Processing at the Nanoscale/NANO 6
Room 302 - Session NS+NANO6+MC-ThA

Near-field Optics and Photonics

Moderator: Y. Kuk, Seoul National University, Korea

2:00pm **NS+NANO6+MC-ThA1 Optical Sieves - How to Get the Light through Subwavelength Holes**, ***T.W. Ebbesen,*** Louis Pasteur University, France **INVITED**

Metallic films perforated with sub-wavelength holes (~150 nm) can transmit the light with an efficiency thousand times larger than what theory predicts for single holes. The efficency can even be larger than the fractional area of the holes, which means that even the light falling beside the holes emerges on the other side of the sample. This extraordinary transmission is due to the coupling of the incident light with the surface plasmons of the film. The transmission spectrum contains peaks attributed to surface-plasmon modes that depend on both the symmetry and the 2D lattice parameter of the surface corrugation. We have shown that this phenomenon can also be used to tune and enhance the transmission of single subwavelength aperture. These results have broad fundamental and practical implications and show that, with modern fabrication techniques, surface plasmons can be engineered and controlled to yield unique optical properties.

2:40pm **NS+NANO6+MC-ThA3 Near-field Optical Measurements of Two Types of the Super-resolution Near-field Structures**, ***D.P. Tsai,*** National Taiwan University, Taiwan; *W.C. Lin,* National Taiwan University

Two different types of super-resolution structures for the near-field optical storage were studied. Direct experimental observation of the near-field optical properties in the super resolution near-field structures of glass/SiN(170nm)/Sb(15nm)/SiN(20nm) and glass/ZnS-SiO2(20nm)/AgOx(15nm)/ZnS-SiO2(20nm) have been achieved by using a tapping-mode tuning-fork near-field scanning optical microscope. Both propagating and evanescent field intensities were found at the focused spots of the surfaces of the super resolution structures. The evanescent intensity may result from the localized surface plasmons excited at the antimony or silver oxide. Images of the near-field intensity gradients at different excited laser powers demonstrated that the area had the static evanescent intensity could be stably controlled. Direct observation of the focused spot sizes of the static evanescent field intensity and their changes controlled by the excited laser power have demonstrated the working mechanism of both two types of super-resolution structures.

3:00pm **NS+NANO6+MC-ThA4 Near Field Surface Photovoltage Microscopy**, *R. Shikler, S. Saraf,* ***Y. Rosenwaks,*** Tel-Aviv University, Israel

Surface photovoltage (SPV) is a well-established technique for the characterization of semiconductors, which is based on analyzing illumination-induced changes in the semiconductor surface potential. The SPV and other related techniques like surface photovoltage spectroscopy (SPS), has been successfully used to study metal-semiconductor interfaces, surface states, bulk defects, and minority carrier lifetime and diffusion length. To date, all the SPV related technique have a common significant drawback: they do not have high spatial resolution. With the developments of scanning probe microscopy techniques in recent years, the way is paved to conduct SPV measurements with nanometer lateral resolution. In this talk we describe a novel technique called near-field photovoltage (NFPV) which measures the SPV using near-field optical force sensor. The key feature of the technique is that the excited semiconductor sample is in the optical near- field region of a pulled optical fiber that measures the contact potential difference (CPD) between the fiber and the sample using the Kelvin probe force microscopy (KPFM) method. In such a case the illumination spot size is determined by the diameter of the aperture at the end of the tip and is not limited by diffraction. In addition, the light propagation is evanescent i.e. the intensity of the light falls off exponentially with increase distance from the tip edge (perpendicular to the crystal surface). This in combination with the high spatial resolution of the KPFM makes it possible to obtain depth-sensitive two-dimensional photovoltage images in semiconductors, and other materials. The method is demonstrated by photovoltage measurements conducted on buried p-n junctions of III-V compound semiconductors. . When the sample was excited under far-field conditions, a decrease in the PV of the whole structure was observed due to a larger photovoltaic effect (band flattening) in the p-n junction. This is due to the fact that under super-bandgap illumination the band bending of the p-n junction decreases and causes a decrease of the structure work function. On the other hand, when the sample was excited and measured with the near-field optical force sensor, an increase in the PV was observed due to band flattening only in the surface space charge region. Our results demonstrate the large surface sensitivity of the NFPV technique, and opens the way for a variety of ultra-surface sensitive SPV measurements and applications.

