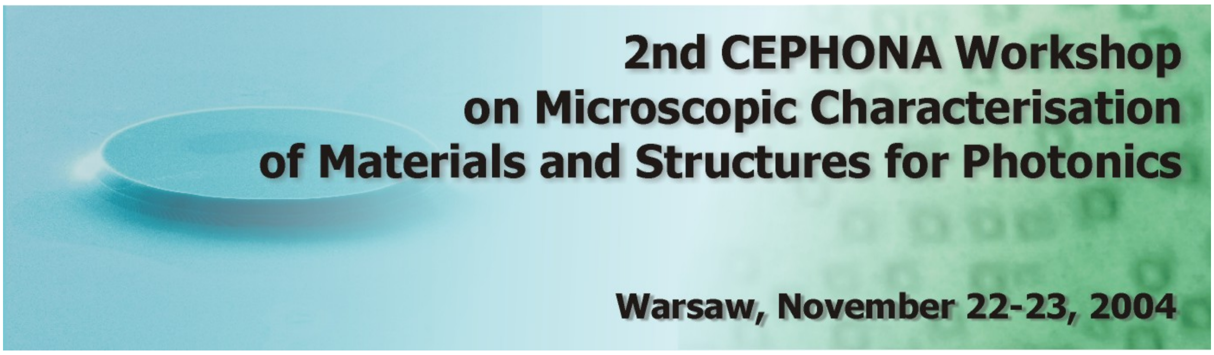

Institute of Electron Technology, Warsaw, Al. Lotników 32/46, Bldg. VI, room 120

PROGRAM

Monday, November 22		
9:00-9:15	**Openning**	
9:15-10:15	**P. Dlużewski (Institute of Physics, PAS, Warsaw, Poland)** The principles of transmission electron microscopy image formation	
10:15:11:15	**B. Grandidier (IEMN/CNRS, Lille, France)** Electronic and structural properties of III-V heterostructures characterized by scanning tunneling microscopy and spectroscopy	
11:15-11:45	**Coffee Break**	
11:45-12:45	**H. Kirmse (Humboldt-Universität,Berlin, Germany)** Structural and analytical characterization of semiconductor quantum dots by TEM	
12:45-13:45	**G. Salviati (IMEM-CNR,Parma, Italy)** Cathodoluminescence investigations of optoelectronic heterostructures and devices	
13:45-15:00	**Lunch Break**	
15:00-16:00	Laboratory training in TEM specimen preparation and SEM analysis	A trip around CEPHONA laboratories
16:00-17:30		Meeting of the CEPHONA Advisory Board

Tuesday, November 23	
9:00-10:30	**M. Henini (University of Nottingham, UK)** Self-Organised Quantum Dots for Advanced Applications in Optoelectronics
10:30-11:00	**Coffee Break**
11:00-12:30	**J. Tomm (Max-Born-Institut, Berlin, Germany)** Application of Raman-Spectroscopy to Analytical Purposes at Semiconductor Structures and Devices
12:30-14:00	**Lunch Break**
14:00-15:30	**P.O. Holtz (Linkoping University, Sweden)** Micro-luminescence characterization of quantum dots
15:30-16:00	**Coffee Break**
16:00-16:45	**J. Piotrowski (VIGO SYSTEM S.A., Warsaw, Poland)** Recent progress in detection of long wavelength infrared radiation with advanced heterostructural phototodetectors
16:45-17:30	**J. Muszalski (Institute of Electron Technology, Warsaw, Poland)** **Resonant cavity enhanced photodetectors**
17:30-17:35	**Closing remarks**

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2nd CEPHONA Workshop on Microscopic Characterisation
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The principles of transmission electron microscopy image formation

