PCSI

Room Ballroom South - Session PCSI-MoM

Nanostructured Surfaces/Oxides I/Semiconductor Growth I/New Techniques I

Moderators: Aaron Arehart, The Ohio State University, Stacey Bent, Stanford University, Shane Johnson, Arizona State University, Frances Ross, IBM T. J. Watson Research Center

8:30am **PCSI-MoM-1 Quantum dots created by atom manipulation with the scanning tunneling microscope***, Stefan Fölsch,* Paul-Drude-Institut für Festkörperelektronik, Germany **INVITED**

Atom manipulation with the scanning tunneling microscope (STM) makes it possible to create ultimately small structures at surfaces. We extended this technique to III-V semiconductor surfaces [1,2] and found that their electrostatic potential landscape can be precisely designed by the controlled positioning of charged adatoms. In this way, quantum dots with identical, deterministic sizes can be created one atom at a time. By using the lattice of the InAs(111)A surface to define the allowed atomic positions, the shape and location of the dots is controlled with effectively zero error. The dots are assembled from +1 charged indium adatoms, leading to the confinement of intrinsic surface-state electrons [3,4]. This approach enables one to construct quantum dots with a perfectly defined level structure, as well as dot assemblies whose quantum coupling has no intrinsic variation but can nonetheless be tuned over a wide range.

In a related experiment, we found that the tunneling conductance of a single organic molecule adsorbed on InAs(111)A can be controlled by the adatom-induced gating potential, with the STM tip and substrate acting as source and drain contacts, respectively [5]. Depending on the potential, the molecular charge state can be tuned from neutral to -1, as well as to bistable intermediate states. Moreover, the molecule changes its orientational conformation upon charging. This coupling between charge and conformation induces a conductance gap more than one order of magnitude larger than normally found, for example, in electron transport through single molecules in the regime of strong electron-vibron coupling. The observed behavior can be rationalized within the framework of charge transport through a gated molecular quantum dot with strongly coupled charge and orientational degrees of freedom.

The discussed results illustrate that atom manipulation in combination with scanning tunneling spectroscopy provides detailed insight into the quantum-physical properties of artificial surface structures at the smallest size scales. Understanding and controlling these properties – and the new kinds of behavior to which they can lead – will be crucial for integrating atomic-scale devices with existing semiconductor technologies.

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9:00am **PCSI-MoM-7 Distance-Dependence of Chemical Interactions and Image Contrast Reversal in Noncontact Atomic Force Microscopy: A Case Study on Highly Oriented Pyrolytic Graphite***, Omur Dagdeviren, J Goetzen, E Altman, U Schwarz,* Yale University

The structural and chemical nature of surfaces governs a material's ability to interact with its surrounding. Designing nanodevices requires tailoring surfaces to meet specific needs and revealing underlying fundamental principles, which determine surface reactivity at the atomic scale. A particularly interesting case occurs when the surface site exhibits varying attraction with distance. To shed light on this issue, noncontact atomic force microscopy experiments combined with scanning tunneling microscopy experiments have been carried out where the evolution of the atom-specific chemical interaction leads to contrast reversal in the force channel. Due to the importance of sp^2-hybridized carbon surfaces in functional nanostructures, we have used highly ordered pyrolytic graphite surface and metal probe tips as the model system. Our experiments reveal that at larger tip-sample distances, carbon atoms exhibit stronger attractions at hollow sites while upon further approach, hollow sites become energetically more favorable. The analysis suggests the fundamental factors promoting contrast reversal are local varying decay lengths and an onset of repulsive forces that occurs for distinct surface sites at different tip-sample separations. In addition to these, a change of the hybridization state of carbon atoms from sp^2 to sp^3 under the influence of an approaching reactive probe can also result in contrast reversal. Our experiments address the unexpected nature of contrast reversal due to different governing mechanisms, which are determined by local properties of the sample as well as interacting materials. Combined with in-depth computational analysis, such experiments will lead to a deeper understanding of the fundamental effects that govern how materials interact with their surroundings at sub-nanometer scale. Entangling these fundamental principles with design will enable fabrication and synthesis of better nanodevices with graphene and other layered materials as well as nanotubes.

