Deep Data in Materials Characterization CNMS Workshop Agenda

Tuesday, August 9th – Wednesday, August 10th

Organizers

Alex Belianinov

Abstract
Machine learning tools and accessible computing power are enabling scientists across various disciplines to take advantage of novel data processing workflows, to push the limit of quantifiably extractable information from scientific instrumentation. Notably, material scientists, in the fields of combinatorial synthesis, and characterization have begun to actively adapt these methods. This workshop will bring together experts from these diverse backgrounds to illustrate how supervised and unsupervised learning methods can be leveraged to significantly improve the rate of understanding and processing of materials. The challenges and opportunities offered by Deep Data in material science with data mining, visual analytics, and knowledge-discovery technologies, will also be discussed.

Day 1 – Tuesday, August 9th Building 8600 Room C-156

G-mode Imaging and Spectroscopy

9 AM
Opening Remarks and Welcome, *Sergei Kalinin*

9:30 AM
High-Throughput Experimental Methodologies for Investigation Stability and Oxidation Resistance of Metallic Alloys, *Jason Hattrick-Simpers*

10:30 AM
Complete Information Acquisition in SPM and Application to Ultrafast Imaging of Polarization Switching in Ferroelectrics, *Suhas Somnath*

11 AM
Fast acquisition of electromechanical and electrical characteristics of materials with voltage spectroscopies, *Rama K. Vasudevan*

11:30 AM
Bringing Kelvin probe force microscopy into the information age, *Liam Collins*

Lunch Demo
Band Excitation/G-mode SPM with BEAM
Eric Lingerfelt

Quantitative Atomic Image Processing

1:30 PM
Atom and Pattern Finding Using Multivariate Analysis, *Stephen Jesse*

2 PM
Atomic-scale analysis of images: insights from reciprocal and real-space techniques, *Rama K. Vasudevan*

3:30 PM
Identifying Local Structural States in Atomic Imaging by Computer Vision, *Nouamane Laanait*

4 PM
Electron Ptychographic Imaging in the STEM, *Andrew Lupini*

Day 2, – Wednesday, August 10th Building 8600 Room C-156

Chemical Imaging

9 AM
Multimodal Chemical Imaging, *Olga S. Ovchinnikova*

9:30 AM
Combined Scanning Probe Microscopy and Confocal Raman Spectroscopy for Functional Imaging of the Layered Materials, *Anton Ievlev*

10 AM
Imaging and Understanding Ultrafast Processes in Complex Materials, *Benjamin Doughty*

10:30 AM
Scanning Transmission Electron Microscopy & Electron Energy Loss Spectroscopy, *Albina Borisevich*

11 AM
Atom Probe Tomography for Nanoscience Applications, *Jonathan D. Poplawsky*

Lunch Demo
Band Excitation/G-mode SPM with BEAM
Eric Lingerfelt

1:30 PM
Chemical state evolution in ferroelectric films during tip-induced polarization and electroresistive switching: Secondary Ion Mass Spectrometry Study, *Anton Ievlev*

2:00 PM
Helium ion imaging and chemical analysis of soft materials, *Matt Burch*

2:30 PM
Nano-IR Atomic Force Microscopy, *Alex Belianinov*

User Meeting Poster Session

High-Throughput Experimental Methodologies for Investigation Stability and Oxidation Resistance of Metallic Alloys

Jonathan Kenneth Bunn[1,2], *Benjamin Ruiz-Yi*[1,2], *Travis Williams*[1,2], *Jason Hattrick-Simpers*[1,2]

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Two major goals of the Materials Genome Initiative (MGI), announced by President Obama in 2011, are to cut the time between discovery and commercialization of advanced materials in half, from 10 – 20 to 5 – 10 years, and to do so at lower cost. Thus far, the MGI has made significant progress in computational simulation, modeling, and prediction of materials properties. Going forward, prodigious amounts of experimental data will be required to inform and validate these computational models. High-throughput experimental (HTE) methodologies, which allow accelerated synthesis and testing of materials for optimized performance represent the key enabling counterpart to generating the high quality experimental data required to bring the MGI to fruition. Here, I will discuss our efforts in developing and applying novel *in situ* HTE techniques to explore complex coating materials exposed to high-temperature oxidative environments. Along the way, I will discuss how techniques to model plasma-matter interactions and isolate "a voice in a noisy room" can be leveraged to effectively create knowledge from thousands of experiments, ensuring every data point is used to create a comprehensive overview of material behavior and help guide future experiments.