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ABSTRACT

The knowledge of the theoretical principles of image formation is crucial for understanding what we observe in transmission electron microscope. The image contrast is mainly determined by two processes: the electron interaction with specimen and the electron-optical imaging process including the microscope aberrations. However, the mathematic formulas are “the language” of the theory, this lecture tries to illustrate the subject with a use of the pictures and computer animations. The electron gun, sample, objective lens, image detector, are described by procedures performing appropriate mathematic transformations acting on the electron wave function. The definitions of the parameters like: coherence and divergence of illuminating electron beam, aperture’s diameter, defocus and spherical aberration of objective lens, and its influence on the resultant image will be presented. For example, the dependence between aperture diameter in focal plane and spatial resolution will be tested to prove the validity of the Abbe theory. After that, the concept of contrast transfer function will be introduced to explain another definition of spatial resolution, called the information limit. A few words will be devoted for a calculation of the wave function at the exit surface of the object from the wave function in the image plane. Next, the principles of electron beam interaction with specimen and basis of multi-slice calculations will be discussed. Finally, the image formation theory and multi-slice method for simulation of high-resolution images will be applied for retrieval information about object structure.

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Electronic and structural properties of III-V heterostructures characterized by scanning tunneling microscopy and spectroscopy

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ABSTRACT

Features in the atomic scale structure of alloys and heterojunction interfaces can exert a profound influence on electronic, optical and transport properties in semiconductor heterostructure materials and devices. The challenge is how best to achieve a complete microscopic characterization of these structures in order to optimize the devices performance. Through a few examples given in this talk, we will see that scanning tunneling microscopy (STM) can be reliably used to investigate atomic-scale alloy layer and interface structure of III-V compound semiconductors.

Cross-sectional imaging of III-V semiconductor structures is performed on (110) surfaces prepared by *in situ* cleavage. After a brief introduction of the technique, which focuses on the identification of impurities in III-V semiconductors and the determination of their electronic structures, cross-sectional STM will be firstly used to study strain compensated InGaAs/InAsP superlattices. These superlattices were grown with or without InP interlayers inserted in the barrier. We find that the InAsP barriers appear defective and intermixed when they are grown over the InGaAsP wells compared with those barriers grown over the InP layers. To more fully characterize the electronic properties of the superlattice, we use the spectroscopic capabilities of the STM and determine precisely the position of the interface between the InGaAsP and InAsP layer.

Similar investigations achieved on InAs quantum dots in GaAs, will then be shown. As the tunneling current depends on the electronic properties of the semiconductor, we will first discuss the contrast mechanism of the topographic STM images. Measurements of the strain distribution along the growth direction and of the dot interface roughness are performed. Investigation of the electronic structure of individual quantum dots will then be carried out. The amplitude of the electron wave functions can be resolved for the ground and first excited-state at room temperature. As the roughness of the interface may influence the shape of the electron wave function, theoretical calculations are made to study to what extend it is possible to observe experimentally a modification of the wave function shape by STM as a function of the interface roughness. Finally, comparison between our measurements achieved on embedded dots will be made with recent results obtained on bare InAs dots.

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Structural and analytical characterization of semiconductor quantum dots by TEM

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ABSTRACT

Semiconductor materials can form quantum dots (QDs) via strain driven self-organization on a substrate during epitaxial growth. For these structures quantum-physical phenomena become important due to confinement of charge carriers to a space of only some nm^3. The optoelectronic properties of the QDs essentially depend on their structural perfection, size, arrangement, morphology, and chemical composition.

In order to have a thorough understanding of the structural and chemical peculiarities of the QDs transmission electron microscopy (TEM) is an appropriate method of characterization. A detailed insight in the correlation between microstructure/microchemistry and materials properties requires the combined use of several TEM methods, as, e.g., imaging, diffraction and analytical TEM.

The TEM diffraction contrast imaging techniques provide information on size, shape, and arrangement of the QDs. The classical diffraction contrast method can also be applied to visualize the strain field in the surrounding of the QDs. In special cases dark-field imaging allows an estimation of chemical composition using chemically sensitive reflections.

In order to analyse the structure and the composition of QDs on an atomic scale high-resolution TEM (HRTEM) has to be applied. The methods of quantitative HRTEM (qHRTEM) enable the extraction of detailed information on strain and chemical composition of one and the same area.

Furthermore, STEM Z-contrast imaging can be used for obtaining chemical information on atomic scale.

Results of TEM characterization will be discussed for selected materials systems:

(In,Ga)As QDs on GaAs
Ga(Sb,As) QDs on GaAs
(Cd,Zn)Se QDs on ZnSe

The possibilities and limitations of the several TEM methods of the will be outlined.