9:05am **PCSI-MoM-8 Epitaxial Graphene Induced Surface Reconstruction in Ge(110)***, Gavin Campbell,* Northwestern University*; B Kiraly,* Northwestern University, Netherlands*; R Jacobberger,* University of Wisconsin-Madison*; A Mannix,* Northwestern University*; M Arnold,* University of Wisconsin-Madison*; N Guisinger,* Argonne National Laboratory*; M Hersam, M Bedzyk,* Northwestern University

Understanding and engineering the properties of single-crystal surfaces has been critical in developing functional microelectronics at the nanoscale. Previously achieved through covalently bonded adatoms at surfaces, here we report how weakly bonded van der Waals' solids influence the development of new surface reconstructions in the EG/Ge(110) system. Employing scanning tunneling microscopy (STM), in-plane X-ray diffraction (XRD), and crystal truncation rod scattering (CTR) we investigate EG/Ge(110) and present a Ge(110) reconstruction stabilized by the presence of epitaxial graphene unseen in bulk semiconductor surfaces [1]. The combined STM and XRD results show the EG/Ge(110) interface, upon annealing, rearranges into a (6x2) superstructure persistence over large areas of the EG/Ge(110). CTR studies confirm the vdW gap and reveal that graphene sits atop the surface reconstruction with a 0.34 nm spacing. This structure represents a new avenue towards nanoscale engineering, using a vdW atomic layer to induce new stable surface reconstructions.

9:15am **PCSI-MoM-10 Emerging Memory Technologies and the Future of Computing***, Matthew Marinella,* Sandia National Laboratories **INVITED**

The most significant bottleneck in modern computing is that between the processing and storage of information. Decades of improvement in microprocessor technology have rendered the energy and time requirements for computation insignificant compared to those for reading and writing to off-chip main memory and storage. Improvements in computational efficiency are now swamped at the system level by memory access – and solving this von-Neumann bottleneck is one of the key challenges to enable the next generation of computing. Fortunately, several compelling memory technologies are emerging which may solve this challenge. Chief among these are a class of devices in which the state of the memory is stored as the resistance across its terminals. These technologies include redox resistive memory (ReRAM), conducting bridge memory (CBRAM), phase change memory (PCRAM), ferroelectric tunnel junctions (FTJ), and spin transfer torque (STT-RAM). All of these technologies can be integrated into the back end of line with a standard CMOS logic process. Monolithic integration of memory with logic drastically reduces the latency and energy of memory access. Voltage controlled technologies like ReRAM, CBRAM, and PCRAM can be configured in a dense crossbar with an area as small as $4F^2$ when using an inline select device (where F is the minimum lithographic feature size). When layered, these devices can reach densities of 100 terabits per cm^2, which can enable extraordinarily dense information storage integrated close to the computation. Magnetic and ferroelectric memories are capable of nearly infinite endurance with a very low switching energy, and hence may offer a replacement for the large SRAM cell for caches. It is also possible to use emerging memories to perform logic operations, further increasing the efficiency and performance of a computing system. However, several challenges remain before the full potential of emerging memory technologies will be realized. Chief among these are improving retention, endurance, and bit error rates through better understanding of the basic physics of switching. In addition, the development of suitable in-line select devices will be required to enable maximum density. This presentation will discuss the basic physical mechanisms, state of the art, and future prospects for these key emerging memory technologies and their role in the Beyond Moore era of computing.