Complete Information Acquisition in SPM and Application to Ultrafast Imaging of Polarization Switching in Ferroelectrics

Suhas Somnath[1,2] Alexei Belianinov[1,2] Sergei Kalinin[1,2] Stephen Jesse[1,2]

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SPM imaging can be represented as an information channel between the dynamic processes at the tip-surface junction and the observer. Current SPM techniques use heterodyne detection methods such as lock-in amplifiers which result in significant loss in vital information such as information from higher eigenmodes, mode-mixing, and other non-linear phenomena in the tip-surface interaction. We present a new technique called General-mode (G-mode) where we capture the complete broad-band response of the cantilever at sampling rates of 1-100 MHz. The availability of the complete cantilever response facilitates the application of various physical models as well as extraction of information that has been unavailable from standard SPM techniques using multivariate statistical methods. We apply G-mode imaging to intermittent contact mode imaging of polymer blend sample and show multiple strategies for extracting information from G-mode imaging data.

Polarization switching in ferroelectric and multiferroic materials underpins the next generation of electronic devices such as tunneling devices, field effect transistors, and race-track memories. The switching mechanisms in these materials are highly sensitive to the local defects and structural imperfections at the micro and nanometer scale, which have undesirable effects on ferroelectric domains. These considerations necessitated the development of Piezoresponse Force Microscopy (PFM) imaging and spectroscopy techniques to measure and manipulate local polarization states. However, the current state-of-art PFM spectroscopy techniques suffer from serious compromises in the measurement rate, measurement area, voltage and spatial resolutions since they require the combination of a slow (~ 1 sec) switching signal and a fast (~ 1 – 10 msec) measurement signal. Furthermore, these techniques only capture the narrow-band cantilever response. We report on a fundamentally new approach that combines the full cantilever response from G-mode with intelligent signal filtering techniques to directly measure material strain in response to the probing bias. Our technique enables precise spectroscopic imaging of the polarization switching phenomena 3,500 times faster than currently reported methods. The improved measurement speed enables dense 2D maps of material response with minimal drift in the tip position.

Fast acquisition of electromechanical and electrical characteristics of materials with voltage spectroscopies

Rama K. Vasudevan[1,2], S. Somnath[1,2], S. Jesse[1,2], P. Maksymovych[1,2] and S. V. Kalinin[1,2]

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A large number of spectroscopies have been applied to explore the electronic and electromechanical properties of materials with nanoscale resolution, through implementation on scanning probe microscopy platforms. These include, for example, switching spectroscopy piezoresponse force microscopy for elucidation of polarization switching properties in ferroelectric materials, and dI/dV acquisition with scanning tunneling microscopy for determining (electronic) local density of states. In general, the spectroscopic modes that are offered tend to be slow, largely due to the constraints imposed by use of lock-in detection systems as well as stepped waveforms, to increase the signal to noise ratio and reduce capacitive contributions to the signal.

In this talk, I will discuss two spectroscopies that have been developed recently at the CNMS, that reduce the acquisition time as well as greatly increase the spatial resolution, by at least two orders of magnitude. Firstly, the use of the general voltage spectroscopy (G-VS) mode allows for implementation of many different waveform types, that serve as an envelope for an excitation sinusoidal waveform. Acquisition of all the data from the photodetector through the experiment, combined with filtering, then allows recovery of the system response to each step in the voltage waveform. I present data from two types of waveforms, that are used to probe different aspects of electromechanical response in ferroelectrics. This includes (1) Use of triangular envelopes, to explore the piezoelectric response as a function of AC amplitude, giving insight into the nonlinear piezoelectric properties and therefore contributions to the field-induced strain from the motion of domain walls. I will also show (2) use of first-order reversal curve type envelopes to probe the history-dependent response in ferroelectric thin films. Both these methods offer at least two orders of magnitude greater speed than the existing state of the art, as well as increased spatial resolution and the ability to simultaneously capture the higher harmonics for further processing.

Finally, the acquisition of I-V curves in both atomic force microscopy and scanning tunneling microscopy is crucial for gathering insight into spatial variations in electronic behavior with atomic or near-atomic resolution. I will present our recent investigations into rapid acquisition of I-V curves by applying waveforms at tens to hundreds of Hz. Decomposition of the acquired datasets by principal component analysis allows noise filtering of the data, thus obviating the need for long lock-in times.

