Short overview of laser physics and applications research activities of Institute of Electronics – Bulgarian Academy of Sciences

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The Institute of Electronics at BAS is a non-profit state organization conducting research, education and dissemination of scientific knowledge in the fields of Physical Electronics, Photonics and Quantum Electronics and Radio Sciences.

Research priorities:

- **Topic 1.** Electronic, ionic and optical techniques for development of new materials and methods for their characterization. Nano-materials and nanotechnologies
- **Topic 2.** Photonics for quality of life improvement: photonic techniques for analysis of media and structures.
- **Topic 3.** Physics and diagnostics of the plasma in controlled thermonuclear fusion (CTF) reactors. Theory, modeling, experiments.
- **Topic 4.** Social physics and application of physical methods in economics.
PLASMA PHYSICS AND ENGINEERING
PHYSICAL PROBLEMS OF ELECTRON BEAM TECHNOLOGIES
PHYSICAL TECHNOLOGIES
PHYSICAL PROBLEMS OF ION TECHNOLOGIES
SUPERCONDUCTIVITY AND CRYOELECTRONICS

BIOPHOTONICS
LASER RADARS
LASER SYSTEMS
MICRO- AND NANO-PHOTONICS
NONLINEAR AND FIBER OPTICS

MICROWAVE MAGNETICS
MICROWAVE PHYSICS AND TECHNOLOGIES
Research infrastructure of the National Center on Biomedical Photonics of Institute of Electronics

Research topics of the Biophotonics group

- Skin cancer fluorescence and reflectance spectroscopy
- Exogenous fluorescence spectroscopy of GIT cancer
- Time-resolved spectroscopy (TCSPC) of bio-samples
- Photophysics and photobiology investigations
- Laser-tissue interactions research
- Diffuse optical tomography
- Photodynamic medicine
- Synchronous fluorescence spectroscopy of nutrients
- Photo-immuno modulation of human body
- Collagen-, gelatin and elastin-based scaffolds
- Engineering tissues development
- Development of medical laser systems

- Ultrafast lasers (fs-laser Ti:S and ps-laser Nd:KGW)
- Frequency- and time-resolved (TCSPC) fluorescence
- Laser-induced breakdown (LIBS) spectroscopy
- NIR spectroscopy of liquids and solid samples
- Optical spectroscopy laboratory
Students training lab:
Based on modular systems based on OOptics Inc. micro-spectrometers and accessories:
1) Fluorescence / phosphorescence measurements (200-800 nm)
2) Diffuse reflectance and colorimetric measurements (300-1000 nm)
3) Transmission/absorption spectroscopy measurements (350-1100 nm)
4) Fluorescence dermatoscopy imaging
Ultra-short laser surface modification of biomaterials for tissue engineering applications

- Tissue engineering scaffolds play a main role in regenerative medicine.
- Provides a temporary 3D support during tissue repair, regulates the cell behaviour:
  - Cell adhesion
  - Cell proliferation
  - Cell differentiation
- Scaffold should have improved interface for cell interactions

Key surface characteristics:
- wettability, charge, roughness, chemistry, rigidity

Short pulse laser-matter ablation
- Reduced ablation thresholds
- Negligible heat diffusion into the material
- Minimized energy loss
- Minimized heat affected zones
- Almost absent mechanical damage
- Absence of molten zones
- Absence of liquid phase
- Reduced molecular fragmentation
Field emission microscopy images of the cytoskeleton of NIH3T3 mouse fibroblasts migration along laser processed grooves

- Cells density raises towards the laser treated part of the surface.
- Enhanced adhesion of fibroblast cells on laser modified stripes.
- Mice fibroblasts remained viable for several days and showed little mobility outside of the micropattern.
- The actual mechanism of contact guidance and selective cell adhesion on the laser grooves is a complex process of chemical and topographical stimuli.
- The amount and/or orientation of the (initial) protein adsorption are different on the topographically structured samples than on the untreated ones.
- The hydrophobicity or hydrophilicity of the surfaces are also a factor which influences the proteins adsorption.

NIH3T3 cells attached on fs laser modified collagen/elastin layers following a 3 day culture period: (a) non-patterned surface, cell migration without a preferred direction (b-c) preferential cell migration on laser modified grooves.
LIDARs (LIght Detection And Ranging) are powerful tools for remote sensing of the atmospheric aerosol processes with high spatial and temporal resolution, high sensitivity and accuracy, covering large observation areas. Founded about 35 years ago, the Laser Radars Laboratory is the only LIDAR station in Bulgaria and the first on the Balkans. Now it is a part of the European LIDAR Network (EARLINET).

Systematic lidar measurements of the aerosol fields above Sofia, Bulgaria, up to stratospheric altitudes are performed. They cover the transport of aerosol masses above the European continent as well as the pollution transport of Saharan dust, volcanic ash, dusts from the forest fires in Europe and US, under-satellite measurements for the European Space Agency and NASA.

The work is performed in the frame of the European Union 5th, 6th and 7th FP s, as well as Horizon2020 under the projects EARLINET, EARLINET-ASOS, ACTRIS and ACTRIS2.
Lidar measurements of ash layers over Sofia, originated from Eyjafjallajökull volcano (left) and Alaska’s Mt. Redoubt volcano (right).