Sandia National Laboratories is a multi-mission laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

9:45am **PCSI-MoM-16 Optochemical Sensing using Metal Oxide Nanoparticles: Adsorption and Detection**, ***James Whitten***, *S Kim, R Somaratne, C Granz, S Sengupta,* The University of Massachusetts Lowell

While a large amount of literature exists related to the use of metal oxide nanoparticles for chemical sensing, most of those studies have involved measuring chemical resistance changes of heated metal oxide nanoparticle films upon exposure to gases or vapors. One disadvantage of this type of sensor is the relatively high electrical power needed for heating the film. However, many metal oxide nanoparticles are photoluminescent, with their emission spectrum related to the presence of defects and surface states. This offers a new opportunity for chemical sensing, since adsorption is expected to affect the emission spectrum. Zinc oxide is a particularly interesting photoluminescent metal oxide with a bimodal room temperature emission spectrum that consists of an excitonic recombination peak at 380 nm and a visible, defect-related peak in the 500-600 nm range. Examples of other photoluminescent metal oxide nanoparticles include zirconium oxide and cerium oxide. The goals of this work are to measure and understand the changes in the photoluminescence spectra of metal oxide nanoparticles upon exposure to various gases and vapors. In addition to atmospheric gases, reactive gases such as sulfur dioxide, methanethiol, hydrogen chloride and chlorine have been investigated. Experiments using nitrogen saturated with various organic vapors have also been performed, including methanol, benzene, toluene and pyridine. Photoluminescence measurements have been carried out in real-time using a custom-built UV LED-based fluorometer, and these have been accompanied by surface science studies on the powders to determine if irreversible chemisorption occurred. It has been found that molecules that chemisorb on ZnO nanoparticles, such as benzene and pyridine, cause an irreversible decrease in the intensity of visible emission peak and an increase in that of the UV peak. For physisorbates, such as methanol, the changes are completely reversible. Density functional theory (DFT) calculations have also been performed in an attempt to correlate the strength of adsorption to the photoluminescence changes.

9:50am **PCSI-MoM-17 Strained MoO_3/MoS_2 Heterostructures: Facile Fabrication,Structure and Electronic Properties**, ***Vijay Saradhi Mangu***, *S Brueck, F Cavallo,* University of New Mexico

Few atomic-layer-thick MoO_3/MoS_2 heterostructures are receiving increasing attention for application in opto-electronics as a result of their unique mechanical and electrical properties. For instance, this material combination can support a high strain field without undergoing plastic deformation, due to its nano-scale thickness. Strain significantly affects the band structure of MoS_2 and MoO_3, allowing a variety of different electronic heterostructures without altering the chemical composition of the bilayer on nm-scale transverse dimensions. Despite all this interest, the fabrication technology of MoO_3/MoS_2 heterostructures is still relatively primitive, and the fundamental electronic properties of this material combination have not been investigated in detail. We develop a facile process to fabricate few-layer MoO_3/MoS_2 heterostructures on textured substrates, and therefore achieve mechanically strained films. In our approach a ~1-3 mm-thick MoS_2 flake is extracted from a bulk crystal via mechanical exfoliation and transferred to bulk Si patterned into a matrix of ultra-sharp tips. After this process step the MoS_2 flake is only supported by the ultra-sharp tips and hence mostly suspended over the substrate. A thermal annealing step in air/Ar atmosphere results in: (i) formation of MoO_3 at the top and bottom surface of the MoS_2 flake, (ii) delamination of few-layer Mo-compounds at the bottom surface of the transferred flake (i.e., the one in contact with the Si tips), (iii) conformal contact of the delaminated layers to the substrate pattern. We obtain ultra-sharp tips of Mo-compounds with height ranging from 350 to 500 nm, and base of ~350 nm, as measured by scanning electron microscopy (SEM). The remaining portion of the MoS_2 flake stays intact, and it is removed by mechanical exfoliation. We demonstrate that different annealing conditions result in guided self-assembly of a variety of Mo-compounds. Specifically, we vary annealing temperature, air partial pressure, and annealing time to gain some insight on the chemical and physical processes which result in delamination and guided self-assembly of the ultra-thin films. The geometry, structural quality and spatially varying strain are characterized by optical contrast, electron microscopy, Raman and photoluminescence spectroscopies. The effect of different annealing conditions on carrier type and carrier concentration is estimated by X-ray photo-electron spectroscopy.