Bringing Kelvin probe and magnetic force microscopy into the information age

Liam Collins, [†,‡] *Alex Belianinov,* [†,‡] *Suhas Somnath,* [†,‡] *Nina Balke,* [†,‡]*Sergei V. Kalinin*[†,‡]*, and Stephen Jesse* [†,‡]

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Atomic force microscopy has advanced well beyond simply topographical imaging to simultaneously allow advanced functional imaging of materials magnetic, electrostatic, electrochemical properties amongst a myriad of other material properties. In classical SPM, additional channels of information were captured using heterodyne detection and/or closed-loop feedback regulation. Practically, these detection methodologies can limit the measurement in terms of channels of information available and the time resolution of the measurement (e.g. ~1-10 MHz photodetector stream is down sampled to a single readout per pixel). Despite the popularity of techniques such as Kelvin probe force microscopy (KPFM), the level of information available (i.e. CPD) is not sufficient for some systems such as electroactive materials, devices, or solid-liquid interfaces, involving nonlinear lossy dielectrics. In this presentation, the foundations are laid for a new era in functional imaging using SPM utilizing big data collection and analytics. We will show that by using big data approaches in SPM it is possible to emulate, and even surpass the level of information available through classical SPM approaches. In particular, General Acquisition mode (G-Mode) AFM will be introduced which involves sampling the data at sufficiently high sampling rates and later combined with physics based and information based analysis. G-Mode is shown to have several advantages for KPFM and MFM over its predecessors as it negates many of the drawbacks associated with heterodyne detection and closed- loop-bias feedback, as well as significantly simplifying the techniques by avoiding cumbersome instrumentation optimization steps (i.e. lock-in parameters, feedback gains, etc.). G-Mode KPFM/MFM is immediately implementable on all atomic force microscopy platforms, is shown to allow simultaneous capture of numerous channels of information simultaneously, as well as increased flexibility in terms of data exploration across frequency, time, space, and noise domains.

BEAM: A Computational Workflow System for Managing and Modeling Material Characterization Data in HPC Environments

E. J. Lingerfelt[1], A. Belianinov[1], E. Endeve[1], O. Ovchinikov[2], S. Somnath[1], J. M. Borreguero[1], N. Grodowitz[1], B. Park[1], R. K. Archibald[1], C. T. Symons[1], S. V. Kalinin[1], O. E. B. Messer[1], M. Shankar[1], and S. Jesse[1]

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Improvements in scientific instrumentation allow imaging at mesoscopic to atomic length scales, many spectroscopic modes, and now—with the rise of multimodal acquisition systems and the associated processing capability—the era of multidimensional, informationally dense data sets has arrived. Technical issues in these combinatorial scientific fields are exacerbated by computational challenges best summarized as a necessity for drastic improvement in the capability to transfer, store, and analyze large volumes of data. The Bellerophon Environment for Analysis of Materials (BEAM) platform provides material scientists the capability to directly leverage the integrated computational and analytical power of High Performance Computing (HPC) to perform scalable data analysis and simulation via an intuitive, cross-platform client user interface. This framework delivers authenticated, “push-button” execution of complex user workflows that deploy data analysis algorithms and computational simulations utilizing the converged compute-and-data infrastructure at Oak Ridge National Laboratory's (ORNL) Compute and Data Environment for Science (CADES) and HPC environments like Titan at the Oak Ridge Leadership Computing Facility (OLCF). In this work we address the underlying HPC needs for characterization in the material science community, elaborate how BEAM's design and infrastructure tackle those needs, and present a small sub-set of user cases where scientists utilized BEAM across a broad range of analytical techniques and analysis modes.

Atom and Pattern Finding Using Multivariate Analysis

Stephen Jesse[1,2]

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Capturing atomic-resolution images is only a first step in the process of revealing and understanding material behavior at the nanoscale. Gross descriptions of lattice structure can be gathered fairly easily from STEM or STM images. However, useful material functionalities often lie in the subtle deviations of atomic positions from the ideal lattice structure or in the variations in density or motion of vacancies and ions throughout the lattice in ways that large scale description fail to capture. Revealing such subtle variation requires the development of methods that reliably determine the exact position of every atom in an image in an automated fashion as well as the development of tools that convert atom position information into new insight of material properties. Presented here will be several straightforward and robust methods that rely on various image transforms and multivariate analysis approaches to identify and locate atoms and atomic structures (and more generally) patterns within an image. As these techniques are often computationally expensive, the implementation of atom-finding workflows in a high-performance computing environment will be described as well.

