Slovak University of Technology in Bratislava
Faculty of Electrical Engineering and Information Technology
Institute of Electronics and Photonics
Ilkovičova 3, 812 19 Bratislava, Slovakia

Doctoral Course Program

Complex Analysis of Advanced Micro-/Nano-Electronic Structures

Course abstract

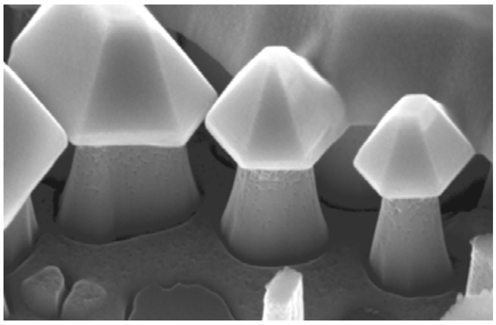
The **objective of this course** is to offer a comprehensive, state-of-the-art training particularly but not solely for PhD students in the fundamentals, emerging trends and applications of advanced analytical, electrical and optical methods of characterization and analysis of micro/nano-electronic materials, structures and devices.

The scheduled lectures and practical training will provide a unique environment to improve knowledge and skills in the application of rapidly evolving techniques, equipments, and tools. The course is also opened for professionals as well as for experienced engineers from industry for retraining in related disciplines like nanometrology, failure analysis and other characterization and analytical techniques.

The course will be hosted by the Slovak University of Technology (STU) in Bratislava in the premises of Faculty of Electrical Engineering and Information Technology, and in the training facilities of the International Laser Centre, both located in Bratislava.

This course is accredited by the doctoral school at the STU Bratislava, by the Scientific Board of the Faculty of Electrical Engineering and Information Technology. PhD students can be granted **3 ECTS credits** after successfully passing evaluation based upon a written report on a topic to be approved by the course program board.

This course fulfils all criteria imposed by the FP7 EURO-DOTS project, and has been provisionally **granted the EURO-DOTS label**. PhD students fulfilling the requirements can apply for a **scholarship**. The necessary requirements, application procedure and other details can be found at the EURO-DOTS project web site http://www.eurodots.org/Courses-15.asp.



Who should attend?

The course is principally intended but not limited to PhD students who want to get an in-depth education and practical training in the basics of analytical, electrical and optical characterization methods of analysis of semiconductor materials and/or micro/nano-electronic structures and devices. During one week the course will introduce PhD students into a variety of diagnostic methods as well as associated techniques and equipments. The course is also open to engineers at semiconductor companies, supervisors and lecturers at universities and technical and non-technical professionals who work or are responsible for:

- Material and structure characterization
- Semiconductor device design
- Device processing
- Process monitoring and support
- Device characterization and diagnostics
- TCAD modelling and simulation
- Expert techniques in electronics
- Metrology tool development and support
- Optoelectronic and photonic device characterization
- Failure analysis
- Reverse engineering

The course offers in-depth information on the principles, techniques, applications and benefits of various diagnostics techniques, including requirements for sample specifications and preparation as well as interpretation of obtained results. Overview of new methods in rapidly evolving fields of nanoelectronics and photonics will be beneficial for experts in nanoelectronics, nanometrology and failure analysis of advanced materials and devices.

Programme

Day 1. - Monday		*16. April 2012*	
8:00	8:30		Registration
8:30	9:00	Donoval, D.	Introduction
9:00	9:50	Breza, J.	General overview of analytical characterization methods
9:50	11:00	Držík, M.	Optical microscopy techniques
11:20	12:30	Držík, M.	Optical characterization of periodical structures
13:30	14:15	Kováč, J., Srnánek, R.	FTIR and Raman spectroscopy
14:15	15:15	Dobročka, E.	X-ray diffraction methods
15:35	16:35		
Day 2. – Tuesday		*17. April 2012*	
9:00	11:00	Kováč, J., Haško, D.	Scanning probe microscopy – SPM
11:20	12:30	Šatka, A.	Scanning electron microscopy – SEM
13:30	14:40	Šatka, A.	SEM – Cathodoluminescence, EBIC
15:00	16:15	Kováč, J.	Photoluminescence of semiconductors
Day 3. – Wednesday		*18. April 2012*	
9:00	11:10	Breza, J.	AES, XPS, XRF methods
11:30	12:30	Vincze, A.	Ion scattering and Secondary ion mass spectrometry
13:30	14:30	Vávra, I.	Focused ion beam technique
14:50	16:40	Vávra, I.	Transmission electron microscopy
Day 4. – Thursday		*19. April 2012*	
9:00	11:00	Donoval, D., Kordoš, P.	I-V based characterization of semiconductor structures
11:20	12:30	Tomáška, M.	Microwave characterization of semiconductor devices
13:30	14:45	Harmatha, L., Stuchlíková, Ľ.	C-V based characterization of semiconductor structures
15:05	16:00	Marek, J.	TCAD modelling and simulation
16:00	16:30	Šatka, A.	Failure analysis
Day 5. – Friday		*20. April 2012*	
9:00	12:30	All	Hands-on Training 1
13:30	15:00	All	Hands-on Training 2
15:00	16:00	All	Preparation of evaluation, closing remarks