9:55am **PCSI-MoM-18 Photoinduced Electron Transfer Across Single Crystal Oxide Electrolyte Interfaces**, ***Bruce Parkinson***, University of Wyoming

Oxide single crystals are attractive substrates to study the fundamentals of photoinduced electron transfer process at interfaces. A variety of crystals are available in both synthetic and natural forms, including TiO_2, SnO_2 and ZnO, all of which have different surface chemistries, band gaps and conduction and valence band energies. We have studied the binding and photoinjection yields of various dyes, photoactive polymers, quantum dots and semiconducting nanotubes adsorbed on these carefully prepared atomically flat single crystal surfaces. The atomic flatness of the crystals allows imaging of the adsorbate structures possible using scanning probe microscopies. The experiments can be used to provide fundamental insights into solar energy conversion devices such as the dye-sensitized solar cells where we have developed and verified a physical model for predicting the electron collection yields in these systems [1]. We have also performed simultaneous total internal reflectance and photocurrent spectroscopy measurements on ZnO single crystal electrodes with adsorbed dyes to correlate the absorption spectra of the adsorbed monomer and aggregate species with the photoinjection yields measure with photocurrent spectroscopy and adsorbed dye structures as indicated by atomic force microscopy [2]. Using anatase TiO_2 single crystals we were the first to demonstrate photoinjected electron quantum yields of greater than one as a result of multiple exciton generation in adsorbed PbS quantum dots [3] opening the door for devices that exceed the Shockley/Queisser limit for photovoltaic energy conversion efficiency. Recently we have measured photoinjection from purified semiconducting carbon nanotubes on atomically flat synthetic crystals of SnO_2 [4] where multiple exciton generation and collection is also possible.

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11:00am **PCSI-MoM-31 The Atomic-Scale Mechanisms of Ternary Semiconductor Alloy Growth: Self-limited vs. Accumulating Anion Processes**, ***Joanna Millunchick***, *G Rodriguez, C Tait, E Anderson,* University of Michigan **INVITED**

Alloys of compound semiconductors are necessary to create heterostructures for optoelectronic and electronic devices. Growth of alloys that vary the cation component, eg: AlGaAs or InGaP, is fairly straight forward because there are few reactions between the cation species. Growth of mixed anion alloys, such as InAsSb and GaSbBi, are more complex because of the strong tendency for the individual anion species to interact. In the case of InAsSb, for instance, the displacement of Sb with impinging As is well documented. Furthemore, it is proposed that Sb atoms are weakly physisorbed on the surface. We investigate this hypothesis by scanning tunneling microscopy coupled with *ab initio* total energy calculations. We show that rather than remaining weakly physisorbed, Sb roughens the surface by increasing the coverage of divots (vacancy clusters) and two dimensional islands. Our calculations show how that As-terminated surface reconstructions may transform into mixed heterodimer terminated configurations, which causes the roughening by pulling atoms from the terrace. Thus we propose an alternative model for interfacial broadening by intermixing rather than by surface segregation. Another example of a complex mixed anion alloy is the Bi-containing materials system. The growth of GaAsBi and GaSbBi often leads to low Bi incorporation, droplets on the surface, and nonuniformity in the composition. We have developed a kinetic Monte Carlo simulation that explicitly takes cation and anion reactions into account that is capable of examining the unique characteristics of Bi-containing III-V semiconductor alloys. A phase diagram for a range of growth rates was generated using this simulation that predicts both Bi content and droplet formation. Furthermore, we propose a new kinetic model that captures the dynamics of incorporation and droplet formation in the growth of these alloys.