Lidar measurements of Vitosha Mountain forest fire smoke layers.

Lidar mapping of near-surface aerosol fields over the city of Sofia (Bulgaria).
Optical magnetometry: Coherent laser spectroscopy and All-optical magnetometers for medical and geophysical applications

All-optical magnetometer protected by European Patent No. EP 1570282B

Earth magnetic field fluctuations: measured in IE-BAS and compared with geomagnetic observatory in L’Aquila, Italy

“Coherent optics sensors for medical applications”
Coherent optical sensors miniaturization

Study of atomic vapour layers of nano-metric thickness for photonic sensor miniaturization

(A) L from 0.5λ to 6λ, where λ = 852nm

(B)(1)-L = 2mm, (2)-L = 700μm, (3)-L = 6λ, λ = 852nm

Micrometric optical cells

Light – induced atomic desorption

Nanometric optical cell: (a) Atomic movement in cell of thickness L: (b) Practical realization of optical cell with L = 100 – 30000nm.
Laboratory
MICRO- AND NANO-PHOTONICS

Laser assisted methods for micro- and nanofabrication
Optical properties of noble metal nanostructures. Plasmonics.
Theoretical modeling of: laser-mater interaction; interaction of electromagnetic field with nanostructures
Applications of nanostructures.

Fabrication of noble metal colloids

TEM images of Au nanoparticles

Laser processing of thin metal films on different substrates

Ag nanoparticles on SiO$_2$  
Au/Ni nanoparticles on SiO$_2$  
Au nanoparticles on Al$_2$O$_3$ ceramic
Pulsed Laser Deposition of nanostructures

Nanostructures in high sensitive detection based on Surface Enhanced Raman Spectroscopy

ZnO nanorods

Au nanostructures by PLD at atmospheric pressure

TiO$_2$, W$_2$O$_3$, Nanostructured thin films
Gold nanoparticle cover on the surface of alumina ceramic fabricated by laser annealing of initially deposited gold film.

Gold nanoparticle composed lines fabricated by femtosecond laser processing into composite glass. The lines have width of 100 μm and are 1 mm under the glass surface.

Gold and silver colloids fabricated by nanosecond laser ablation in water. TEM image of Au nanoparticles with average size of 10 nm is also shown.

Laser microstructuring of biocompatible PDMS for further metallization.
Experimental and theoretical research on propagation of power femtosecond laser pulses in optical fibers and gases.

Mathematical models, numerical programs and algorithms which describe the evolution of narrow-band and broad-band (phase modulated) laser pulses in linear and nonlinear regime.

One of the main achievement of the Laboratory is in the creating non-paraxial model of diffraction and dispersion of pulses up to single-cycle regime (attosecond pulses).

Now ion-free filamentation and nonlinear interaction (exchange of energy and merging) between optical filaments.

Collaborations

- Prohorovsky Institute of General Physics, RAS, Russia
- Moscow University, Laboratory of Nonlinear Optics, Russia
- Optical Institute, Jena, Germany
- Institute of Optics, Iowa, USA

Mathematical model of ionisation-free filamentation.
a1/ Plot of the initial pulse’s spot
a2/ Evolution on three diffraction lengths
b/ Experimental result obtained in Laboratory of Applied Optics (Ecole Polytechnique, Palaiseau).

Diffraction of few-cycle (attosecond) pulse with an initial Gaussian profile at four diffraction lengths. Analytical solution. Side (x,z,y=0) projection.
Non-paraxial diffraction of broad-band fs optical pulse.
The theory verifies the experiment.

New mechanism for THz generation and asymmetrical broadening of laser pulses
Recent IE-BAS collaborations & agreements in the field of laser physics research

- Prof. Jean-Claude Kieffer - Institut national de la recherche scientifique (INRS), Canada – ultrafast laser applications
- Prof. Wolfgang Husinsky, Technical University of Vienna, Austria – fs-laser-matter interactions – metal ablation, collagen scaffolds development using fs- laser ablation
- Prof. Costas Fotakis, FORTH – HELAS, Crete-Greece – engineering tissues development using ultrafast laser ablation of biopolymers
- Prof. Luigi Moi, Siena University, Italy – laser spectroscopy, optical magnetometry
- Prof. Alex Serafetinides, National Technical University of Athens, Greece – pulsed laser deposition, biophotonics applications
- Prof. Minoru Obara, Keio University, Japan – laser-matter interactions, nanoparticles direct production using laser ablation
- Prof. Valery Tuchin, Saratov State University, Russia – biophotonics applications
- Prof. Evgeny Krasavin, Joint Institute for Nuclear Research - Dubna, Russia – biophotonics applications
- Prof. Ion Mihaiescu, National Institute for Lasers, Plasma, and Radiation Physics, Romania – laser-matter interaction investigations
- National Institute of Research and Development for Optoelectronics, Romania – laser spectroscopy, biophotonics applications
- Centre for Earth Science Studies, Biophotonics Laboratory (CESS), India
- General Physics Institute "A.M. Prokhorov", Russia – nonlinear optics, biophotonics
- Italy, France, UK, USA, Poland, Serbia, Belarus, Ukraine, Sweden, Ireland, etc.
Thank you for your attention!

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