Plasma Science and Technology
Room: A8 - Session PS2+PV-MoM

Plasma Processing for Photovoltaics
Moderator: T.A. Gessert, National Renewable Energy Laboratory

8:40am **PS2+PV-MoM2 Plasma Etching and Texturing of Multi-Crystalline for Silicon Solar Cells using Remote-Type Pin-To-Plate Dielectric Barrier Discharge**, ***J.B. Park****, J.S. Oh, E.L. Gil, G.Y. Yeom*, Sungkyunkwan University, Republic of Korea

During the preparation of the wafers for the multi-crystalline silicon (mc-Si) solar cells, the mechanical saw damage induced during the slicing of mc-Si ingots into wafers needs to be removed by etching in addition to the texturing of the silicon surface for the increased light scattering. For the etching and texturing of the mc-Si substrates, isotropic wet processing by using alkaline or acid solution is generally applied, however, wet treatments are environmentally undesirable due to the large amount of chemicals used.

In this study, an atmospheric pressure plasma called "remote-type pin-to-plate DBD" was used for the application to the etching of the saw damage removal and texturing process of mc-Si to increase the processing rate by increasing the plasma density without damaging the substrate surface. Especially, the effect of additive gases such as NF_3 and O_2 to the N_2-based atmospheric pressure plasma on the etching and texturing characteristics of mc-Si was investigated.

The results showed that the addition of NF_3 up to 1 slm increased the mc-Si etch rate continuously by increasing the F radicals in the gas mixture. Furthermore, the addition of a certain amount of O_2 (400sccm) to the mixture of N_2(40 slm) /NF_3(1slm) increased the mc-Si etch rate further by showing the two times higher etch rate of mc-Si (749.6 nm/scan, 1meter/scan). Especially, the addition of O_2 to the N_2/NF_3 improved the surface morphology by increasing surface texturing and, by the addition of 600sccm O_2, the reflectance less than 20% could be obtained.

9:00am **PS2+PV-MoM3 Production of Crystalline Si Nanoparticles for Third Generation Photovoltaics using a Multi-Hollow Discharge Plasma CVD Method**, ***Y. Kawashima****, H. Sato, K. Koga, M. Shiratani,* Kyushu University, Japan, *M. Kondo*, AIST, Japan

Novel solar cells employing multiple exciton generation (MEG) are attracting much attention as third generation solar cells of high efficiency above 20%. For the MEG, an energetic exciton is generated in a semiconductor nano-crystal by a high energy photon more than twice as large as the band gap of the nano-crystal. Subsequently, the energetic one produces another in the nano-crystal by the inverse Auger process [1]. An issue for realizing the MEG solar cells is production of size-controlled crystalline Si nanoparticles. We have produced crystalline Si nanoparticles of 1 nm in size using a multi-hollow discharge plasma CVD method [2]. For the multi-hollow discharge plasma CVD method, discharges are sustained in small hollows of 5 mm in diameter. Crystalline nanoparticles are nucleated and grow in the discharges of SiH_4+H_2 (>99.5%) and then they are transported to the downstream region by gas flow. Their size is limited up to a few nm in size due to a short gas residence time in hollows. Nanoparticles are collected by stainless mesh grids located at the downstream region. They are dispersed in methanol to measure their photoluminescence. The excitation laser wavelength is 244nm or 405nm. For 405nm light irradiation,the photoluminescence spectrum has a peak at 490nm (2.53eV), corresponding to the bandgap of the Si nanoparticles of 1 nm in size. For 244nm light irradiation, the spectrum has a 380nm (3.27eV) peak corresponding to recombination centers at their surface as well as a 484nm (2.56eV) peak corresponding to their bandgap. These experimental results demonstrate generation of excitons in the Si nanoparicles. Si nanoparticles produced may be applicable as a material for MEG solar cells. We also have measured absorption spectrum of Si nanoparticles dispersed in methanol. Si nanoparticles show stronger light absorption at the shorter wavelength (<250 nm). To realize MEG solar cells, fabricating nanoparticles of an optimaized size for MEG in large quantity is important.

[1] A.J.Nozik, Physica E **14**, (2002)115.

[2] T. Kakeya, Kazunori Koga, Masaharu Shiratani, Yukio Watanabe, Michio Kondo, The Solid Films, **506-507**, (2006)288.

9:20am **PS2+PV-MoM4 Novel Model-Based Sensor for Thin Film Deposition on Large Area Substrates**, *M. Klick,* Plasmetrex, Germany, ***L. Eichhorn****, R. Rothe*, Plasmetrex

Large area plasma coating becomes more important with increasing diameter of semiconductor wafers and thin film Si solar cells. The layer characteristics as uniformity of films produced by capacitive RF plasmas depends on effects as the standing wave and skin effect.

A reduced plasma physical model in the novel sensor is used to describe special features of large area and capacitive RF plasmas. It involved dynamic electron effects by a fluid model for the plasma bulk and nonlinear mechanisms by a nonlinear sheath model - called it Nonlinear Extended Electron Dynamics (NEED).

It involves also the nonuniformity and nonlinearity of the plasma sheath in the front of the substrate electrode, large electrode area, and medium pressure. The model provides also the dependence of the Fourier spectrum of the local RF current on the plasma density and the electron collision rate. Only lower harmonics of the RF current can be observed at medium pressure (100 Pa – 1000 Pa). Depending on the amount of harmonics of the local RF current used, it can be utilized also to estimate important plasma parameters as the electron collision rate and the ratio of the excitation frequency to the resonance frequencies of the spatial modes is found to determine the nonuniformity caused by the standing wave. The skin depth can be estimated as well to show the influence on spatial distribution of the RF current.

The major advantage is the real time, robust, and non-intrusive characterization of large area plasmas. An additional feature is the easy calculation of the plasma sheath voltage distribution at the grounded counter electrode. Both is mandatory to understand and to control the deposition rate distribution in particular for large area RF plasmas. So cost-efficient virtual metrology can substitute partially the expensive and time intensive real metrology.