11:30am **PCSI-MoM-37 Preparation of InSb Surfaces for Molecular Beam Epitaxy Growth and Re-growth**, ***Mihir Pendharkar***, *J Lee, P Iyer, B Shojaei, A McFadden, J Schuller, C Palmstrom,* University of California, Santa Barbara

Molecular Beam Epitaxy of III-V semiconductors has allowed for a continued improvement in the understanding of materials and the discovery of novel physical phenomenon. The narrow band gap of InSb coupled with its low electron effective mass have generated significant interest for its applications in high electron mobility transistors and infrared detectors and metasurfaces. Lack of lattice matched wide band gap III-V substrates and the challenging thermal desorption of the InSb surface oxide, has led to the growth of InSb on highly lattice mismatched materials. Performance of functional InSb devices based on mismatched substrates has been limited due to very high defect and dislocation densities.

In this work, preparation of InSb (001) substrates by atomic Hydrogen cleaning, in Ultra High Vacuum, and subsequent growth of InSb epi-layers by Molecular Beam Epitaxy, has been demonstrated. The efficiency of Hydrogen cleaning on the surface of InSb, for removal of the surface oxide, was studied by X-Ray Photo-Electron Spectroscopy (XPS), Reflection High Energy Electron Diffraction (RHEED) and Scanning Tunneling Microscopy (STM). The developed surface preparation technique has allowed for the first demonstration of an InSb quantum well on an InSb substrate, with record electron mobility.

Re-growth of III-V epi-layers of InSb, after ex-situ device fabrication, has also been demonstrated. A combination of wet chemical etching and in-situ atomic Hydrogen cleaning has been used to achieve an epi-ready surface. The demonstrated ability of growth and re-growth on InSb (001) surfaces is expected to be a paradigm shift in the discovery and development of new electronic and photonic devices using (Al,Ga)xIn1-xSb material system as a template.

11:35am **PCSI-MoM-38 Mechanisms of Light-Assisted Epitaxy of III-V and II-VI Alloys**, ***Kirstin Alberi***, *K Park, D Beaton,* National Renewable Energy Laboratory*; M Scarpulla,* University of Utah

The synthesis of semiconductor epilayers, heterostructures and interfaces is often limited by adatom incorporation processes, dopant solubility and native defect formation. Modern uses of semiconductors therefore depend on our ability to control these processes during growth. Some degree of control is typically achieved by tuning the substrate temperature and chemical potential of the system. However, these variables may be inadequate for substantially manipulating some growth mechanisms. External stimulation of the growth surface through photon irradiation provides an additional process variable. Investigation of the mechanisms by which photon irradiation alters semiconductor growth suggests that the most substantial changes occur via electronic processes. Photogenerated carriers can directly modify adatom incorporation sites through enhanced desorption and passivation of dangling bonds [1,2]. Splitting of the quasi-Fermi levels caused by the presence of non-equilibrium carrier concentrations also affects the formation energy of native defects and built-in electric fields at the growth surface [3]. These mechanisms and the potential to exploit them to solve challenges related to the growth of metastable semiconductor alloys and heterovalent heterostructures as well as the impact on defects will be discussed.

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11:40am **PCSI-MoM-39** ***Ab initio*****-based Approach to Adsorption of In atom with Strain Relaxation on InAs Wetting Layer Surface Grown on GaAs(001)**, ***Ryo Kaida***, *T Akiyama, K Nakamura, T Ito,* Mie University, Japan

InAs/GaAs(001) lattice mismatched system has been paid much attentions to fabricate low dimensional nanostructures such as self-assembled quantum dots (QDs) by molecular beam epitaxy (MBE) [1]. Despite the importance of the InAs/GaAs(001) system, there has been few theoretical studies for the QD formation mechanisms because of the difficulty of understanding the behavior of InAs wetting layer (WL) grown on GaAs substrate by *ab initio* calculations. We previously revealed that the growth of InAs and resultant surface structural change cannot proceed without eliminating lattice strain in the InAs WL at 0.96 monolayer (ML) [2]. Furthermore, we recently clarified that misfit dislocation (MD) formation as one of promising candidates for strain relaxation mechanisms starts at the InAs/GaAs(001) interface from 0.5ML during the growth [3]. These findings suggest that the InAs growth and its surface structural change are closely related to the lattice relaxation mechanisms on the InAs WL. In order to clarify the relationship between the growth process and the strain relaxation, lattice relaxation mechanisms on the InAs WL, we investigate the adsorption behavior of In atom on InAs WL surfaces including various lattice strain conditions on the basis of *ab initio* calculations.