3:20pm **NS+NANO6+MC-ThA5 Dual-Wavelength Scanning Near-Field Optical Microscopy**, ***P.R. LeBlanc,*** *M. Gu, P. Grutter, D.G. Gray,* McGill University, Canada

We have developed a Dual-Wavelength Scanning Near-Field Optical Microscope to shed light onto the scanning process and investigate biological samples in air. We couple 442 and 325 nanometer light into a tapered optical fiber glued to a quartz tuning fork which serves as our `shear-force' sensor. Light transmitted through the sample is detected in a confocal arrangement by two photomultipliers. We have achieved topographical and optical resolutions of 10 and 30 nanometers, respectively. The dual-wavelength nature of our microscope permits the discrimination of topographical and optical cross-talk. It also allows the distinction of far-field artifacts from near-field features. Our primary biological application of the microscopy focuses on the investigation of the lignin distribution in wood fibers. Lignin, a cross-linked phenolic polymer, is of paramount importance in the pulp and paper-making processes. Our instrument permits the discrimination between chemical species density and topographical variations of the sample. The ratio of the two wavelength channels provides a simple and accurate parameter to determine the local concentration of lignin. These studies agree with atomic force microscopy images of wood cells and ultraviolet studies of wood cell walls.

3:40pm **NS+NANO6+MC-ThA6 Novel Scanning Near-field Optical Spectroscopy/Atomic Force Microscope Probes with High Polarisation Single/Double Slit and Cross Aperture Tips**, ***H.P. Zhou,*** University of Glasgow, UK, United Kingdom; *G. Mills, L. Donaldson, J.M.R. Weaver,* University of Glasgow, UK

We have developed novel scanning near-field optical microscopy/atomic force microscope (SNOM/AFM) probes. These probes have high polarisation single/double slit and cross apertures situated at the hollow tip apex of a silicon nitride cantilever. Direct-write electron-beam lithography (EBL) and silicon micromachining are used in a reliable batch process. The apertures are defined by lithographic means, therefore, the size, shape and orientation of apertures are well controlled and reproducible. The integration of a conventional force microscope cantilever with the aperture allows reliable control of the aperture-sample distance. The cross aperture probe has two very narrow orthogonal slits which have a width of much smaller than a wavelength, and a length on the order of a wavelength. We have designed and constructed a SNOM system based on the cross aperture probes. A parallel-polarised (p polarised) beam passes through the vertical slit and illuminates a sample hold in the near field of the aperture. The reflected light from the sample with the incident polarisation is received by the same slit, while the perpendicular-polarised (s polarised) fluorescent component is received by the horizontal slit. Using this system, we have obtained near-field fluorescence imaging and have demonstrated spectrally resolved photoluminescence imaging with a spatial resolution of 50nm. The single and double slit apertures are vertically or horizontally oriented. The polarisation properties of the optical transmission from the slit aperture probes have been investigated as a function of the polarisation orientation. The polarisation behaviour of the slit probes is linearly polarised. The polarisation ratio ranged from 1:60 to 1:1000 for different ratios of length to width of slits.

4:00pm **NS+NANO6+MC-ThA7 Optical Properties of Strained GaInP/InP Quantum Dots Studied with STM Based Electro-luminescence**, ***M.K.-J. Johansson,*** *U. Hakanson, J. Johansson, M.-E. Pistol, L. Montelius, L. Samuelson,* Lund University, Sweden

The physics of nanometer scale structures has become a rapidly evolving field sparked by considerable interest from both science and technology. In the effort to assess the optical properties of individual nano-structures the use of scanning tunneling microscopy (STM) as the excitation source has received a lot of attention.@footnote 1@ Compared to more conventional techniques such as photoluminescence and cathodoluminescence the excited volume is very small and a further advantage is that the excitation energy can be greatly varied, from resonant conditions to above the impact ionization threshold. In addition STM provides very detailed information of the electronic structure and thus a manifold of data can be obtained within the same experiment. Here we will present measurements using a variable

temperature UHV-STM combined with a scanning electron microscope. Furthermore, the system is equipped with an ex-situ laser source and optical detection system allowing a combined study of STM based electroluminescence, laser induced photoluminescence and cathodoluminescence to be performed without the need to change experimental conditions and set-up. In this report we investigate the optical properties of capped InP quantum dots grown by metalorganic vapor phase epitaxy on a highly doped GaInP layer, lattice matched to GaAs grown on a GaAs(001) substrate. We discuss the mechanisms of inducing luminescence and the dependence on excitation energy using the InP quantum dots as a model system. @FootnoteText@ @footnote 1@See for instance, A. Gustafsson et al. J. Appl. Phys. Rev. 88, 1715 (1998) and references therein.