9:40am **PS2+PV-MoM5 Plasma Processing of Thin Silicon Films for Photovoltaic Applications**, ***A.H.M. Smets****,* National Institute of Advanced Industrial Science and Technology, Japan and Eindhoven University of Technology, Netherlands*, M.C.M. van de Sanden,* Eindhoven University of Technology, The Netherlands*, T. Matsui, M. Kondo*, National Institute of Advanced Industrial Science and Technology, Japan **INVITED**

Hydrogenated amorphous silicon (a-Si:H) and hydrogenated microcrystalline silicon (μc-Si:H) are thin film silicon phases which are generally deposited at low processing temperatures by means of plasma enhanced chemical vapour deposition (PECVD) using hydrogen diluted silane gas mixtures. The lattice of dense a-Si:H is best described by a vacancy rich network (1-2 %) which lacks any medium and long range order, whereas the lattice of μc-Si:H consists of crystalline silicon grains (few nm's up to microns) imbedded in to an amorphous network or tissue. One hot application of these films is the integration in to thin silicon film photovoltaic devices. In comparison to a-Si:H phase, the μc-Si:H phase has the advantage of an enhanced spectral response in the red part of the solar spectrum and a better opto-electronic stability under illumination.

Since the deposition of the μc-Si:H phase under low processing temperatures (~160-250 ºC) is obtained by increasing the hydrogen dilution in a silane plasma, it is believed that additional flux of atomic hydrogen at the surface enhances crystalline relaxation of the silicon atoms in the lattice during growth.

With respect to photovoltaic applications of μc-Si:H, high quality material is classified as dense material without any significant post-deposition oxidation, as oxidation is linked to a reduction in the red response of the *p-i-n* solar device. This specific μc-Si:H phase has the following properties: 1) crystalline grains with a preferentially [220] oriented growth, 2) has no crystalline grain boundaries, as these internal surfaces have been identified as the location at which the unwelcome post-deposition oxidation occurs and 3) is deposited close to conditions in which the growth transfers from amorphous to microcrystalline.

In this contribution we will address in detail the material properties of μc-Si:H and its relation to its performance in solar cells, the growth mechanism of the μc-Si:H phase under plasma deposition conditions and the crucial role of the control of plasma processing in obtaining device grade material. Finally, we will discuss the upscaling of the deposition technology (high deposition rates over large areas), which is an important issue in substantially reducing the cost-price of thin silicon photovoltaic products. We will present the recently explored deposition regime at higher processing pressures (~5-25 Torr), which has a high potential to bring about this important breakthrough in the thin silicon film photovoltaic technology.

10:40am **PS2+PV-MoM8 Atomic Hydrogen Induced Defect Kinetics in Hydrogenated Amorphous Silicon: An In Situ Real Time Study**, ***M.C.M. van de Sanden**, F.J.J. Peeters,* Eindhoven University of Technology, The Netherlands*, J. Zheng,* Peking University, China*, I.M.P. Aarts,* ASML, The Netherlands*, A.C.R. Pipino,* Tanner Research*, W.M.M. Kessels*, Eindhoven University of Technology, The Netherlands

Near-IR Evanescent-Wave Cavity Ring-Down Spectroscopy (EW-CRDS) is applied to an a-Si:H thin film subjected to quantified H fluxes from an atomic H source in the range of $(0.4\text{-}2)\times10^{14}$ $cm^{-2}s^{-1}$. To this end 20-80 nm a-Si:H films were grown on the Total Internal Reflection (TIR) surface of a folded miniature optical resonator by thermal decomposition of silane on a hot filament. Measurements are performed over a temperature range of 80 – 200 ºC. The observed changes in the optical loss during H dosing of a-Si:H are attributed to the creation and healing of sub-gap Dangling Bond (DB) defect states and were measured with a sensitivity of ~ 10^{-6} and a time resolution of 33 ms. The DB density is shown to increase during H dosing cycles and the DBs reversibly 'heal' when the H flux is terminated. The effect increases in magnitude with H flux and decreases with temperature. Through the use of polarizing optics the CRDS signal was split into s- and p-polarized components, which, combined with field calculations, revealed that H-induced DB formation is not limited to the surface of the film but progresses into the bulk with a penetration depth of ~10 nm. Due to their limited lifetime the created DB defects are identified as the result of H insertion into strained Si-Si bonds in the bulk material. Extensive kinetic modeling of this process is used to determine activation energies for the hydrogen-material interactions and DB formation in a-Si, which are of key importance in a-Si:H thin film solar cells. Moreover the implications of this study for Eley-Rideal type reactions on the surface and hydrogen exchange reactions in the bulk will be addressed.

11:00am **PS2+PV-MoM9 Hydrogen-dominated Plasma, Due to Silane Depletion, for Microcrystalline Silicon Deposition***, **A.A. Howling**, R. Sobbia, Ch. Hollenstein*, EPFL Lausanne, Switzerland **INVITED**

Plasma conditions for microcrystalline silicon deposition generally require a high flux of atomic hydrogen, relative to SiH_x radicals, on the growing film. The necessary dominant partial pressure of hydrogen in the plasma is conventionally obtained by hydrogen dilution of silane in the flow inlet. However, a hydrogen-dominated plasma environment can also be obtained due to plasma depletion of the silane in the gas mixture, even up to the limit of pure silane inlet flow, provided that the silane depletion is strong enough. At first sight, it may seem surprising that the composition of a strongly-depleted pure-silane plasma consists principally of molecular hydrogen, without significant contribution from the partial pressure of silane radicals. The aim here is to bring some physical understanding by means of a zero-dimensional, analytical plasma chemistry model. The model is appropriate for uniform, large-area showerhead reactors as shown by comparison with results of three-dimensional numerical simulations. The SiH_x densities remain very low because of their rapid diffusion and surface reactivity, contributing to film growth which is the desired scenario for efficient silane utilization. Significant SiH_x densities due to poor design of reactor and gas flow, on the other hand, would result in powder formation wasting silane. Conversely, hydrogen atoms are not deposited, but associate on the film surface and re-appear as molecular hydrogen in the plasma. Therefore, in the limit of extremely high silane depletion fraction (>99%), the silane density falls below the low SiH_x densities, but only the H radical can eventually reach significant concentrations in the hydrogen-dominated plasma.

11:40am **PS2+PV-MoM11 Plasma Uniformity Measurements in a Scalable, Multi-Electrode, VHF/UHF Plasma Source***, **D. O'Farrell**, A.R. Ellingboe, S. Linnane, C. Gaman*, Dublin City University, Ireland

The ability to deposit large area thin film amorphous silicon films using PECVD is of significant interest in a number of fields including photovoltaics and flat panel display. The desire to deposit larger area films faster has lead to a recent push towards the use of VHF/UHF frequencies which result in faster deposition rates but also result in significant film non-uniformities due to wavelength effects even over relatively small areas. Several methods have been employed in an attempt to overcome these non-uniformity issues but many barriers still exist when it comes to wide scale application. In this work a scalable, multi-electrode, VHF/UHF plasma source is described which aims to resolve these issues. Data is presented demonstrating plasma uniformity over the source for a series of powers, pressures and operating frequencies. Different operating regimes are discussed.