Atomic-scale analysis of images: insights from reciprocal and real-space techniques

Rama K. Vasudevan[1,2], L. Vleck[1,2], M. Ziatdinov[1,2], A. Belianinov[1,2], A. Tselev[1,2], A. P. Baddorf[1,2], P. Maksymovych[1,2] and S. V. Kalinin[1,2]

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With ever increasing ease of acquisition of large numbers of atomically resolved images from scanning transmission electron microscopy and scanning tunneling microscopy (STM), a gap presently exists between the image acquisition and subsequent analysis and correlation with relevant physical and chemical descriptors. Therefore, automatic image analysis is a required step as the data volumes increase, and manual efforts are no longer be feasible. In this talk, I will introduce methods through which atomic-scale images can be analyzed automatically, and then linked with Monte-Carlo simulations to provide insight into the physics of the system being studied.

The first task is to identify automatically the crystalline phases that are present in a given image. I will show our implementation of a sliding window Fast Fourier Transform technique, wherein a stack of FFT images are generated by moving a small window across the larger image being studied. Subsequent analysis by use of linear unmixing techniques, specifically a geometric endmember extraction algorithm termed N-FINDR [1] is shown to be well-suited to this particular problem and provides the spatial distribution and type of crystal phases present. The same methods can also be used to map co-existing electronic phases in correlated electron materials, such as $RuCl_3$.

Secondly, especially for STM data, much information is also contained in the relative atomic positions (ie., the distortions within unit cell) and intensities of the atoms (proportional to local density of states). With a test case of atomically resolved images of adatoms on mesas on $La_{5/8}Ca_{3/8}MnO_3$ thin films, use of a simple Monte-Carlo model simulating the random walk of adatoms on a sinusoidal potential landscape allows determination of relative differences in surface energies as well as barrier heights, which are critical for determination of growth mechanisms. Moreover, analysis of atom intensities in this system allows potential determination of in-plane segregation of the divalent cation, paving the road towards chemical identification in complex oxides at the atomic scale by STM.

References

[1] Winter, Michael E. "N-FINDR: an algorithm for fast autonomous spectral end-member determination in hyperspectral data." *SPIE's International Symposium on Optical Science, Engineering, and Instrumentation*. International Society for Optics and Photonics, 1999.

A Computer Vision Approach to Local Crystallography

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The availability of atomically resolved imaging modalities enables fundamentally new approaches in determining the local crystal structure of materials that do not rely on the implicit assumptions of periodicity and symmetry underlying the classical approach to crystallography. In this talk, I will present a computer vision-based approach that emphasizes a local description and extraction of structural states in atomically-resolved images, supplemented by a statistical classification of the identified structural states. In particular, this approach is rooted in computer vision techniques such as engineered feature detection/description schemes, and concepts such as scale-invariance. I will show that this approach, when applied to simulated and experimental scanning transmission electron microscopy images, can provide a local description and global classification of structural states present in a system without the use of prior information on its properties. The robustness of the presented methodology in the presence of common instrumental factors such as noise and weak contrast will be discussed, in conjunction with machine learning approaches to overcome these experimental limitations in the detection and classification of structural states.

Electron Ptychographic Imaging in the STEM

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A Scanning Transmission Electron Microscope (STEM) forms images by focusing a beam of high-energy electrons to a near atomic size prove, which is then scanned over a sample while the scattered intensity is detected as a function of position. The high-angle annular dark field (HAADF) scattering offers 'Z-contrast' images because the scattering to high angles depends on the atomic number, whereas bright field (BF) images are equivalent to conventional TEM images. However, one of the traditional limitations of electron microscopy is that although the phase and the amplitude of the transmitted electron beam both contain information about the sample, the detectors are only able to record the intensity. The solution to this predicament is to use a pixelated detector to record the scattering to every angle as a function of probe position. The resulting four dimensional (4D) data set consisting of a 2D scattering distribution or 'Ronchigram' for each probe position in a 2D array provides a wealth of information about the sample. This vast array of data can be used to measure aberrations, to image more efficiently, or to determine the phase change of the electron beam. New pixelated detectors both offer faster and more efficient ways to access this data, but pose a huge challenge in terms of the computational resources that may be required to analyze it.

