

Optoelectronic Characterization of Nanostructures

Aims of Research

- Improvement of diagnostic methods used for testing semiconductor materials and electronic components and structures.
- Determination of the correlation between the properties and the geometrical and structural parameters of nanostructures.
- Low-frequency noise – analysis of bulk and interface defects, determining quality and reliability of electronic devices.
- Development of highly sensitive sensor for detection of chemical substances dissolved in gases or liquids.
- Application of novel diagnostic methods.
- Experimental and theoretical research of stochastic processes and charge carrier transport as a basis for new advanced technologies.
- Methods for non-destructive diagnostics of electronic components and structures.
- Investigation of material surfaces, characterization of local structure inhomogeneities.
- Electromagnetic emission in dielectrics for the monitoring of the generation and growth of cracks under mechanical load.

Key Research Equipment

- Instruments for noise and dielectric measurements (Novocontrol Alpha-A analyzer, $10^{-5} - 10^7$ Hz)
- Scanning Electron Microscopy – Lyra FEG, FIB
- Scanning Microscope SNOM (< 40 nm) with AFM
- Optical He closed-circuit cryostat 10 K – 500 K
- Semiconductor characterization system Keithley
- Set of devices for EME and AE experiments, in particular low-noise preamplifiers and piezoelectric sensors and multichannel high-speed (10 MSPS) A/D converters
- FTIR – spectrometer Nicolet 8700
- Shared infrastructure within CEITEC core facilities Nanofabrication and Nanocharacterization

Topics studied

1. Electron transport and fluctuations in electronic materials and structures, such as MOSFET structure, sensors, supercapacitors etc.
 - Experimental analysis of temperature dependences of the charge carrier transport and of current fluctuations will be carried out.
 - Theoretical analysis of the charge capture and emission from the localized state and determination of trap parameters.
 - Analysis of bulk and interface defects that determine the quality and reliability of electronic devices.
 - Research is being carried out in cooperation with Prof. Munacazu Tacano (MEISEI University, Japan) and Prof. Gerard Ghibaudo (University of Grenoble – MINATEC, France).
2. Quality and reliability of nanoscale oxide/polymer layers for electronic devices
 - Analysis of ion diffusion in external or internal electric fields, its impact on the quality and reliability of electronic devices as microchip sensors, electrochemical sensors, capacitors and cathode tips for autoemission of electrons into vacuum.
 - Defects in oxide layers are mostly represented by oxide vacancies; their concentration depends on the oxidation technology.
 - Results will be used for the technology tuning in cooperation with Dr. Tomas Zednicek from AVX Czech Republic, Ltd., and Prof. Armin Delong from Delong Instruments.
3. Carbon nano-tubes and nano-particles used in super capacitors
 - Charge carrier storage on the electrodes and in deep localized states will be analyzed in order to show the correlation between energy stored in the capacitor and the dynamics of the super capacitor charging/discharging.
 - Irreversible processes leading to the degradation.
 - Optimization of the super capacitor energy density with respect to the maintenance of the quality and reliability.
 - Part of the project “Evaluation of super capacitors within the program ARTES 5.1” which is the research project of the European Space Agency (ESA).
4. Microscopic characterization and optoelectronic device testing
 - Testing of optoelectronic devices using electroluminescence, noise spectroscopy and termography
 - Nanometrology on bulk materials with nano-structures, nanomaterials and nano-composites. Microscopic characterization and contrast mapping of different physical quantities.

- Focused Ion Beam nanofabrication
5. Dielectric spectroscopy of materials in electronics
- Nanocomposites for electrical insulations.
 - Addition of nanoparticles to epoxy resins increases their ability to withstand higher voltages and thus allows the reduction of insulation thickness.
 - Giant-permittivity calcium copper titanates ($\text{CaCu}_3\text{Ti}_4\text{O}_{12}$, CCTOs) with pseudo-perovskite structure for high-C capacitors.
 - Research of electrical properties of CCTO-based ceramics doped with transition metals and lanthanides, focused toward the identification of the mechanism leading to their high dielectric constant.

SUBGROUP:

Dielectric relaxation spectroscopy

This method measures electric response of a material under study to electric fields with frequencies from $100\mu\text{Hz}$ to 1 GHz under different temperatures, pressures, moisture levels, concentrations etc.

Dielectric relaxation spectroscopy yields information about the dielectric response of a material under study to electric fields with frequencies from $100\mu\text{Hz}$ to 1 GHz under different temperatures, pressures, moisture levels, concentrations etc. The main information delivered by the DRS is both permittivity (dielectric constant) and dielectric losses (loss number and loss factor) as functions of frequency and temperature. From these parameters, further evidence can be obtained, as e.g. relaxation plot (activation diagram), characteristics of observed relaxations, their cooperativity, existing steric hindrances to the reorientation of molecules, associated activation energies and characteristic frequencies (eigenfrequencies). Generally, the information provided by DRS, is related to molecular dynamics of charges and dipoles within the structure under study.

The equipment currently available in the Department of Physics includes the helium closed-cycle CCS-400/204 cryostat by Janis Research with specifically designed cold head allowing the connection of various structures and devices with dimensions not exceeding 25 mm in diameter. This cryostat allows dielectric measurements in the temperature range 20 K – 500 K.