Thin Film
Room: A8 - Session TF1+PV-MoA

Chalcogenide Photovoltaics
Moderator: A. Rockett, University of Illinois, Urbana-Champaign

2:00pm **TF1+PV-MoA1 Growth and Structure of RF Sputter-Deposited Cadmium Sulfide (CdS) Thin Films**, ***R.S. Vemuri***, *D. Zubia, C. McClure, C.V. Ramana*, University of Texas at El Paso

Cadmium sulfide (CdS) is a group II–VI semiconductor, which finds many scientific and technological applications. CdS thin films are particuatlrly interesting for application in large area photovotaics in addition to field-effect transistors, visible spectral range photoconductors, optical filters and nonlinear integrated optical devices. However, growth and optimization of conditions to produce high-quality CdS layers is important for enhanced photovoltaic device performances. In the present work, ordered cubic structured CdS films for application in CdTe/CdS solar cells were produced using RF magnetron sputtering. Pure CdS target was employed for sputtering. Two sets of CdS films were deposited: (1) at varying powers, in the range of 70-130 W, at constant Ar pressure of 7 mTorr, and (2) at varying Ar pressures, in the range of 5-20 mTorr at a constant power of 100 W. A detailed structural characterization was made to understand the effect of processing conditions on the morphology evolution, grain size, and crystal structure of the CdS films. High-resolution scanning electron microscopy (HRSEM) measurements revealed the smooth surface morphology of the CdS layers both as a function of sputtering power and Ar-pressure. CdS films grown at 70-130 W were found to be nanocrystalline, exhibiting grain-size (L) dependence on the sputtering-power (W). L increased with W yielding the highest average L=145 nm at 105 W. Further increase in W resulted in decreasing L. Similarly, under varying Ar pressure, the highest L (~138 nm) values were found at 5 mTorr. X-ray diffraction (XRD) analysis indicated that the entire set of deposited CdS films exhibit highly oriented cubic structure. L values evaluated from XRD are in good agreement with the HRSEM results. The optical characteristics were evaluated and a functional relationship between growth conditions and band gap, useful to tailor the CdS films for desired solar-cell application, was found. The results obtained will be presented and discussed.

2:20pm **TF1+PV-MoA2 Characterization of Photovoltaic Thin Films Materials Using RF GD-OES and LA ICP-MS**, ***F. Li***, *S. Anderson,* Air Liquide - Balazs*, P. Hunault*, HORIBA Jobin Yvon

Photovoltaic thin film materials have been characterized by a number of traditional vacuum techniques; Auger, XPS, SIMS, and GD-MS to name only a few. Depth profiles of solar cell modules, contamination in the sputtering targets or surface stoichiometry of photovoltaic thin films are specific application examples which predicate the technique best suited for the data requirement. The evolution of thin films with new chemistries and the importance of surface modification for photovoltaic applications provide a continuing need for thin film analyses along with an avenue for new analytical tools.

In this paper we will discuss the application of two non-traditional surface and material analysis techniques for the photovoltaic solar industry, glow discharge optical emission spectroscopy (RF GD-OES) and laser ablation inductively coupled plasma mass spectrometry (LA ICP-MS). The RF GD-OES and LA ICP-MS techniques enable direct analysis and depth profiling of a variety of conductive and nonconductive materials and photovoltaic thin films such as SoGSi, CdTe, CIGS, and TCO. With each technique, the ability to simultaneously depth profile more than 40 elements is possible. RF GD-OES and LA ICP-MS are much faster and more cost effective for depth profiling than SIMS. When using the techniques as an elemental survey technique, each analysis is more sensitive and also much faster than Auger and XPS.

Additional specific advantages of RF GD-OES and LA ICP-MS will also be discussed. Using radio frequency (RF) plasma for analytical signal generation, these techniques do not have the surface equilibrium issues seen with other surface analytical techniques such as SIMS. The charging effect that can cause issues with electron and ion beam techniques is also avoided. Additionally, there are no artifacts in their sputtering processes, especially on the top surface. Therefore, the surface stoichiometry of some solar thin films before and after chemical treatment can be reliably characterized. This feature is extremely important for surface modification projects in an effort to produce far more efficient photovoltaic thin films. Finally both RF GD-OES and LA ICP-MS don't require any sample preparation unlike GD-MS, thin films and materials can be directly characterized in their natural states against NIST traceable standards.

2:40pm **TF1+PV-MoA3 Multi-technique Lateral and Vertical Surface Characterisation of Thin-film Photovoltaics**, ***A.J. Roberts***, Kratos Analytical Ltd, UK, *C.J. Moffitt,* Kratos Analytical Inc.*, J.W. Pankow*, National Renewable Energy Laboratory

Thin-film photovoltaic production is an important and fast growing field in energy technology. The most widely applied thin-film photovoltaic technology is based on the use of cadmium telluride / cadmium sulfide (CdTe/CdS) heterojunctions and although research in CdTe dates back to the 1950s the challenges associated with junction quality and electrical contacting have not been well addressed. Both vertical (depth) and lateral composition of thin film PV devices is of great importance for optimum performance.

The cadmium tin oxide (CTO)/zinc tin oxide (ZTO) bilayer structure is an alternative to traditional tin oxide front contacts and provides lower resistance and better light transmission. Modern multilayer stacks such as CdTe/CdS/ZTO/CTO/glass have lead to the best reported cell efficiencies of ~16.5% but disparate differences in efficiencies can be observed for devices made from films located within even a cm of each other and back contacted in identical fashion. This work presents the use of photoemission spectroscopies combined with Ar+ ion depth profiling to characterise a CdTe/CdS/ZTO/CTO/glass multilayer sample. X-ray photoelectron spectroscopy (XPS) depth profiling has been used to generate elemental and chemical information as a function of depth through the layer and interface regions using sputtering conditions chosen minimize surface roughening and knock on phenomena that can cause difficulties in discerning between true depth variations and sputter induced artifacts when analyses are done under traditional sputter conditions. In combination with XPS, ultraviolet photoemission spectroscopy (UPS) depth profiling has been used to measure the pseudo work-function of the layers and interface regions, allowing a pseudo work-function depth profile to be generated.