Abstract of the lectures

General overview of analytical characterization methods (J. Breza)

Classification of analytical techniques. Primary and secondary particles, physical principles of analytical methods. Bulk and surface analytical methods. Analysis of surfaces, thin films and interfaces. Lateral and depth resolving power, sensitivities. Line-scanning, depth profiling. Sample preparation, etching, bevelling.

Optical microscopy techniques (M. Držík)

Conventional optical ray tracing laws and light wave diffraction limitations – optical lenses, magnifier and compound microscope, objectives, eyepieces, condensers, image formation, limitations of lateral and line of sight resolving power, Airy disc, immersion observation, depth of field and depth of focus, optics aberrations. Hardware based enhancement of image processing - optical filtration principles, dark field, bright field, polarizing and phase contrast, Nomarski interference and differential interference contrast (DIC), direct and inverse microscope, transmission and reflected microscopy, Scanning laser microscopy. Digital image processing in optical microscopy, preparation techniques in optical microscopy. Breaking the diffraction limit of light in optical microscopy – confocal principle of microscopy, NSOM, ANSOM, STED.

Optical characterization of periodical nanostructures (M. Držík)

Interaction of optical waves with solids, reflexion, absorption, constructive/destructive thin film interference, spectroscopic reflectometry. Principles of light diffraction, transform lens, Fourier plane, binary filtering, zero order diffraction technique, large area diffraction technique, bright-field and dark-field illumination, Brillouin zone diffraction pattern. Diffraction limit, spatial resolution. Application examples: determination of parameters of periodic structures, 2D photonic crystals, Bragg's diffraction, lattice constant, optical band gaps; imaging and identification of defects in periodical structures; sub-wavelength diagnostic of periodic structures.

Fourier transform infrared spectroscopy – FTIR, Raman spectroscopy - RS (J. Kováč, R. Srnánek)

Light absorption and reflexion, Raman scattering, electron-phonon interaction, resonance effects, selection rules, forbidden scattering, scattering from plasmon-LO-phonon modes, Stokes, anti-Stokes processes, probing depth of the laser light. FTIR and RS techniques. Diagnostics examples: identification and composition of materials, crystal structure, crystal orientation, surface and interface analysis, phase, temperature, mechanical stress, doping. Difference in Raman spectroscopy of bulk materials and thin layers. Micro-Raman spectroscopy. Raman-diagnostics of multi-layer structures, heterostructures, nano-structures: analysis of the surface, scan on a cleaved side-face, scan on the surface after bevel etching, temperature mapping.

X-ray diffraction methods (E. Dobročka)

X-rays, X-ray beam, the wavelength. Basic phenomenon of X-ray diffraction by a crystalline lattice, X-ray scattering in condensed matter and ordered nanoobjects, principles of high-resolution X-ray diffraction. Detection principles, measurement geometries, X-ray reflectometry, small angle X-ray scattering (SAXS), grazing incident SAXS (GISAX). Application examples, bulk materials, crystallites, the orientation of crystallites in thin films, epitaxial thin films, self-assembled nanoparticle arrays.