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Cathodoluminescence investigations of optoelectronic heterostructures and devices

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ABSTRACT

The basic principles of the Cathodoluminescence (CL) technique in addition to its potentiality and limits in the study of the optical transitions of semiconducting heterostructures (HSs) and devices for optoelectronic applications will be discussed.

In addition to a sub-micrometric spatial resolution, the two main advantages of CL are:

i) the chance to get information on the optical transitions coming from different depths both in bulk materials and in HSs (depth-resolved SEM-CL)

ii) the possibility to change the injection power over many orders of magnitude in a continuous and controlled way to study excited states and/or internal electric fields (SEM-CL, TEM-CL)

Those two experimental approaches can result in quantitative CL provided suitable computer simulation programs are developed. In this respect, the following few examples related to the two afore mentioned peculiarities of the CL technique will be presented:

1. Study by depth resolved CL of the correlation between shape and integrated intensities of CL emissions and structural defects distributed along the growth axis in III-N based bulk layers, QWs and QDs.
2. Semi-quantitative investigations of the effects of internal electric fields on band gap-bending in III-N based QWs and QDs by means of power dependent CL.
3. Study by depth-resolved and power-dependent CL of the influence of point defects complexes in the failure analysis of InGaN based commercial LEDs.
4. Influence of surface to volume ratio and nanobelt thickness on the energy peaks position and shifts of the CL emission from a single SnO_2 nanobelt.

Finally, all the examples will stress how CL can contribute to an accurate characterization of the optical properties of materials and devices for optoelectronics provided complementary techniques like TEM, HRXRD, μ-Raman, EL, DLTS etc. are employed.

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Self-organised quantum dots for advanced applications in optoelectronics

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ABSTRACT

Low dimensional structures (LDS) form a major new branch of physics research. They are semiconductor structures, which have such a small scale in one or two spatial dimensions that their electronic properties are significantly different from the same material in bulk form. These properties are changed by quantum effects. Throughout the world there is increasing interest in the preparation, study and application of LDS. Their investigation has revitalised condensed matter science, in particular semiconductor materials. These complex LDS offer device engineers new design opportunities for tailor-made new generation electronic and photonic devices. New crystal growth techniques such as molecular beam epitaxy (MBE) and metal-organic chemical vapour (MOCVD) deposition have made it possible to produce such LDS in practice. These sophisticated technologies for the growth of high quality epitaxial layers of compound semiconductor materials on single crystal semiconductor substrates are becoming increasingly important for the development of the semiconductor electronics industry.

One of the main directions of contemporary semiconductor physics is the production and study of structures with a dimension less than two: quantum wires and quantum dots, in order to realize novel devices that make use of low-dimensional confinement effects. During the last few years much attention has been devoted to the strain in the grown layer and characterization of self-assembled semiconductor quantum dots (QDs). The strong interest in these semiconductor nanostructures is motivated by the possibility to use them as active media in future high-speed electronic and photonic devices. This talk is intended to convey the flavour of the subject by focussing on the technology and applications of self-assembled quantum dots.

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Application of Raman-Spectroscopy to Analytical Purposes at Semiconductor Structures and Devices

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ABSTRACT

We present an introduction into the methodology of Raman spectroscopy at semiconductors. After a brief overview of the physics involved into the Raman-process, a survey on applications to semiconductor spectroscopy is given. These applications involve the scattering at phonons and local defect modes as well as electronic Raman scattering. Applications of phonon Raman scattering for strain detection and for the understanding of the physics involved into technological processes such as ion-implantation are presented.

In the second part we address the use of micro (μ) Raman spectroscopy as a unique 'micro-thermometer'. The extremely small volume from which an integrated temperature is detected (excitation spot ∅~1 μm, information depth ~ 100 nm) makes μRaman a unique tool for investigations at modern semiconductor devices. A number of examples of μRaman investigations at facets of diode lasers is presented. This involves investigations of devices with different waveguide widths and the monitoring of facet temperatures versus operation time in long-term aging experiments. Furthermore, we discuss facet temperatures measured during the catastrophic optical mirror damage (COMD) process as well as investigations of the facet temperatures of quantum-dot lasers. Methodological limitations will be addressed, too.