As well as vertical compositional charaterisation the lateral composition has been investigated for a different thin-film PV system comprising Cu:In:Ga:Se (CIGS)/Mo/glass. Changes across the surface are undesirable in the manufacturing process as small differences in Cu/(In+Ga) or Ga/(In+Ga) can compromise ultimate device efficiency. These compositional changes typically occur over centimeter scales necessitating mapping over >5x5 cm. The multi-technique approach to surface characterisation of these thin film photovoltaics has provided chemical, elemental, pseudo work-function as a function of depth and lateral compositional information from two different thin film photovoltaic systems.

3:00pm **TF1+PV-MoA4 XPS Band Offset Measurements of ZnO, CdTe, and CuSCN for Application in Nanostructured Photovoltaics**, ***T.C. Kaspar***, *T. Droubay, J.E. Jaffe, V. Shutthanandan, W. Jiang, S.A. Chambers, G.J. Exarhos*, Pacific Northwest National Laboratory

All photovoltaic devices require efficient electron-hole separation, transport, and collection. It is relatively straightforward to experimentally determine the charge transport properties of the individual component materials in a given cell design, allowing optimization. However, the charge transport across heterojunction interfaces between component materials is just as critical for overall cell performance. The electron or hole injection efficiency is determined by the band structure alignment at the interface; optimization of the interface for facile charge injection requires detailed knowledge of the band offsets, which cannot easily be determined by electrical transport measurements. We utilize high resolution x-ray photoelectron spectroscopy (XPS) to directly quantify the band offsets of heterojunctions relevant to photovoltaic cells. Nanostructured extremely thin absorber (ETA) photovoltaic devices have been proposed as an inexpensive alternative to current single-crystal device technology, although the devices reported thus far suffer from low conversion efficiency. Thus, materials relevant to ETA devices were chosen for study: n-ZnO as the electron transporter, solid-state p-CuSCN as the hole conductor, and CdTe as the photon absorber. High quality ZnO thin films were deposited by pulsed laser deposition (PLD) on F:SnO_2/glass substrates for XPS band offset measurements. The band offsets were determined as a function of ZnO conductivity, and strategies for improved electron conduction across the interface will be discussed. In addition, the materials properties of CuSCN were thoroughly characterized, and its electronic structure was compared to density functional theory (DFT) calculations. The calculations show an indirect bandgap of 2.7eV and highly anisotropic charge transport with the unusual prediction that hole mobility exceeds the electron mobility. Avenues to improve hole conduction through the introduction of defects in CuSCN were explored.

3:40pm **TF1+PV-MoA6 Effects of Cu Doping Level in ZnTe:Cu Back Contacts on Cu Diffusion and CdTe Solar Cell Performance**, ***J.N. Duenow***, *R.G. Dhere, S.E. Asher, W.K. Metzger, J. Li, T. Moriarty, T.A. Gessert*, National Renewable Energy Laboratory

CdTe photovoltaic (PV) cells require a low-resistance back contact for optimal device performance. Cu-doped ZnTe (ZnTe:Cu) has been implemented successfully as an ohmic back-contact interface layer to CdTe, enabling PV cells with efficiencies of 14%. ZnTe:Cu offers the additional advantage of being easily manufactured by vacuum processing, which enables highly controlled, reproducible films. Although CdTe devices have been made without Cu-containing contacts, devices with Cu contacts have generally exhibited higher performance. Controlled Cu diffusion from the back contact is known to be critical for optimal performance. Sufficient Cu is required for doping the CdTe absorber to provide a strong electric field in the junction region. Excessive Cu, however, can lead to poorer collection by narrowing the depletion region to the extent that few minority carriers are generated within a diffusion length of the depletion region. Cu may also adversely affect the junction by diffusing into the CdS window layer.

Previous studies of Cu diffusion from ZnTe:Cu back contacts have been performed at NREL using a fixed doping level of Cu in ZnTe, but altering Cu diffusion by changing the deposition temperature or film thickness. In this study, we instead deposit ZnTe:Cu films from targets containing a range of Cu amounts—from 0.45 to 5 wt.%—while holding the temperature and film thickness constant. Capacitance-voltage, red-light-biased quantum efficiency, and secondary-ion mass spectrometry depth-profile measurements will indicate the net acceptor concentration in the CdTe and the degree of Cu diffusion as a function of the Cu density in the back-contact interface layer. Minority-carrier lifetime measurements will be used to correlate the effects of Cu density to the carrier recombination rate.

4:00pm **TF1+PV-MoA7 Surface and Interface Properties ZnTe-based Solar Cell**, ***F. Fang***, *B.E. McCandless, R.L. Opila*, University of Delaware

In order to substantially reduce the capital costs of present crystalline silicon photovoltaics, alternative thin film solar cell (TFSC) devices are favored because of the inexpensive materials, simple material preparation, and low-cost large area fabrication. There is interest in growing polycrystalline thin films of II-VI direct band gap semiconductors, such as CdS/CdTe. TFSCs are well studied and currently being used for manufacture of commercial scale solar modules. Here, we are proposing a heterojunction system *n*-ZnSe/*p*-ZnTe as a wide band gap TFSC ($E_G > 2$ eV) for potential application in tandem cells. This provides an efficiency enhancement for future generation photovoltaics, provided the wide band gap cell efficiency can be increased. In addition, we are using Close Space Sublimation (CSS), which is a low-cost deposition method already demonstrated for high efficiency and commercial CdTe TFSC.

Our ZnSe/ZnTe TFSC is a heterojunction device with a high density of defect states at interfaces which can provide interface recombination centers; also the grain boundaries in polycrystalline semiconductor films act as shallow and deep defect levels within the bandgap and create different recombination mechanisms than radiative band-to-band recombination in ideal crystalline devices. As a result, minority carrier collection relies on the built-in electric field, and results in voltage-dependent collection of photo-generated current. Therefore, it is crucial to form a high quality diffused junction. Some earlier work reported a diffusion voltage of 1.70 eV for single crystal ZnSe/ZnTe structure, which suggests that open circuit voltage, $V_{OC} > 1$V is feasible. We have used Al-Kα X-ray photoelectron spectroscopy and Soft (Ultra-violet) X-ray photoelectron spectroscopy (Synchrotron Light Source) to investigate the surface chemistry and valence band structures of the as-deposited films, scanning electron microscopy (SEM) to investigate the surface and cross-section morphology, energy-dispersive X-ray spectroscopy (EDX) to verify the chemistry. Surface oxides on ZnSe have been identified and their effects on interface band offset are evaluated. A significant valence band maximum shift is also observed with UPS which indicates an increased maximum open circuit voltage of the junction. This result is consistent with our I-V testing. Better devices with $V_{OC} > 600$ mV and photocurrent $J_{SC} > 5$ mA/cm^2 were only obtained for films with ZnTe deposited immediately after ZnSe, i.e., no time for oxide formation. More detailed understanding of the chemistry and interfacial band structure are being investigated and used to guide a path to improved conversion efficiency.

