Midwest Microscopy and Microanalysis Society (M^3S) Spring meeting 2025

Program Schedule

8:30 – 9:00 **Registration:** Continental Breakfast and Coffee

9:00 – 9:05 **Welcome and Opening Remarks**

9:05 – 9:50 **Dr. Akshay Murthy**, SQMS Center Interim Deputy Director, Materials Focus Area Lead, Associate Scientist, Fermi Lab

Title: Electron Microscopy: A Critical Analytical Tool for Advancing the Performance of Superconducting Qubits
Abstract: "Advances in our understanding of materials have played a crucial role in driving recent increases in the performance of superconducting qubits. This includes the development of new schemes to passivate exposed surfaces and post-fabrication treatments to tune device parameters to the desired values systematically. Nonetheless, continued performance advancements and reproducibility across arrays of qubits are needed to achieve fault-tolerant platforms for large-scale deployment. Achieving these goals requires dedicated studies aimed at establishing robust structure-property relationships that will enable researchers to target and eliminate defects strategically. As part of the Superconducting Materials and Systems (SQMS) center, we have extensively employed scanning/transmission electron microscopy in conjunction with device measurements and have found S/TEM to be an indispensable tool in elucidating such relationships.

In this talk, I will first discuss results from a comprehensive and coordinated blind study where qubit chips of known performance were interrogated with unique non-destructive and destructive characterization techniques to pinpoint the underlying materials-level sources of device-to-device performance variation. Our electron microscopy findings suggest a correlation between specific nanoscale structural features and overall performance across different devices and these observations provide us with a pathway to reduce performance variations across neighboring devices. I will then discuss the use of electron microscopy to examine the surface morphology and chemical homogeneity of amorphous oxides at the surface of niobium and tantalum qubit devices. Through this comparative study, we gain insight into the types of defective structures prevalent in these oxides that must be eliminated in future devices."

9:50-10:15 **Kayna Lee Mendoza Trujillo,** Northwestern / Argonne

Title: Quantitative Phase Retrieval and Characterization of Magnetic Nanostructures Using Lorentz (Scanning) Transmission Electron Microscopy

Abstract: Magnetic materials phase reconstruction using Lorentz transmission electron microscopy (LTEM) measurements have traditionally been achieved using longstanding methods such as off-axis holography (OAH) fast-Fourier transform (FFT) technique and the transport-of-intensity equation (TIE). Recent developments of advanced algorithms such as reverse-mode automatic differentiation (RMAD) and the extended electron ptychography iterative engine (ePIE) enable phase reconstruction of micro-to-nano- scale magnetic materials with greater efficacy and resolution. This work evaluates phase retrieval using TIE, RMAD, and ePIE in simulations of Permalloy ($Ni_{80}Fe_{20}$) nanoscale islands, or nanomagnets. Extending beyond simulations, we demonstrate total phase retrieval and image reconstructions of a NiFe nanowire using OAH and RMAD in LTEM and ePIE in Ltz-4D-STEM experiments and determine the saturation magnetization through corroborations with micromagnetic modeling. Finally, we demonstrate the efficacy of these methods in retrieving the total phase and highlight its use in characterizing and analyzing the proximity effect of the magnetic nanostructures.

10:15 – 10:40 **NICHOLAS LINCOLN HAGOPIAN**, UW-Madison

Title: STEM Characterization of Two-Dimensional Material Surfaces and Interfaces

Abstract: Surfaces and interfaces govern many material and device properties. This talk will discuss two examples: graphene-enabled epitaxy of a Heusler alloy, GdAuGe, and preparing clean surfaces on transition-metal dichalcogenides for STEM experiments. Graphene coating of either Ge or SiC substrates enables epitaxial growth of GdAuGe thin films on a low energy surface. When exfoliated and subjected to strain gradients through rippling, flexomagnetism in the GdAuGe membrane induces ferro/ferrimagnetic ordering from an initially antiferromagnetic film. Factors such as the substrate material and graphene stack thickness have significant ramifications for epitaxial growth. Cross sectional STEM imaging in different crystal orientations reveals variations in epitaxial orientation and interface structure which may point to differences in the role of graphene in the initial stages of growth.