Multimodal Chemical Imaging for Physical and Chemical Characterization

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The functionality of materials is largely determined by the mechanisms that take place at sub-micron length scales and at interfaces. In order to understand these complex material systems and further improve them, it is necessary to measure and map variations in properties and functionality at the relevant physical, chemical, and temporal length scales. The goal of multimodal imaging is to transcend the existing analytical capabilities for nanometer scale spatially resolved material characterization at interfaces through a unique merger of advanced scanning probe microscopy, mass spectrometry and optical spectroscopy, this merger is rooted in innovative data processing algorithms and techniques. In this talk I will discuss how to visualize material transformations at interfaces, to correlate these changes with chemical composition, and to distil key performance-centric material parameters using a multimodal chemical imaging. I will also discuss the benefits of a multimodal imaging system and demonstrate our results for a broad range of material system. I will also talk about future instrumentation developments for multimodal chemical imaging.

Combined Scanning Probe Microscopy and Confocal Raman Spectroscopy for Functional Imaging of the Layered Materials

Anton V. Ievlev[1,2], Michael A. Susner[3], Michael A. McGuire[3], Petro Maksymovych[1,2] and Sergei V. Kalinin[1,2]

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Comprehensive investigations of the nano-structured materials and devices are impossible without development of the modern investigative techniques, allowing noninvasive imaging of the processes defining materials functionality on the nanoscale. Scanning probe microscopy (SPM) is one of such paradigmatic tools. Since its development, about thirty years ago, it has given rise to numerous ancillary techniques from basic topography mapping to complex investigations of the ionic and electronic motion, as well as coupled electrochemical and electromechanical functional response in almost all possible environmental conditions. However, the capabilities of SPM are limited by the properties of the tip-surface junction, which introduces a number of shortcomings, including limited time resolution, reduced to null sensitivity to bulk response and elusive chemical and crystallographic information. Introduction of other, concomitant microscopic and spectroscopic techniques into the measurement setup can not only provide a solution to these shortcomings, by enhancing resolution, but also augment the overall information obtained, with infinite opportunities for comprehensive nanoscale studies of the coupling between different material properties (electrical, mechanical, optical, chemical, etc.).

Here we used approach combining SPM and confocal Raman spectroscopy for nanoscale functional study of copper indium thiophosphate ($Cu_{1-x}In_{1+x/3}P_2S_6$) layered ferroelectric. Despite significant attention to investigations of this material during last decade, nanoscale origin of its electronic properties remains poorly discovered.

Performed investigations allowed to study in details ferroelectric-paraelectric phase transition. The in-situ measurements by Piezoresponse force microscopy (PFM) and Raman spectroscopy revealed correlated changes in the ferroelectric domain structure and Raman spectra during laser heating. However, non-polar inclusions of $In_{4/3}P_2S_6$ hampered direct identification of the phase transformation. The problem was resolved using Bayesian linear unmixing and principal component analysis for the separation of the Raman spectra corresponding to different material phases. These results, along with the macroscopically measured Curie temperatures and finite element simulation of the temperature distribution, allowed us to calibrate the temperature in the irradiated region close to the tip.

Results of the current research are important for fundamental studies of the dielectric layered materials and development of novel SPM techniques for systematic studying of temperature dependent material functionalities in previously inaccessible temperature regimes.

Imaging and Understanding Ultrafast Processes in Complex Materials

Benjamin Doughty[1], Mary Jane Simpson[1], Bin Yang[2], Sanjib Das[2], Kai Xiao[2], Ying-Zhong Ma[1]

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Electronic and molecular level dynamics in complex materials take place on a wide range of time and length scales. In order to directly track these dynamical processes, nonlinear optical spectroscopies have been adapted to microscopic platforms to obtain joint spatio-temporal images of excited state relaxation dynamics. The resulting 'snap-shots' of electronic motions acquired with femtosecond transient absorption microscopy (TAM) describe the initial mechanistic steps underlying many technologically important fields such as light harvesting and emitting applications, chemical sensors, and photocatalysis. This powerful technique, however, generates complex multi-dimensional data sets that lead to challenges in visualization, analysis, and understanding of the underlying processes. Similarly, spatially co-registered optical modalities naturally included in our experimental design yield complementary information on electronic excitation trapping at defects, morphology and structure. The question then becomes: How does one look at these orthogonal measurements to learn about the sample of interest? This talk will discuss our recent work and approaches to simplify the ultrafast optical imaging data and spatially correlate these dynamics with other materials properties in order to distill essential physical insight into the function of complex materials.