4:20pm **TF1+PV-MoA8 Issues of Large-Scale Photovoltaic Energy Production from Thin-Film CdTe Devices**, ***T.A. Gessert***, National Renewable Energy Laboratory **INVITED**

It is now widely accepted that thin-film photovoltaic (PV) devices will be important contributors of new US electricity generation. The annual production of PV devices needed to meet conservative U.S. Department of Energy goals for 2050 represents ~100 square miles of active module area (20 GW), or ~200 times the total area of photovoltaic modules installed in the US by 2004. However, if the rate of growth observed in PV module production for the past eight years continues, 100 square miles of annual US PV production could be achieved as early as 2018. Further, the amount PV installed by 2036 could generate the entire 2004 US Total Energy Consumption (~100 Quadrillion BTU's, i.e., the combined energy consumed in the US from petroleum, coal, natural gas, nuclear, and all renewable sources). Regardless of what assumptions are made, PV represents a significant future market, especially for thin-film modules based on CdTe and related process technologies. This talk will discuss CdTe thin-film PV devices within the context of the major PV technologies in production today, and indicate areas where improved material and device understanding would be beneficial.

5:00pm **TF1+PV-MoA10 Novel Solar Cells based on a ZnGeAs$_2$ Absorber Layer**, ***T.J. Peshek***, National Renewable Energy Laboratory and Arizona State University, *T.J. Coutts, T.A. Gessert,* National Renewable Energy Laboratory, *Z.Z. Tang, L. Zhang, N. Newman, M. van Schilfgaarde*, Arizona State University

We present the latest results on the development of a novel thin film solar cell based upon the direct gap chalcopyrite semiconductor ZnGeAs$_2$. This material has long been viewed as a promising solar material for high efficiency multijunction cells due to it being lattice matched to GaAs and having a band gap of about 1.1 eV. In light of recent advances in single junction solar cells based on chalcopyrite materials such as CuInSe$_2$ we have fabricated the first, to our knowledge, single junction cell based on ZnGeAs$_2$. Initial tests show the devices to have low conversion efficiencies because the photogenerated currents are low. However, we find that the open-circuit voltage in our first tests is approximately 0.135 V. It is our hypothesis based on the J-V curves that the current sourced by the cell can be improved significantly at this point by reducing the series resistance of the device and minimizing any shunts that seem to be present in these devices. The cell is structured according to the superstrate configuration using RF sputtered CdS as the n-type buffer layer. The p-type ZnGeAs$_2$ absorber was deposited at about 600 K by pulsed laser deposition.

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Nanometer-scale Science and Technology
Room: A8 - Session NS1+PV-TuA

Organic Photovoltaics I
Moderator: P. Sharps, Emcore Corporation

2:00pm **NS1+PV-TuA1 Probing Polymer Photovoltaics: Imaging Photocurrents and Controlling Morphology in Organic Solar Cells**, ***D.S. Ginger***, University of Washington **INVITED**

Organic solar cells are a potential low-cost alternative to conventional inorganic photovoltaics. The most successful organic solar cells rely on nanoscale phase separation between different components to achieve high efficiencies. Understanding and controlling nanoscale film structure has thus become the central challenge that affects every aspect of the field, from the optimization of new low-bandgap polymers to early efforts to scale up manufacturing of polymer solar cells. Our group has pioneered several scanning-probe methods, including time-resolved electrostatic force microscopy (trEFM) and photoconductive atomic force microscopy (pcAFM), as tools to characterize active organic solar cells. We discuss applications of these tools to study several model polymer systems, including the local origin of the photocurrent in polyfluorene blends, the effect of annealing on the formation of hole transport, electron transport and photocurrent collection networks in the archetypal polythiophene (P3HT) fullerene (PCBM) system, and the role that mesoscopic PCBM crystallites play in polyfluorene-copolymer/PCBM cells during solvent-vapor annealing. These data show the power of scanning-probe methods in correlating morphology with performance, and underscore the need to model these devices as fully 3D networks, rather than as uniform 2D semiconductor slabs.

2:40pm **NS1+PV-TuA3 Nanoscale Confinement Induced 3-D Chain Alignment of Poly (3-hexylthiophene) for Organic Solar Cells**, ***M. Aryal***, *K. Trivedi, W. Hu*, University of Texas at Dallas

Organic semiconducting polymers are of wide interests for many applications in organic solar cells, field effect transistors, light emitting diodes, and biosensors. The optical and electrical properties of these polymers are anisotropic which largely depends on their nanoscale morphology, crystallinity and the direction of chain configuration. Furthermore, control over direction of chain orientation is essential as certain devices prefer chain alignment in certain directions as determined by device structures, e.g. vertical alignment for solar cells where vertical charge transport occurs, while for FETs, lateral orientation along the channel is preferred instead. Though the significant progress has been made by the development of varieties of techniques for control of nanoscale morphology, crystallinity and orientation of polymer chains for years, the perfect crystallization and preferred chain ordering in nanoscale regime still remains challenging. We report the fabrication of highly-ordered nanostructure arrays of nanopillars and nanogratings in poly (3-hexylthiophene) (P3HT) using nanoimprint lithography and show 3-D chain ordering by x-ray diffraction (XRD) analysis. We have proved for the first time that nanoscale confinement exerted by the mold can induce only one possible configuration of the chain network in the three dimensional P3HT nanostructures during thermal nanoimprint process. Such monodical 3-D chain configuration strongly depends on the geometry of the nanoconfinement. Interestingly the configuration is arranged in a favorable way for solar cell and FET applications, e.g. vertical chain alignment, and π-stacking along gratings.

In this report, uniform 80 nm thin films of reriorегular P3HT were prepared on a Si substrate. The nanograting of 200 nm height, 65 nm wide gratings at a period of 200 nm while hexagonal array of nanopillars of 150 nm high nanopillars with 80 nm diameter were fabricated using nanoimprint lithography. The P3HT nanostructures were characterized by SEM and crystallization and chain orientation were studied by both in-plane, out-of-plane and in-plane grazing incident XRD. The chain ordering of thin film, nanopillar and nanograting structures are proved to be entirely different. The conjugated polythiophene backbones which are horizontal to the substrate in the thin film are reordered into vertical direction in the imprinted structures of P3HT. The interaction of hexyl side chains with hydrophobic mold surface in turn results π-stacking along nanogratings. We will present XRD results analysis and expect to present solar cell device results using these imprinted P3HT nanostructures.