Preparing high quality monolayers of 2D materials for plan-view STEM characterization is an ongoing challenge. WS_2 monolayers contaminated with polymers and adhesives by common exfoliation and transfer procedures can be reproducibly and thoroughly cleaned by combining several cleaning methods relying on different mechanisms. In addition to creating clean surfaces, indirect air plasma exposure creates a self-terminating, monolayer WO_x sheet which can be reduced under the electron beam to yield W-nanoparticles which can be arbitrarily patterned with features sizes below 2 nm and pitches below ~4nm.

10:40 – 11:00 **break & vendor**

11:00 – 11:25 **Professor Rosa Diaz Rivas, Purdue University**

Title: Atomic-Scale Analysis of Heterogeneous Interfaces: Developing Metrics for Quantum Device Engineering

Abstract: Understanding and engineering superconductor-semiconductor and quantum well interfaces are crucial for optimizing the performance of topological quantum computation platforms. Atomic-scale disorder and strain at these interfaces can significantly impact electronic

properties, including carrier mobility [1] and superconducting behavior [2]. High-resolution scanning transmission electron microscopy (HRSTEM) has become an indispensable tool for characterizing these interfacial phenomena due to its ability to provide Z-contrast imaging, while operating at low electron doses and short dwell times to minimize material damage. This capability is particularly beneficial for analyzing heterogeneous interfaces where compositional and structural complexities are prevalent.

In this study, we utilize HRSTEM, advanced image processing using Python libraries, and in some cases Geometrical Phase Analysis (GPA) to investigate structural properties in key systems:

(1) Topological superconductors can be engineering by interfacing a thin superconductor layer with a semiconductor heterostructure. Atomic-scale structural variations and strain distributions at the interfaces between the superconductor layer and the semiconductor layer are analyzed. The textured nature of the metallic superconductor induces distortions at the superconductor-semiconductor interface, around its grain boundaries, leading to localized strain fields.

(2) Semiconductor heterostructure interfaces were studied to assess interface roughness and compositional variations. By leveraging HRSTEM images, advanced image processing using Python libraries and mathematical models, we established metrics for interface quality that could be correlated to electron mobility of 2DEG system in quantum wells.

(3) Metal ohmic contacts were analyzed to investigate chemical composition variations at the metal-semiconductor interface. The study focused on identifying the predominant alloy component responsible for achieving low-resistance ohmic behavior. HRSTEM together with energy-dispersive X-ray spectroscopy (EDX) were employed to characterize interfacial composition and assess its correlation with electrical performance.

The broader implications of this work extend beyond quantum computing and could impact a wide range of electronic and optoelectronic devices that rely on heterogeneous integration. By developing a universal framework for interface characterization, this study establishes a foundation for improving the performance and reliability of hybrid quantum computation devices. The ability to systematically quantify interface quality will not only facilitate the rational design of next-generation qubit architecture but also contribute to the advancement of material platforms for other quantum information technologies such quantum sensors and quantum emitters.

11:25 – 11:50 **Peter G. Lim**, Northwestern University

Title: Leveraging Multimodal Electron Microscopy to Understand and Address Performance-Limiting Materials Properties in Superconducting Qubits

Abstract: Despite rapid advances toward scalable, fault-tolerant quantum computing, our understanding of how materials properties contribute to qubit performance degradation remains limited. Precisely characterizing the structural and chemical disorder in the materials that comprise qubit devices is critical for uncovering these performance-limiting mechanisms and pushing quantum computing capabilities forward. Electron microscopy is an indispensable tool in this endeavor.

In this talk, I will detail how we leverage the unique multimodal capabilities of electron microscopy to investigate the materials properties of superconducting quantum devices. By employing both scanning

electron microscopy (SEM) and transmission electron microscopy (TEM), we examine macroscopic and atomic-scale features that influence performance. Specifically, this approach allows us to analyze surface and interface morphologies, grain structures, the short- and mid-range order of amorphous interfaces, as well as electrical and chemical variations in lossy dielectric elements, among other characteristics. This comprehensive analysis enhances our understanding of the structure-performance relationship in quantum devices and informs strategies to mitigate defects and disorder.

11:50 – 12:10 **M3S Business Meeting**

12:10 – 13:30 **Lunch & Visit with Vendors**

13:30 – 14:15 **Dr. Yanqi (Grace) Luo,** Argonne National Laboratory

Title: Shining X-ray Light on the Complex Chemistry of Next-Generation Perovskite Solar Cells

Abstract: High-brilliance synchrotron light sources, coupled with rapidly advancing characterization techniques, have revolutionized our ability to investigate energy materials at the nanoscale. By integrating spatial, temporal, and chemical measurements across multiple modalities, researchers can probe deeper into the structure and performance of functional materials—ranging from photovoltaics to fuel cells and batteries—revealing the mechanisms that govern their behavior.