Finally, we summarize and stress pros and cons of the application of the method.

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Micro-luminescence characterization of quantum dots

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ABSTRACT

Photoluminescence (PL) measurements employing a laser with a relevant excitation wavelength combined with a high sensitivity detector/CCD camera constitute is well established characterization method. PL excitation (PLE) experiments can provide information on the excited states at low temperatures i.e. valuable information on the electronic structure of the nitride wires/dots can be achieved. By means of perturbation spectroscopy, using magnetic fields and/or microwave perturbations, the electronic structure and other properties of the quantum system can be obtained.

For a corresponding study of a nano-particle e.g. a quantum dot, the micro-luminescence (micro-PL) characterization has been developed. It is possible to monitor the formation of a single electron-hole pair (exciton), a double electron-hole pair (biexciton) and/or charged complexes (charged excitons), originating from an individual dot.

Furthermore, charging of individual dots by pure optical means will be demonstrated. The charging of the dot can be monitored by exciton type detected in (micro-PL). The main advantage of this new method proposed is that no special sample design or contact is needed, while the traditional method to perform experiments on charged exciton complexes in dots assumes the application of an external electric field to feed the dots with additional charges from the doped barriers, which is accompanied by the inevitable deformation of the particle wave functions and the interaction energies.

The opposite effect, employing the dots as an ultra-sensitive charge probe has been demonstrated. This tool can be used to investigate the role of defects in the close environment of the dot in competing processes for capture of charge carriers into the dots.

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Recent progress in detection of long wavelength infrared radiation with advanced heterostructural phototodetectors

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ABSTRACT

The common believe is that infrared photodetectors of long wavelength radiation need to be cooled to achieve a high sensitivity. Cooling is necessary to suppress thermal generation of charge carriers. Actually, there are various ways of suppressing of thermal generation other then cooling so there is no fundamental obstacles in perfect detection of infrared radiation at elevated temperatures. The limitations are of technogical nature and can be overcome with understanding of photoelectrical phenomena in semiconductor heterostructures.

This review reports on recent progress in development of uncooled infrared photodetectors operating in the middle 3-8 µm (MWIR) and long 8-14 µm (MWIR) wavelength range of the infrared spectrum.

Advanced architectures of various uncoooled IR devices such as photoconductors, photoelectromagnetic and photovoltaic detector are described. The most promising are unconventional heterojunction photodiodes monolithically integrated with optical concentrators. The optimized heterostructures required for the devices have been grown grown with low temperature epitaxial technologies.

The progress in technology of the devices will eventually lead to perfect and fast detection of long wavelength radiation without cooling.

Various applications of the devices are discussed. One their use in quantum cascade-based IR systems.

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Resonant cavity enhanced photodetectors

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ABSTRACT

New type of the device a Resonant-Cavity Enhanced Photo-Detector (RCE-PD) can be created by enclosing an active region of a conventional photo-detector by a microcavity formed by two parallel mirrors. For such device the high bandwidth and high external quantum efficiency can be simultaneously achieved. This is because the presence of a Fabry-Perot microcavity makes multiple pass of the incident light through the active region in consequence the high absorption i.e., the high external quantum efficiency is achieved even for very thin layers for witch, in turn, the carrier transition time can be small. High external quantum efficiency together with high bandwidth makes RCE-PD a promising candidates for application in high speed optical communication and interconnections.

In this paper the state-of the art of RCE-PDs are discussed. The design of a microcavity is analyzed. Those analyses are sensitive for the standing wave effect. The analyses show that for RCE-PD the optimum absorption of the active region can be defined although this is a trade between the high bandwidth and narrow spectral sensitivity. The thinnest absorbing layers which allows for the grates bandwidth require the cavities of high finesse. This, in turn, is a weak point of RCE-PD since high cavity finesse results in a spectral shrinkage and direction dependent photo-response of detector.

Finally the material and technological requirements are discussed. The progress on RCE-PD in IET is presented.