Figure 1 shows the calculated adsorption energy of In atom on the (4×3) reconstructed surface consisting of In-As dimers as a function of hypothetical lattice constant of the InAs WL, which corresponds to the strain relaxation of the InAs WL. The calculated adsorption energy on the (4×3) surface with lattice constant a=5.76 Å, which corresponds to InAs WL without strain relaxation, is larger than that for adsorption of In atom under the MBE condition at 730 K (-2.63 eV). This indicates the adsorption does not occur without strain relaxation [3]. In contrast, the adsorption energy of In atom drastically decreases when lattice constant is larger than 6.08 Å, and becomes close to the value for fully relaxed InAs WL of -2.63 eV. The reduction of adsorption energy around a=6.08 Å thus manifests that the adsorption of In atom and resultant surface structural change toward the (2×4) reconstruction [4] can be realized by eliminating lattice strain of the InAs WL such as MD formation.

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11:45am **PCSI-MoM-40 Atom Probe Tomography of Low-Dimensional Materials: III-As Nanowire Heterostructures and Doped Layered Chalcogenides**, ***Lincoln Lauhon***, Northwestern University **INVITED**

We will describe the application of atom probe tomography (APT) to the analysis of facet driven composition fluctuations in GaAs-AlGaAs nanowire core-shell heterostructures and the distribution of Ag dopant atoms in $(PbSe)_5(Bi_2Se_3)_3$. AlGaAs is a ternary semiconductor whose composition can be tuned smoothly from GaAs to AlAs in molecular beam epitaxial growth. However, transmission electron microscopy and APT of GaAs-AlGaAs core-shell heterostructures have revealed facet dependent segregation.[1] Furthermore, APT analysis has linked quantum dot like emission spectra to composition fluctuations that exceed those expected for a random alloy,[1] despite the absence of a miscibility gap at typical growth temperatures. When the shell growth temperature is reduced from 560 °C to below 400 °C, the *non*-randomness of the alloy distribution in the AlGaAs shell is greatly reduced.[2] These observations will be explained in terms of a facet dependent segregation that is kinetically suppressed at reduced growth temperatures.

van der Waals heterostructures in layered or two-dimensional (2D) materials represent an entirely new class of ultrathin heterostructure. Doping of the constituent 2D materials provides a route to tuning electronic properties and forming new types of heterojunctions between semiconductors, metals, and superconductors. A nanoscale perspective on the dopant distribution can provide important insights into electronic structure and physical behaviors. APT analysis of Ag doped $(PbSe)_5(Bi_2Se_3)_3$ [3] shows that Ag dopes both Bi_2Se_3 and PbSe layers in $(PbSe)_5(Bi_2Se_3)_3$, and correlations in the position of Ag atoms suggest a pairing across neighboring Bi_2Se_3 and PbSe layers. Density functional theory (DFT) calculations confirm the favorability of substitutional doping for both Pb and Bi and provide insights into the observed spatial correlations in dopant locations. This work demonstrates the feasibility of APT analysis of 2-D materials.

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12:15pm **PCSI-MoM-46 High Aspect Ratio GaN Nanowires for Tip Metrology and Optical Application**, ***Mahmoud Behzadirad***, *M Nami, D Feezell, T Busani,* University of New Mexico