3:00pm **NS1+PV-TuA4 Porphyhrin-Gold Junctions in Molecular Optoelectronics**, ***S.U. Nanayakkara***, University of Pennsylvania, *P. Banerjee*, University of Maryland, *D. Conklin*, University of Pennsylvania, *T.-H. Park*, University of Michigan, *M.J. Therien*, Duke University, *D.A. Bonnell*, University of Pennsylvania

Photo-conductance in novel multi-chromophoric molecules with porphyrin centers has been measured. This class of molecules is fully conjugated optical absorption properties that induce hole mediated conductivity with delocalization lengths on the order of 8 nm. Conjugated linker groups that terminate with a thiolate functionality (on one or both sides of the molecule) enable facile, co-valent attachment to a gold surface. We have attached these multi-chromophoric molecules between surface-bound Au nanoparticles and have measured transport as a function of varying laser excitation wavelengths. Additionally, we have measured spatially varying, charge transport in individual molecules within a tunneling junction utilizing a laser-coupled ultra-high vacuum scanning tunneling microscope. The wavelength dependent conductance will be discussed within the context of the molecule-Au junction.

4:00pm **NS1+PV-TuA7 Torsional Defects in Conjugated Polymers: Modeling and Nanostructured Photovoltaic Materials**, ***S.B. Darling***, *M. Sternberg*, Argonne National Laboratory **INVITED**

Conjugated polymers represent a promising class of organic semiconductors with potential applications in a variety of molecular devices. Poly(3-alkylthiophene)s, in particular, are garnering interest due to their large charge carrier mobility and band gap in the visible region of the spectrum. Defects play a pivotal role in determining the performance of polymer electronics, and yet the function of specific types of defects is still largely unknown. Density functional theory calculations of alkyl-substituted oligothiophenes are used to isolate the effect of static inter-ring torsion defects on key parameters such as electronic coupling between rings and band gap. These polymers are often modeled with very short backbones and without their side chains. These results demonstrate the shortcomings of this approach for modeling torsional disorder and identify a minimal acceptable model.[1] Two experimental systems, one based on block copolymers and the other on a hybrid oxide nanotube-polymer system, with nanoscale morphology rationally designed to minimize torsional disorder will also be discussed. Results have potential implications both for the fundamental understanding of intramolecular charge transport and for improving processing in organic optoelectronic devices.

[1] Use of the Center for Nanoscale Materials was supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract #DE-AC02-06CH11357.

5:00pm **NS1+PV-TuA10 Locally Probing the Efficacy of Photoinduced Charge-Generation and Trap Clearing in Pentacene-Based Thin-Film Heterojunctions and Transistors using Electric Force Microscopy**, ***J. Luria***, Cornell University, *A. Gorodetsky, C. Nuckolls*, Columbia University, *J.A. Marohn*, Cornell University

Pentacene and its derivatives are leading candidates for many organic electronics applications including electron donors in organic photovoltaics. Charge trapping, which is associated with device degradation in both photovoltaics and transistors, remains poorly understood even in this comparatively well studied class of materials. Northrup and Chabinyc [1] have carried out ab initio studies showing that reactions of holes with hydrogenated and oxygenated pentacene is a plausible charge trapping mechanism. Jaquith et al. [2] demonstrated a dependence of trap formation rate on hole concentration in pentacene, which is consistent with traps forming by a defect-mediated chemical reaction, and showed that traps could be cleared by the application of light. Coffey and Ginger [3] have shown that the fastest charging rates under illumination in polymer/fullerene films do not occur at phase interfaces, as widely assumed. Charge generation at the donor-acceptor interface in organic heterojunctions also remains poorly understood.

To resolve such open questions, we have developed a general approach to illuminating samples (from above) in an electric force microscope. We will describe studies where variable-wavelength light is utilized to clear traps in polycrystalline pentacene transistors. We will also discuss investigations into image charge generation in bis(thienyl)-pentacene/PCBM bulk heterojunction thin films.

[1] J.E Northrup and M.L. Chabinyc, *Phys. Rev. B* **68**, 041202 (2003).

[2] M.J. Jaquith, E.M. Muller, and J.A. Marohn, *J. Phys. Chem. B* **111,** 7711 (2007).

[3] D.S. Ginger and D.C. Coffey, *Nat. Mater.* **5**, 735 (2006).

5:20pm **NS1+PV-TuA11 A New Look at Si Inversion-Layer Solar Cells, Meeting Ground for Inorganic, Molecular and Organic Electronics**, ***R. Har-Lavan***, *O. Yaffe, D. Cahen*, Weizmann Institute of Science, Israel

We suggest a near-ambient temperature, simple and potentially low-cost approach to fabricate semiconductor solar cells. To this end we use a monolayer of organic molecules that self-assembles onto n-Si, to passivate and buffer the Si surface. The direct binding of the molecules to the oxide-free Si surface also provides a strong interface dipole and effectively reduces the semiconductor's electron affinity by as much as 0.7 eV. A thin layer of a conducting polymer with a high work function, that is spin-coated on top of the molecular layer plays a threefold role:

the high work function induces inversion in the Si and leads to an n-p^+ homojunction in the Si;

with n~1.5 refractive index the polymer acts as an anti-reflective coating to the Si.

because it protects the molecular monolayer, subsequent metal deposition and encapsulation is now possible.

Good and stable interface passivation along with strong inversion allow minority carriers, generated by absorbed sun light, to move laterally within the inverted Si top layer and to be collected by a minimal area metal grid, deposited on the conducting polymer. For the same reason (lateral conductance) photo-current losses, due to polymer sheet resistance, are minimized. Not only are cells fabricated without high temperature steps, the use of small organic molecules appears to convey here a unique advantage over inorganic passivation or buffer layers. The approach, which includes no or minimal (for metal grid) high vacuum steps, should be applicable to other inorganic absorbers, amorphous materials and thin films to improve photovoltaic solar energy conversion.