4:20pm **NS+NANO6+MC-ThA8 Silicon Nanostructures via Intense Ultrafast Electronic Excitation**, ***A.V. Hamza***, *M.W. Newman,* University of California, Lawrence Livermore National Laboratory*; T. Schenkel,* University of California, Lawrence Berkeley National Laboratory*; H.W.H. Lee,* University of California, Lawrence Livermore National Laboratory*; P. Thielen,* University of California, Lawrence Livermore National laboratory*; J.W. McDonald, D.H. Schneider,* University of California, Lawrence Livermore National Laboratory

Due to the indirect nature of its band gap, bulk silicon is typically a poor photon emitter upon external excitation. However, as the crystal size approaches nanometer scales, the band gap widens due to quantum confinement and may become direct allowing for more efficient photon emission. Phase transformations induced by intense, ultrafast electronic excitation from slow, highly charged ions have produced nanometer-sized structures in silicon. Beams of highly charged ions of various charge state from 20+ to 69+ and various kinetic energies from 5 to 14 keV times charge have been utilized to induce this phase transformation in clean, silicon surfaces. The new phase is characterized by ex situ photoluminescence from the irradiated area after excitation with laser wavelengths from 379 - 514 nm. Photoluminescence spectra from the exposed areas show emission centered at ~540 nm. This is consistent with emission observed from 1-2 nm silicon nanocrystals. A series of sharp lines at 565, 555, and 548 nm are present in the photoluminescence spectrum from areas exposed to Xe@super 44+@ which are characteristic of an excitonic series in nanometer-sized material.

4:40pm **NS+NANO6+MC-ThA9 Microstructural and Optical Properties of Porous SiC**, *S. Zangooie,* University of Nebraska, Lincoln*; H. Arwin,* Linkoping University, Sweden*;* ***J.A. Woollam***, University of Nebraska, Lincoln

Electrochemical etching of crystalline SiC in hydrofluoric acid creates a high surface area material with room-temperature light-emitting properties stronger than those obtained from bulk SiC. The luminescence properties of porous SiC (PSC) open up application possibilities with, e.g., SiC-based integrated electronics. Applications of PSC demand a detailed understanding of microstructure and its relation to different fabrication parameters. In this work, ellipsometry and electron microscopy are used for characterization of 4H- and 6H-PSC. The dominant surface morphology consists of branched rosette-like structures surrounding sparsely located and circularly shaped holes with diameters of the order of 20 nm or less. The density of pores descending from the surface does not show clear dependence on the etching conditions. It is likely that pore initiation is favored at certain defect sites. Pores in PSC are found to initially propagate nearly parallel to the surface and gradually change direction and align with the c-axis. Consequently, well-defined columnar pores are formed. Thickness dependent anisotropy in pore propagation influences the etch rate, which varies nonlinearly with anodization time. Etching parameters such as hydrofluoric acid concentration and current density influence the rate of change of propagation direction. Pore sizes are found to increase with depth due to a decrease in acid concentration. A disordered phase is encountered at the interface between crystalline SiC and the pores. Spectrsocopic ellipsometry is used to study the microstructure, and we find that a simple effective medium approximation assuming mixtures of crystalline SiC and void does not result in good agreement with experimental data. To obtain good agreement with thickness and porosity, the disordered phase must be consideration. Anodization of SiC introduces remarkable changes to the optical properties due to depth-inhomogeneity and particle shape effects.

5:00pm **NS+NANO6+MC-ThA10 Development of a Photon Detection STM for Inelastic Light Emission**, ***D. Fujita***, *W.-L. Deng, T. Ohgi, K. Ishige,* National Research Institute for Metals, Japan

Recently it has been demonstrated that the light emission induced by tunneling electrons can be detected with normal STM operation even with atomic resolution. The possible processes are inelastic tunneling (IET) and hot-electron thermalization (HET). Generally speaking, in the case of IET, the tunneling electrons lose a part of the energy during the tunneling events to excite the state with some radiative decay processes. In the latter case, hot electrons lose the excess energy in the bulk. However, in order to get more detailed understanding of the luminescence process, much more precise measurements of these photons are required. For this purpose, we have developed a novel LT-UHV-STM system for the detection of light emission caused by the tunneling electrons. The emitted photons can be collected by the apex of a conductive and transparent optical fiber coated with a 100nm ITO (Indium-Tin-Oxide) film. Using a cooled photon detection system, single photon counting and spectroscopy with a very low noise level can be achieved. The system has been successfully applied to noble metal surfaces (Ag(111) and Cu(100)), and a direct-gap semiconductor surface (GaAs(110)) in UHV.

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