- Agilent (formerly Hewlett-Packard) impedance analyzers HP 4284A, HP 4285A, E 4991A and E 4980A with the necessary equipment,
- Novocontrol AT-A analyzer
- the total frequency range of the measuring equipment is $10^{-3} - 10^9$ Hz,
- Keithley 617 series electrometers with 10^{-17} A resolution,
- two cryostats – the ISI liquid nitrogen cryostat and the Janis closed-cycle CCS-400/

204 helium cryostat, the total temperature range is 10 K – 450 K,

- a constant climate chamber Binder KMF 115 for stress testing with temperature range -10 °C/ 10 °C to 100 °C/90 °C (without/with humidity) and with humidity range 10 % to 90 %,
- muffle furnace/oven by BMT Brno with the temperature range 20 °C – 900 °C.
- FTIR spectroscopy (Nicolet 8700, 7800 – 350 cm⁻¹, optical resolution 0.09 cm⁻¹),

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SUBGROUP:

Noise and electrical characterization of electronic materials and structures

The subgroup focuses on the research of electronic noise and charge carrier transport in electronic components and structures, and was established from members of Czech Noise Research Laboratory (CNRL) that is recognized as one of laboratories included in the ELEN (European Laboratory for Electronic Noise) network since 1995.

Characteristics

Experimental and theoretical research of stochastic processes and charge carrier transport is a basis for new advanced technologies, for a further development of non-destructive diagnostics and advanced methods for the estimation of the lifetime of electronic components and structures.

The laboratory offers:

- Evaluation of quality and reliability of electronic materials and structures, such as supercapacitors, capacitors, electrochemical sensors, piezoresistive sensors, etc.

- Design of appropriate quality indicators for the manufacturing process.
- Modelling of time and voltage characteristics, and temperature dependencies.
- Development of new methods and new instruments for material characterizations.

Experience and Equipment

The subgroup has more than 15 years of experience with analyses of electronic components and estimation of their reliability. Our research team is based on mutual cooperation of perspective junior researchers and experienced senior scientists, who have been working in their research fields for many years. The laboratory is equipped by advance instrumentation available for noise spectroscopy, where key devices are

- Keithley 4200- Semiconductor Characterization System for I-V measurements,
- HP/Agilent instruments for electrical impedance measurements,
- equipment for temperature measurement, such as temperature chambers, helium cryostat (Janis) and nitrogen cryostats, climatic chamber, and
- accessories, e.g. low-noise preamplifiers and amplifiers, digitizers, Faraday cages, etc.

The subgroup maintains a close cooperation with key European and Japanese laboratories; participates in EU programs and has its own PhD students. The laboratory is currently involved in several domestic and international research projects.

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SUBGROUP:

Optoelectronic and microscopic characterization of structures

Research of the subgroup is focused on the investigation and application of advanced characterization

and diagnostic methods. These methods are based on the monitoring of transport and fluctuation processes in materials and electronic components, measuring of their optical response to external excitation, the use of Atomic force microscopy (AFM), Near-field scanning optical microscopy (SNOM) and Scanning electron microscopy (SEM).

Characteristics

- Basic characterization of semiconductor materials and electronic components in temperature range 10 K – 400 K by using wide spectrum of laboratory equipment (analyzer Agilent E4991, signal analyzer Agilent 35670A, semiconductor characterization system Keithley 4200, impedance analyzers, etc).
- Local optical and electrical characterization of optoelectronic structures with lateral resolution better than 250 nm (topography, local changes of material properties, local photocurrent, photoluminescence, electroluminescence).
- Characterization of passive electronic components in temperature range of 10 K – 400 K.
- Measurement of the surface potential distribution.
- Experimental evaluation of semiconductor devices parameters: charge carrier concentration, minority carrier lifetime, PN junction type, diffusion potential, width of the depletion zone, barrier capacity, etc.
- Diagnostics of structure quality (local and bulk defects, contacts) and study of structural parameters in room-temperature conditions and in extreme thermal conditions.
- Diagnostics of micro-cracks creation in non-conductive materials and electronic components in laboratory conditions (at predefined thermal or mechanical loading) or operational conditions by using of electromagnetic emission and acoustic emission.
- Formulation of physical models of electronic components or sensors to optimize their parameters.
- Development of new methods and new instruments for structures characterization.

Equipment

- Probe station Cascade Microtech M150 for micro-scale electrical measurement.
- Keithley 4200 parametric semiconductor analyzer (4 × SMU, CMU and PMU).
- National Instruments PXI system equipped for fine current-voltage characteristics measurement and real-time data acquisition.
- Noise spectrum analyzers: Dynamic FFT analyzer (DC – 100 kHz) Agilent 35670A, Base-band analyzer Rohde & Schwarz FMU36 (DC – 36 MHz) and high frequency analyzer Rhode & Schwarz FSV (100 kHz – 3.6 GHz).
- High sensitivity optical detector for near ultraviolet region (cooled PMT) for study of defects optical activity.
- Astronomy CCD camera cooled down to –50 °C for visible optical region.

- Infra-red camera for study of samples thermal properties.
- Modular microscopes NT-MDT Solaris (SNOM, AFM) and Tescan SEM FIB.

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