GaN has recently received many attentions for their specific optical properties as a wide band gap semiconductor. GaN, in form of single crystal NWs, is taking an important role in future optoelectronic devices as they can increase surface to volume ratio of the active region and enhance the device efficiency [1, 2]. Since the quality of the NWs after growing determine the efficiency of the final device operation, many researches have been devoted to grow high quality NWs [1, 2, 3]. Bottom-up approach has been employed to acquire desire NWs since late 1990s [3], however, it is difficult to control growing parameters in Molecular Beam Epitaxy (MBE) or Metal Organic Chemical Vapor Deposition (MOCVD), and so the fabrication process is complex and expensive. Likewise, growing high aspect ratio NWs with small diameter (<100 nm) is always challenging. On the contrary, top-down approach has demonstrated promising results in creating high aspect ratio structures as an alternative method for NWs fabrication. However, emerging roughness in side wall of the NWs and as a result poor optical property of the device has been an issue in top-down process which hindered wide application of this cost-effective method in device fabrication. Here, we demonstrate two-step (dry-wet etch) top-down fabrication of high aspect ratio (10-18) single crystal GaN NWs with side wall of sub-nanometer roughness. Two methods are employed to inspect NW side wall quality: i) TEM imaging, and ii) optically pumping of NWS. All NWs with different aspect ratio demonstrated very smooth side wall on TEM imaging as well a sharp lasing peak at ~367 nm when they are pumped with 266 nm laser. We also demonstrate how fabricated NWs can outperform standard Si tip in Atomic Force Microscopy, and potentially create more effective optoelectronic devices as they have less roughness compared to other reported works using the same growing method.

12:20pm **PCSI-MoM-47 Nanoscale Chemical Imaging with Photo-induced Force Microscopy**, ***Thomas Albrecht***, Molecular Vista

Correlating spatial chemical information with the morphology of multi-component nanostructures remains a challenge for the scientific community as many such systems are not easily interrogated at the nanometer scale in real space via existing instruments based on optics or electrons. A novel scanning probe technique called Photo-induced Force Microscopy (PiFM) measures the photo-induced polarizability of the sample directly in the near field by detecting the time-integrated force between the tip and sample. Imaging with infrared wavelengths specific to different molecular components, PiFM can resolve the nanometer-scale distribution of individual chemical species in diverse multi-phase and multi-component materials. When coupled to a widely tunable infrared quantum cascade laser system, a rich spectral analysis mode, which we call hyperspectral imaging, can be realized. A hyperspectral image consists of a PiFM spectrum (which correlates well with bulk FTIR spectra for most species) at each pixel of a (n x n) image. By detecting the molecular infrared absorption via mechanical force measurement on a sharp tip, PiFM achieves spatial resolution that surpasses the diffraction limit by an astonishing factor of ~1000 X. The power and utility of PiFM and hyperspectral imaging will be demonstrated by presenting results on several multi-component nanomaterials, including self-assembled block copolymer patterns, star polymers, polymer blends, asphalt binder, organic photovoltaic materials, and a variety of other materials.

12:25pm **PCSI-MoM-48 Z-Scan Photo-Reflectance Characterization of Resonant Optical Nonlinearities of Surfaces**, ***Will Chism***, Xitronix Corporation

Z-scan techniques based upon the distortion of a Gaussian laser beam provide a sensitive means to characterize nonlinear refraction and absorption in a wide variety of materials. In general, Z-scan techniques use the transmittance of a Gaussian laser beam through a finite aperture in the far field to determine the sign and magnitude of nonlinear refraction and absorption. Reflection Z-scan techniques are particularly suited to measure surface nonlinearities of materials with limited transparency. At the same time, photo-reflectance (PR) is a well established technique to study the bandstructure and interfacial electric fields of semiconductors and semiconductor microstructures. In general, PR measures the change in reflectivity of a sample whose surface electric field is modulated by the photo-injection of electron-hole pairs. The physical origin of the PR response is a resonant third order nonlinearity involving one probe photon and two DC field quanta. In this paper, Z-scan techniques are applied to the case of a probe laser beam in a PR setup. In particular, the theory of laser beam propagation as it applies to the probe laser beam in a PR apparatus is described and the use of Z-scan PR to independently characterize resonant nonlinear refraction and absorption in silicon-germanium samples exhibiting large absorption is demonstrated.

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