5:40pm **NS1+PV-TuA12 Modification and Characterization of Transparent Conducting Oxides for Generation III Nanostructured Photovoltaics**, ***D. Placencia***, *N. Armstrong*, University of Arizona

Indium-Tin oxide (ITO), Indium-Zinc oxide (IZO), and Antimony-doped tin oxide (ATO) substrates were modified with ca. 3-5 nm gold nanoparticles to characterize their effect on the performance of Generation III organic photovoltaics (OPVs). This talk will focus on the presumed mechanism for their deposition, their impact on rates of electron transfer (solution), and OPV device performance parameters. ITO, IZO, and ATO thin films were deposited via magnetron sputtering and modified through a deposition-precipitation protocol. X-ray, UV photoelectron, and polarization modulated infrared reflection absorption spectrocopies were used to characterize the interfacial composition, work function changes, and the molecular nature of Au NP nucleation and growth. Planar heterojunction OPVs were created to evaluate the efficacy of oxide modification with metal nanoparticles, as an intermediate step towards the improvement of charge collection at the organic/oxide interface in organic solar cells.

Nanometer-scale Science and Technology
Room: L - Session NS-ThM

Characterization and Imaging at the Nanoscale
Moderator: C. Nakakura, Sandia National Laboratories

8:00am **NS-ThM1 Depth Resolved Luminescence from ZnO Nanowires**, ***R.A. Rosenberg***, *S. Vijayalakshmi, M. Abu Haija,* Argonne National Laboratory*, J. Zhou, J. Liu, S. Xu, Z.L. Wang*, Georgia Institute of Technology

Nanodevices based on wide bandgap semiconductors have great potential in applications running from photon detectors to gas sensors. Critical to their successful implementation is knowledge of the surface and interfacial properties. In the present work we have utilized the limited penetration depth of soft x-rays (550-1000 eV) to study the near surface properties of vertically aligned ZnO nanowires. For a grazing angle of 5 degrees the penetration depth of these x-rays varies between 11 and 65 nm. Thus by obtaining optical luminescence spectra as a function of energy it is possible to probe the near surface region with nm-scale resolution. We will present energy dependent optical luminescence data from ZnO nanowire samples with diameters of 350 nm, 390 nm and 720 nm. In each case the ratio of the oxygen vacancy luminescence to the near band edge luminescence intensity peaks at an energy corresponding to ~17 nm x-ray penetration. This shows that the nanowires of three different diameters have a near surface defect region with a width of ~20 nm, which agrees with the conclusions from previous photoluminescence and cathodoluminescence studies [1-3]. Applications of this technique to other systems will also be discussed.

This work was performed at the Advanced Photon Source and was supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences under Contract No. DE-AC02-06CH11357.

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[2] I. Shalish, H. Temkin, and V. Narayanamurti, Phys. Rev. B 69, 245401 (2004).

[3] J. D. Ye et al., App. Phys. Lett. 92, 131914 (2008).

8:20am **NS-ThM2 Scanning Chemical Microscopy of Nanoscale Roughness Formation in Photoresist Materials**, ***R. Ramos***, *I. Riisness, M. Gordon*, University of California Santa Barbara

Developing a molecular-level understanding of surface chemistry is of critical importance for advancements in the fields of surface science, materials research and catalysis. In particular, the ability to characterize, interrogate and image the chemical composition of surfaces at high spatial resolution would provide greater insight into surface reaction mechanisms and dynamics. For this purpose, optical spectroscopy, when combined with scanning probe microscopy, is a powerful tool for simultaneous chemical identification and imaging of surfaces at the nanoscale. Over the past few years, enhancement of optical fields through plasmonic coupling of light with metal nanostructures has been used for near-field vibrational spectroscopy (e.g., surface- and tip-enhanced Raman spectroscopy – SERS/TERS). However, these techniques have not seen widespread use for surface nanocharacterization because of poor quality field enhancers (i.e., reproducible tips) and difficulties in interpreting spectroscopic data.

In this work, we will show how careful design of the plasmonic properties of the tip and scanning configuration can turn TERS into a robust chemical analysis technique. Our experimental setup combines a tuning fork/cantilever-based scanning probe microscope with in-situ Raman and reflectance spectroscopy; the system also allows simultaneous mechanical and electrical surface interrogation at the nanoscale. In this talk, we will demonstrate that spatially correlating topography with chemical fingerprinting can provide insight into mechanisms of photoresist roughening. This issue is critical in the microelectronics industry as the size of device structures is reduced; specifically, roughness generated during the lithography and plasma etching steps in device fabrication is ultimately transferred into the active parts of the device, leading to lower performance. By combining near-field optical and chemical interrogation with traditional far-field vibrational spectroscopy and X-ray photoelectron spectroscopy, we will highlight the chemical processes involved in roughness formation in advanced photoresist polymers and investigate how they are affected by plasma exposure.

8:40am **NS-ThM3 In Situ Nanoscale Characterization of Gas Fluxes of Organic Membranes by Flux-Lateral Force Microscopy***,* ***L.S. Kocherlakota****, D.B. Knorr, R.M. Overney*, University of Washington

Characterization studies of polymeric membranes for enhancing the gas transport rates are highly significant in current separation technologies. However transport property analyses like gas permeability measurements are bulk scale methods with limited access to local transport properties in multiphase systems such as nanocomposites membranes. In this context our group has developed a flux-lateral force microscopy (F-LFM) technique[1] for the in situ nanoscale characterization of the membranes, by monitoring the gas fluxes through them on a nanoscale. This technique, which is based on atomic force microscopy (AFM) utilizes the lubricating effect and the mechanical property changes in the membrane to determine fluxes. It was demonstrated by this technique that lateral force *vs.* pressure curves offered a direct measure of local gas permeabilities. In this paper we present the nanoflux analysis in Poly(trimethyl silyl propyne) (PTMSP), a glassy polymer with highest gas permeability of all known synthetic polymeric systems as well as high organic vapor/permanent-gas selectivity. The local fluxes in PTMSP films measured by F-LFM are compared to global fluxes obtained from conventional integrated methods. The sensitivity of F-LFM technique is demonstrated by presenting the reverse selective transport rates of He and CO_2 in PTMSP membranes as detected by the technique. The paper will also address the impact of aging, and flux dependence on film thickness.

Reference:

[1] J.H. Wei, M. He, and R.M. Overney**,** *Direct measurement of Nanofluxes and Structural Relaxations of Perflourinated Ionomer Membranes by Scanning Probe Microscopy,* J.Membrane Sci. **279,** 608-14 (2006)

9:00am **NS-ThM4 Nanoscale Electrodes by Conducting Atomic Force Microscopy at Elevated Temperatures**, ***M. Louie***, California Institute of Technology, *A. Hightower,* Occidental College*, S. Haile*, California Institute of Technology

The combination of conducting atomic force microscopy (AFM) and electrical measurements (AC impedance spectroscopy and cyclic voltammetry) offers many advantages for measuring fuel cell electrode kinetics. The use of a conducting AFM probe as a nanoelectrode enables isolation and characterization of a single electrode-electrolyte interface without the need for a reference electrode. Furthermore, this technique permits studies of the spatial dependence of mechanistic phenomena while providing controllable electrode-electrolyte contact areas. The feasibility of using a nanoscale probe as a fuel cell electrode has been examined for the polymer electrolyte membrane system at room temperature (1-2). Higher temperature capabilities would make this technique useful for a wide variety of material systems, including low-to-intermediate temperature solid electrolytes.

