis on both the physics and the engineering aspects of electron-, ion-, and plasma-assisted technologies. The school program covered the fundamentals of gas discharges, beam interaction with solid surfaces, thin film growth and characterization and was balanced with progress reports on challenging practical applications ranging from novel techniques such as for hard coatings and optical/protective layers, to nanosized structures produced by evaporation, sputtering or external irradiation. Recent achievements in 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 Sunny Beach.

VEIT 2005 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, did not spare time and enthusiasm in efforts to deal with the high volume of correspondence, abstracts, etc., as well as to organize the event at the conference site. We also thank Wiley VCH and the Editors of the journal ***Plasma Processes and Polymers*** for the prompt editing of the large input of articles and for their invaluable support in arranging the preparation of the Highlights from the 14th VEIT for publication in a special issue of the journal ***Plasma Processes and Polymers*** (February 17, 2006, vol. 3, number 2). Finally, we thank our sponsors Forschungszentrum Rossendorf, the Bulgarian Academy of Sciences, and Evrika Foundation for their generosity that provided support to deal with mailing, printing and renting the conference site, and enabled us to ensure the attendance of students.

The next conference in the series will be held in September 2007.

## Activities of SPIE - Bulgaria Chapter

SPIE Bulgaria Chapter (SPIE – BG), like SPIE - The International Society for Optical Engineering, is a non-profit 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 bringing 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, workshops, and exhibitions in Bulgaria.

At present, the Chapter associates 79 regular and student members from different institutes of the Bulgarian Academy of Sciences (Institute of Electronics, which hosts the SPIE-BG office, Institute of Solid State Physics, Central Laboratory of Optical Storage and Processing of Information) and key Universities in Bulgaria (St. Kliment Ohridski Sofia University, Paisii Hilendarski University of Plovdiv, Technical University of Sofia, Plovdiv Branch of the Technical University - Sofia). All the information and printed materials kindly provided by the SPIE International have been regularly distributed among these organizations. The journals received (Optical Engineering, OE Magazine, J. of Biomedical Optics, JM3, and Opt. Networking) are donated to the main libraries of these institutes and universities in order to reach the largest possible audience of scientists.

A new Memorandum of Understanding between SPIE – The International Society for Optical Engineering and the SPIE – Bulgaria Chapter for the years 2006-2008, specifying the terms for a royalty-based financial model for Chapter publications and other means of support, was signed in September 2005.

Since 1996, the biennial International School on Quantum Electronics: "Laser–Physics and Applications", organized by the Institute of Electronics, has been co-organized by SPIE – BG and supported by SPIE International. The School's main purpose is to provide a forum for exchange of information, ideas, and opinions, as well as for establishment of scientific contacts between participants from different countries. The Proceedings of the last 13$^{th}$ School, including 16 invited lectures and 81 selected poster presentations, were published in a special issue (vol. 5830) of the SPIE Proceeding Series. Copies of this volume were distributed among the first authors of the contributed papers.

In cooperation with the Institute of Electronics, the organization of the next 14$^{th}$ International School on Quantum Electronics "Lasers-Physics and Applications" started in June 2005. The School will take place in the Black Sea resort Sunny Beach from 18$^{th}$ to 22$^{nd}$ September 2006. The Local Organizing Committee and the International Advisory Committee will handle the organization of this event. Leading scientists from Europe, USA, Japan and Australia are invited to deliver lectures on "hot" topics in the fundamentals of laser physics and their applications, grouped as follows:

- Laser-matter interaction
- Nonlinear optics applications
- Laser spectroscopy and metrology
- Laser remote sensing and ecology
- Lasers in biophysics and medicine

More than twenty invited lecturers already confirmed their participation and provided details concerning their talks. Poster sessions for the participants will also be organized on the above mentioned and related topics. At the end of the School, a certain number of selected posters of young participants will be nominated for oral presentation. In this way young scientists will gain valuable experience for their future scientific career. The invited lectures and selected posters presented at the School will

be published in a special issue of the SPIE Proceedings. Further information can be found on the School web page: http://www.sqe2006.dir.bg/.

In 2005, SPIE – Bulgaria Chapter also co-sponsored the International Conference on Holography, Optical Recording and Processing of Information "Holography 2005" (May 21-25, Varna, Bulgaria). Invited lectures and Chairs/Editors-reviewed contributed papers will be published in a separate volume of the Proceedings of SPIE.

**AWARDS RECEIVED**

*GAS LASERS:*
A.Og. Dikovska, P.A. Atanasov, I.G. Dimitrov, T. Kocuorek, M. Jelinek,
Structural and optical properties of Er, Yb co-doped $Y_2O_3$ thin films,
EMRS, J-PII.09, 8/19, Strasbourg, May 31-June 03 2005 - **Best poster presented.**

*MICROWAVE SOLID STATE ELECTRONICS*:

A. Yanev, B. Todorov, V. Ranev,
Bulgarian Chamber of Commerce Award for the development and application of low noise MW amplifiers.