Scanning probe microscopy - SPM (J. Kováč, D. Haško)

Interactions between a sharp probe tip and a solid matter, tunnelling current, atomic and molecular forces, electrostatic forces. Cantilever, principles of tip nano-positioning and piezoscanners, position detection. Detection principles, spatial resolution and limitations. SPM-based surface morphology methods in different modes: contact and noncontact modes, linescan, mapping. Determination of surface parameters: average roughness rms and defects distributions. The electrical profiling methods: Scanning tunnelling microscopy (STM), Conductive I-AFM microscopy, Electric force microscopy (EFM), Scanning capacitance microscopy (SCM), Kelvin probe force microscopy (KPFM), scanning spreading resistance microscopy (SSRM), Scanning thermal microscopy (SThM). Application examples: surface topography, defect distribution, electronic properties, magnetic or electrostatic forces, optical characteristics, thermal properties.

Scanning electron microscopy - SEM (A. Šatka)

Interaction of a focused electron beam with solid matter, elastic and inelastic scattering, energy losses. Backscattered and secondary electrons, characteristic X-ray, cathodoluminescence. Electron gun, electron lenses, SEM and Environmental SEM. Image formation and image contrast. SEM techniques: Passive and active voltage contrast, energy or wavelength dispersive X-ray spectroscopy, Electron Beam Induced Current; spatial resolution, time-resolved techniques. Electron backscattering diffraction pattern and application on thin film technology. Applications: surface morphology and topography imaging, X-ray microanalysis, composition mapping, CL and electronic structure of semiconductors, revealing/identification of non-radiative defects and inhomogeneities in semiconductors, imaging of radiative regions in light emitting devices. Determination of PN junction position, electric field distribution, diffusion length, carrier lifetime.

Photoluminescence of semiconductors (J. Kováč)

Interaction of photons with solids, excitation, relaxation, recombination. Optical spectroscopy and detection principles, spectral resolution, photoluminescence spectroscopy (PL), photoluminescence excitation (PLE). Excitation sources spatial resolution, macro-PL, micro-PL, time-resolved PL, influence of temperature, excitation power, or light polarization. Application examples: bulk semiconductors, composition determination of an (Al, Ga, In)N films, hetero- and nanostructures (quantum wells, quantum dots, nanowires), internal electric field, localization energy, strain state of semiconducting material, fine structure of the semiconductors such as biexciton binding energy, defects, and internal quantum efficiency.

Auger electron spectroscopy – AES, photoelectron spectroscopy – XPS, and X-ray fluorescence – XRF (J. Breza)

Auger transition, fundamental instrumentation, basis quantities (ionization cross-section, electron escape depth, back-scattering factor), qualitative analysis, quantitative interpretation of Auger spectra (relative Auger sensitivity factors), semi-quantitative evaluation. Typical applications: surface and thin film analysis, depth profiling, examples of utilization.

Ion scattering, Secondary ion mass spectrometry – SIMS (A. Vincze)

Interaction of focused ion beam with solids, ion scattering at low and high energies, release of ions and neutral atoms from the solid surface by ion bombardment, disappearance cross section. Ion optics, primary ion generation methods, detection of secondary ions, mass spectrometer, ion spectrum; static, dynamic, time-of-flight (TOF) detection technique. Ion scattering spectroscopy (ISS), Rutherford backscattering spectroscopy (RBS), Secondary neutral mass spectrometry (SNMS), SIMS and TOF-SIMS techniques. Spatial and mass resolution, sensitivity issues. Ion mapping and imaging, depth profiling with surface removal by low energy primary ion gun, quantitative spectroscopy. Application examples: SIMS spectra of organic materials and semiconductor heterostructures, depth profiling and mapping, composition and structure evaluation, 3D compositional reconstruction.

Focused Ion Beam – FIB (I. Vávra)

Interaction of focused ion beam with solids and metal-organic molecules. FIB applications: local ion etching cross-sectioning of samples, preparation of TEM samples, local deposition of materials, FIB metallization systems, patterning of microelectronic devices. Re-deposition of sputtered material in trench profiles, radiation damage of semiconducting substrates, degradation of superconducting thin films.

Transmission electron microscopy – TEM (I. Vávra)

Electron beam, interaction of electrons with solid matter, transmission of electrons. Detection principles of transmitted electrons, amplitude contrast and phase contrast imaging, spatial resolution. TEM analytical methods, principles and techniques. Selected aspects of the modern TEM. Electron energy loss spectroscopy (EELS) and high resolution EELS, high resolution TEM, 3D TEM tomography at nanoscale, aberration-free techniques in TEM. Preparation of TEM specimens. Applications: cross-sectional and in plane TEM specimens, detailed structural analysis of microelectronic materials and microelectronic devices, characterization of thin nano-composite films.