In this talk, I will highlight how synchrotron-based X-ray microscopy can be harnessed to study an emerging class of materials known as halide perovskites, which hold significant promise for next-generation solar cells. Through a series of pioneering studies, I will demonstrate how these techniques enable unparalleled resolution and sensitivity in examining the chemical and optoelectronic properties of perovskites. I will also discuss the recent development of new in situ microscopic characterization modalities, which couple light microscopy, that will benefit both the materials research community and synchrotron facilities. By shining new light on perovskite chemistry and stability, these advances pave the way toward more efficient and stable perovskite photovoltaics.

14:15 – 14:40 **Dr. Chen-Jui (Ben) Huang**, University of Chicago

Title: Quantitative Non-destructive Morphological Characterization of All-Solid-State Batteries

Abstract: Sulfide-based solid-state electrolytes (SSEs) demonstrated the most promising all-solid-state batteries (ASSBs) chemistry with their room-temperature Li+ ionic conductivity comparable to or exceeding that of conventional liquid electrolytes (~10 mS cm-1). Our previous works demonstrated the scalability of sulfide-based ASSBs at the pouch cell level with cell capacity reaching 100 mAh under significantly low stacking pressure of 5 MPa1, 2, showing promise to accelerate the development and commercialization of ASSBs. Given that, Characterizing ASSBs during and after operation is critical for their further development. However, studying the degradation behavior of ASSBs at the pouch-type cell level could pose different challenges and require advanced characterization techniques.

Previous works using destructive focus-ion beam-scanning electron microscope (FIB-SEM) can only visualize several tens of micrometers with long imaging times for 3D reconstruction up to hours. Thus, techniques with larger field of view (FOV) and shorter imaging time are inevitably needed to have a better statistical analysis. This study leverages the non-destructive nature of synchrotron X-ray microcomputed tomography (sXCT) to visualize the morphology and microstructure of each component within an ASSB pouch cell. Leveraging the large FOV of X-ray micro-CT, up to several millimeters and shorter imaging time, we are able to perform a quantitative analysis of the extracted microstructural information, including porosity, loss of contact, and tortuosity. These findings will provide a broader understanding of the structural evolution in ASSB pouch cells, bridging the gap between lab-level research and application-level production.

14:40 – 15:05 **Dr. Tobias Gokus**, Attocube systems (DMS)

Title: Cryogenic Scattering Near-field Optical Microscopy for Studying Optical Properties with 20nm Spatial Resolution at Temperatures < 10K

Abstract: Near-field microscopy and spectroscopy has matured as a key technology for modern optics, combining the resolving power of atomic force (AFM) based measurements with the analytical capabilities of optical microscopy and spectroscopy.

Scattering-type near-field microscopy (s-SNOM) has already proven itself vital for probing local optical material properties of modern nanomaterials by enabling applications such as chemical identification [1], free-carrier profiling [2], or the direct mapping and measurement of the dispersion relation of propagating plasmon [3,4], phonon [5], and exciton polaritons [6] in layered materials. Transferring these near-field measurement capabilities to cryogenic temperatures opens up new avenues for nanoscale resolved optical characterization of novel materials and their fundamental properties. Until recently, cryogenic s-SNOM measurements were only available to a few experts utilizing home-built microscopes [7].

By integrating a scattering-type near-field optical microscope into an ultra-stable, vibrationally damped and automated closed-cycle cryostat we developed the first commercial cryogenic s-SNOM microscope. It uniquely supports near-field amplitude and phase resolved imaging and spectroscopy in the visible to THZ spectral range and operates in a variable temperature range between < 10K to room temperature. We will demonstrate infrared and visible near-field imaging with deep subwavelength spatial resolution, visualizing phonon polariton modes in hBN and exciton polariton waveguide modes in MoS_2 at temperatures < 10K.

Furthermore, we will present recent research results on spatially resolved measurements of the spectral response of a 2D electron gas and its impact on the surface phonon polariton of $LaAlO_3/SrTiO_3$ heterostructure systems by utilizing s-SNOM based mid-infrared spectroscopy at variable temperatures [8,9].

15:05 – 15:10 **Closing Remarks**

*Optional tour of NU*ANCE*’s facilities in the Technological Institute, AB-Wing