Atom Probe Tomography for Nanoscience Applications

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Atom probe tomography (APT) is a microscopy technique capable of sub-nm resolution and 10 ppm compositional sensitivity, which is currently being used to study metallic, insulating, and semi-conducting materials. During an APT experiment, a needle shaped specimen with an approximately 50 nm diameter apex is positioned in front of an aperture with a standing voltage between the specimen and aperture. Either voltage pulses or laser pulses are used to induce field evaporation of single ions from the specimen, which are accelerated and projected onto a 2D position sensitive detector. The ions can be identified using time-of-flight mass spectrometry. After the experiment, a computer algorithm is implemented to reconstruct the material of interest ion-by-ion with sub-nm resolution in 3 dimensions. A brief overview of the operation, capabilities, and limitations of APT will be discussed. Also, a few example applications involving the identification of elemental segregation within materials related to energy science will be shown.

Chemical state evolution in ferroelectric films during tip-induced polarization and electroresistive switching: Secondary Ion Mass Spectrometry Study

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In the vast majority of experimental and theoretical work, ferroelectric switching is analyzed with the implicit assumption of unchanged stoichiometry of chemical elements and the driving force given by the volume integral of polarization-electric field product. However, it is well recognized that even bulk polarization is unstable unless it is screened at the surfaces, by either metallic electrodes, band bending, or surface ionic charges. By the date all explorations have been done by either interpretation of secondary phenomena (e.g. electric potential change or domain structure evolution) or analyzing data of concomitant spectroscopic techniques (e.g. Raman scattering, X-ray scattering). At same time, Secondary Ion Mass Spectrometry (SIMS) provides capabilities for direct spatially resolved mapping of chemical composition as a function of depth, offering a natural pathway to explore chemical changes on ferroelectric surface and bulk induced by locally applied SPM tip bias.

Here we used SIMS to study surface and bulk modifications in chemical composition of ferroelectric bismuth ferrite thin film induced by the local electric field of the Scanning Probe Microscope (SPM) tip. Reversible ferroelectric and irreversible electro-resistive switching have been considered and demonstrated changes in the surface and bulk chemistry. This confirmed significant role of the surface chemistry on the process of ferroelectric polarization reversal. Furthermore, presence of the ions (e.g. Cl^-) that are not anticipated based on chemistry of the system has been revealed. These ions were concentrated on the surface in the pristine sample and could be locally introduced deeply into the film electric field.

Explored phenomena are important from both practical and fundamental points of view. It potentially enables new applications of tip-mediated electrochemical reactions and local material modification and allows systematic study of the chemical processes following ferroelectric switching.

Helium ion imaging and chemical analysis of soft materials

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Helium ion imaging has been shown to be one of the greatest advancements in the imaging of soft materials in decades. This is due to two main advantages it has over traditional scanning electron imaging. The first is that, due to the size of the He-ion, the interaction with the sample is confined almost completely to the surface of the sample regardless of the accelerating voltage. This means that we can image the topology of the sample in great detail and observe very sensitive surface variance across the sample. The second advantage is that because we are bombarding the surface of the sample with a positive ion we can compensate for any positive charging of the sample by flooding the surface with negatively charged electrons. This allows for very precise control of charging of the sample and can be used to negate charging artifacts during imaging. In this talk, several examples of imaging and characterization of soft materials will be demonstrated with helium ion microscopy.

Further, a recently developed technique, which combine the imaging capabilities of the helium ion microscope and the chemical sensitivity of secondary ion mass spectrometry will be shown.

Nano-IR Atomic Force Microscopy

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AFM-IR combines the precise chemical identification of infrared spectroscopy with atomic force microscopy (AFM) to chemically identify sample components with sub 100 nm lateral resolution beating the diffraction limit by up to 100x. The operating principle behind the AFM-IR is in illuminating a sample with pulses of infrared radiation and using the tip of an AFM to detect the absorbed radiation with nanoscale spatial resolution. The nanoIR2, from Anasys Instruments, is expected to arrive to CNMS in the fall of 2016 and is the second generation of their AFM based IR spectroscopy platform. This multifunctional platform is equipped with a full-featured AFM and nanoscale thermal & mechanical analysis in addition to IR spectroscopy. In this talk, a range of applications will be presented where the combinatorial power of AFM and IR is used to study various materials and obtain well spatially correlated physical and chemical data.