Here, we demonstrate the viability of conducting AFM under controlled environments and at temperatures relevant to proton conducting solid acid compounds. Solid acid compounds have been demonstrated as viable proton conducting electrolytes for fuel cells (3-4), with peak power densities of ~ 400 mW/cm^2 at ~ 240 ºC (5). Such fuel cells provide several advantages over polymer membrane fuel cells, including improved kinetics due to higher operating temperatures, impermeability of the membrane to fuels, and elimination of the need for complex water management systems. However, activation overpotential losses, particularly at the cathode, limit the performance (6), and electrode kinetics are not yet well understood.

We select cesium hydrogen sulfate, $CsHSO_4$, as a representative solid acid electrolyte for the study of oxygen electroreduction. Experiments are performed with a platinum-coated probe in contact with $CsHSO_4$. The Pt-based counter electrode, which covers the entire opposing area of the electrolyte, is effectively reversible and contributes negligible overpotential to the measurements. We discuss the experimental challenges associated with high impedance systems and mitigation strategies to extract meaningful information. We also present impedance spectra and cyclic voltammograms for $Pt|CsHSO_4$.

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3. D. A. Boysen, T. Uda, C. R. I. Chisholm, S. M. Haile, *Science* **303**, 68-70 (2004)
4. S. M. Haile, D. A. Boysen, C. R. I. Chisholm, R. B. Merle, *Nature* **410**, 910-913 (2001)
5. T. Uda and S. M. Haile, *Electrochem Solid State Lett* **8**(5), A245-A246 (2005)

6. S. M. Haile, C. R. I. Chisholm, K. Sasaki, D. A. Boysen, T. Uda, *Faraday Discussions* **134**, 17-39 (2007)

9:20am **NS-ThM5 Unraveling Atomic Structures on CeO_2(111) by Dynamic Force Microscopy**, ***M. Reichling***, Universität Osnabrück, Germany **INVITED**

Cerium dioxide (ceria) is a material that is widely used for catalytic applications. It is, for instance, an essential part of the 3-way catalytic converter known from automotive technology and holds substantial promise in other diverse research areas like solid-fuel cell technology for the production of hydrogen. In this context, ceria acts as an oxygen buffer as well as promoting noble-metal catalytic activity. The capability for storing and releasing oxygen is believed to be the result of the rapid formation and elimination of oxygen vacancy defects. Therefore, defects at slightly and strongly reduced CeO_2, specifically on the thermodynamically most stable (111) surfaces are of great interest as they may be the key to understanding surface chemistry on ceria.

To reveal and identify surface and sub-surface defects on CeO_2(111), we apply dynamic scanning force microscopy (NC-AFM) providing highest resolution images of the surface structure and its irregularities. For the identification of defects, the detailed atomic structures of features found in experiments is related to predictions from DFT calculations on relevant surface defects. In this way, we are able to identify surface and sub-surface vacancies, surface hydroxide and Ce^{3+} ions. Furthermore, we demonstrate that water readily adsorbs at the surface at room temperature but may diffuse and cluster on terraces as well as step edges. Individual water molecules can also be laterally manipulated by the tip of the force microscope with atomic precision.

10:40am **NS-ThM9 High-Resolution Atomic Force Microscopy in Three Dimensions**, ***U.D. Schwarz***, *M.Z. Baykara, T.C. Schwendemann, B.J. Albers, N. Pilet, E.I. Altman*, Yale University

With the recent introduction of three-dimensional atomic force microscopy (3D-AFM), the recording of dense three-dimensional surface force and energy fields with atomic resolution have become possible for the first time [1]. The main obstacles for producing high-quality 3D force maps are long acquisition times that lead to data sets distorted by drift, and tip changes. Both problems are reduced but not eliminated by low-temperature operation.

As we will show, key for the successful realization of 3D-AFM is the application of novel data acquisition and analysis procedures. In particular, an image-by-image data acquisition scheme cuts measurement times by avoiding repeated recording of redundant information, while allowing post-acquisition drift correction. All steps are illustrated with measurements performed on highly oriented pyrolytic graphite in ultrahigh vacuum at a temperature of 6 K. The area covered spans several unit cells laterally and vertically from the attractive region to where no force could be measured. The resulting fine data mesh maps piconewton forces with 6.8 pm lateral and 2 pm vertical resolution. From this 3D data set, two-dimensional cuts along any plane can be plotted. Cuts in a plane parallel to the sample surface show atomic resolution, while cuts along the surface normal visualize how the attractive atomic force fields extend into vacuum. At the same time, maps of the tip-sample potential energy, the lateral tip-sample forces, as well as the energy dissipated during cantilever oscillation can be produced with identical resolution (pN resolution for forces, meV for energies, pm for x, y, and z). Room temperature operation might be possible due to the unique post-acquisition drift correction ability. Applications in the areas of chemical imaging, surface catalysis, nanotribology, thin film growth, and device fabrication are envisioned.

[1] B. J. Albers *et al.*, Nature Nanotechnology **4**, 307 (2009).

11:00am **NS-ThM10 Looking Deeper: Multifunctional Scanning Probe Microscopy**, *I. Riisness, R. Ramos, C. Carach,* ***M. Gordon***, University of California Santa Barbara

Scanning probe microscopy (SPM) has truly revolutionized the morphological and electrical characterization of surfaces at the nanoscale; however, it is still impossible to identify and image the chemical functionality of a surface at similar resolutions. For the latter, one desires a hybrid probe system which combines traditional SPM functionality with spatially-correlated spectroscopic (chemical) data at length scales <10 nm.

To this end, we will highlight multifunctional surface imaging of chemistry, morphology, and elastic/electrical properties for several material systems using our hybrid SPM instrument. In this system, a plasmonically-active metallic tip is used to locally enhance EM fields in the tip-surface gap, enabling near-field chemical imaging via Raman spectroscopy. In this talk, we will discuss instrument design, tip preparation/characterization, and initial imaging results on polythiophene-based photovoltaic films, phase-segregated diblock co-polymers, and adsorbates on metallic nanoparticles.

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