I-V based characterization of semiconductor structures (J. Kováč, D. Donoval)

Static and pulse I-V characteristics of structures. Characterization of ohmic contacts, contact resistance, TLM measurements. Thin films parameters: drift mobility, sheet concentration and sheet resistance. Determination of current transport mechanisms in p-n junction and Schottky contacts: thermionic emission, generation-recombination, tunnelling and leakage currents, apparent barrier height, ideality factor. Characteristics of electronic devices: input, output, transfer and transconductance characteristics, extraction of threshold and pinch-off voltage, saturation current, gate leakage current, self-heating effect. Pulsed I-V measurements: avoiding self-heating effect, determination of trap relaxation times from transient analysis. Determination of failure mechanism: high electric field stress tests, thermal tests.

Microwave characterization of semiconductor devices (M. Tomáška)

Microwaves, interaction with solids, transmission, reflection, scattering, Schmidt diagram. Microwave device parameters, S-parameters, device figures of merit, transition frequency f_T, maximum oscillation frequency f_{max}. Principle of the methods, measurement techniques, experimental setup, on-chip/on-wafer (RFOW) setup, calibration. Power devices characterization issues, DC limitations, self-heating and heating. Application examples: RFOW measurements of GaN HEMTs...

C-V based characterization of semiconductor structures (L. Harmatha, Ľ. Stuchlíková)

The voltage dependence of the capacitance of semiconductor barrier structures, diffusion or contact potential, concentration depth profile of free charge carriers. Capacitance of MIS structures: influence of gate electrodes, insulating layers, semiconductor subsurface regions. Determination of a total defect charge, the work function of the metallic electrode, mobile ions in the insulating layer, and the energy distribution of the traps density at the insulator-substrate interface. Non-equilibrium time dependent capacitance methods: generation parameters, the relaxation time of MIS structures, the minority carrier lifetime, the surface generation velocity, electrical activity of defects. Deep-level transient spectroscopy (DLTS). Time-resolved, frequency-resolved, temperature dependent measurement techniques, detection limits, measurement speed. Characterization of trap levels in semiconductors: concentrations, activation energies, capture cross sections.

TCAD modelling and simulation (D. Donoval, J. Marek)

2-3 D process and device simulation, electro-physical models, drift-diffusion, thermodynamic, hydrodynamic, boundary conditions, electro-thermal simulation, calibration of model parameters, applications – Si power devices, nitrides, visualization and interpretation of simulated results.

Failure analysis of semiconductor devices (A. Šatka)

Sample preparation techniques: total and local decapsulation, delamination, cross-sectioning. Failure analysis examples. Reverse engineering, goals, methods and techniques. Intellectual property issues.

Fees and regulations

The course fee of 1000 EUR for PhD students includes all lectures, a complete set of course notes, lunches and refreshment during breaks. Hotel accommodations and meals other than lunches are not included in the course fee.

PhD students fulfilling the requirements can apply for a scholarship. Details, the necessary requirements and the application procedure are available on the web site of the EURO-DOTS project at www.eurodots.org.

FEI STU reserves the rights to cancel the program up to four weeks before the start of the course and its liability is limited to a full refund of the course fee. Cancellation by a participant between 8 to 21 working days before the start of the course is subject to a 200 EUR administration fee. A 400 EUR fee will be charged for cancellation within 3 to 7 working days of the start of the course.

Registrant substitutions can be made at any time, but announcement to the organizing committee will be kindly acknowledged. Registrants who do not attend and do not cancel will be subjected to full fee forfeiture.

Registration

Register by sending an email to the organizing committee in accordance with EURO-DOTS rules – see also http://kme.elf.stuba.sk/PhD_Course/Registration.htm.

Organizing committee

Prof. Daniel Donoval, DrSc.
e-mail: daniel.donoval@stuba.sk
GSM: +421 903 408703

Prof. Alexander Šatka, PhD.
e-mail: alexander.satka@stuba.sk
GSM: +421 911 371316

Juraj Priesol
e-mail: juraj.priesol@stuba.sk
GSM: +421 944 156909

Course web page

http://kme.elf.stuba.sk/PhD_Course/