WEDNESDAY **AGENDA**

3rd International Cryo-EM (ICE) Workshop for Advanced Materials | June 24, 2026

8:00 am	**BADGING |** (Building 101, Science and User Support Center)
9:00 am – 9:20 am	**WELCOME REMARKS | Robert Konik (Director of CMPMS, BNL) and Judith Yang (CFN, BNL)**
9:20 am – 10:00 am	**FEATURED OPENING TALK | Mingzhao Liu (C2QA, BNL)** Title: Developing and understanding new material platforms for superconducting qubit scaling up
10:00 am – 10:15 am	**COFFEE BREAK | (Provided)**
10:15 am SESSION START	**SESSION 1 | Advances in Cryo-EM instrumentation, Chair, Yimei Zhu (CMPMS)**
10:15 am – 10:50 am	**Peter Denes (LBNL)** Title: Towards an Ultra-Stable, Ultra-Cold Transmission Electron Microscope
10:50 am – 11:25 am	**Cameron Johnson (Bruker AXS)** Title: Stable Liquid-Helium-Cooled STEM with Double-Tilting
11:25 am – 12:00 pm	**Naoya Shibata (Univ of Tokyo)** Title: Recent Progress in the Development of Magnetic-Field-Free Cryogenic Atomic-Resolution Electron Microscope
12:00 pm – 1:00 pm	**LUNCH & INDUSTRY SPOTLIGHT PRESENTATION | (ThermoFischer Scientific)**
1:00 pm SESSION START	**SESSION 2 | Cryo-EM for Quantum Materials Imaging, Chair MG Han (CMPMS)**
1:00 pm – 1:35 pm	**David Muller (Cornell Univ)** Title: Three-dimensional, high-resolution and dose-efficient imaging with cryogenic electron ptychography
1:35 pm – 2:10 pm	**Menglin Zhu (MIT)** Title: Dynamic Antiferroelectric Transformations Revealed by In Situ Microscopy
2:10 pm – 2:45 pm	**Joachim Dahl Thomsen (Forschungszentrum Jülich)** Title: Cryo-TEM of quantum materials and electrically contacted devices
2:45 pm – 3:00 pm	**COFFEE BREAK | (Provided)**
3:00 pm SESSION START	**SESSION 3 | Cryo-EM for Energy/Beam-Sensitive Materials, Chair John Watt (LANL)**
3:00 pm – 3:35 pm	**Michael Zachman (ORNL)** Title: Enabling Multi-scale Cryo-EM of Sensitive and Low-Contrast Interfacial Materials in Electrochemical Devices
3:35 pm – 4:10 pm	**Renae Gannon (NLR)** Title: Advancing Multiscale Cryo-EM Workflows for Functional Energy Materials
4:10 pm – 4:45 pm	**Jianguo Wen (ANL)** Title: Direct Cryo-EM Observation of Non-Equilibrium Ice Phase Transformations

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THURSDAY **AGENDA**

3rd International Cryo-EM (ICE) Workshop for Advanced Materials | June 25, 2026

9:00 am SESSION START	**SESSION 4 | Cryo-STEM/EELS for Quantum Materials I, Chair Stephanie Ribet (LBNL)**
9:00 am – 9:35 am	Miaofang Chi (ORNL) Title: Cryogenic STEM and EELS: New Opportunities for 2D Materials Research
9:35 am – 10:10 am	Shelly Conroy (Imperial College London) Title: Cold Correlations: Microscopy from Liquid Nitrogen to Liquid Helium
10:10 am – 10:45 am	Robert Klie (Univ of Illinois, Chicago) Title: Analyzing Functional Materials using Aberration-Corrected Cryo-STEM
10:45 am – 11:00 am	**COFFEE BREAK** | (Provided)
11:00 am SESSION START	**SESSION 5 | Cryo-STEM/EELS for Quantum Materials II, Chair Michael Zachman (ORNL)**
11:00 am – 11:35 am	Ismail El Baggari (Univ of British Columbia) Title: High resolution electron microscopy with liquid helium: status, updates, and applications
11:35 am – 12:10 pm	Maureen Joel Lagos Paredes (McMaster Univ) Title: Electron spectroscopy studies of collective excitations in quantum materials
12:10 pm – 1:10 pm	**LUNCH & INDUSTRY SPOTLIGHT PRESENTATION** | (TESCAN)
1:10 pm SESSION START	**SESSION 6 | Cryo-EM for Soft Materials, Chair Stephen House (SNL)**
1:10 pm – 1:45 pm	Yue Yu (Chan Zuckerberg Institute for Advanced Biological Imaging) Title: Laser phase plate for phase-contrast imaging
1:45 pm – 2:20 pm	Stephanie Ribet (LBNL) Title: At the intersection of cryo- and computational electron microscopy: characterizing soft materials with 4D-STEM
2:25 pm – 2:35 pm	**GROUP PHOTO**
2:40 pm – 3:30 pm PANEL	**PANEL DISCUSSION | (Junjie Li (PRM, APS), Zach Zachary (Nat Commun, Springer Nature), Yimei Zhu (BNL), …)**
3:35 pm – 5:00 pm	**POSTER SESSION** | (Coffee Provided)
5:15 pm	**DINNER SHUTTLE DEPARTURE** | (from Building 101, Science and User Support Center)
5:45 pm – 8:00 pm	**WORKSHOP DINNER** | (Provided)

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FRIDAY
AGENDA

3rd International Cryo-EM (ICE) Workshop for Advanced Materials | June 26, 2026

8:30 am SESSION START	**SESSION 7 | In situ TEM, Chair, Judy Yang (CFN, BNL)**
8:30 am – 9:05 am	Frances M. Ross (MIT) Title: Opportunities for cryo-electron microscopy in beam-induced defect engineering
9:05 am – 9:40 am	Haimei Zhang (LBNL) Title: Revealing Atomic Dynamics at Solid–Liquid Interfaces through Liquid-Phase Electron Microscopy and Cryo-EM
9:40 am – 10:15 am	Meng Li (BNL) Title: Atomic-Resolution insights into early-stage Oxidation using in situ ETEM
10:15 am – 10:30 am	**COFFEE BREAK |** (Provided)
10:30 am SESSION START	**SESSION 8 | Cryo-EELS, Chair Joy Chao (ORNL)**
10:30 am – 11:05 am	Steffi Woo (ORNL) Title: Localized Excitonic Response in van der Waals Semiconductors below 100K
11:05 am – 11:40 am	David McComb* (OSU) Title: Cryogenic imaging and spectroscopy of solid-liquid interfaces
11:40 am – 11:55 am	**CLOSING REMARKS**
12:00 pm TOUR START	**AFTERNOON FACILITY TOUR |** (Optional), Refreshment will be provided.

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BOOK OF ABSTRACTS

3rd International Cryo-EM (ICE) Workshop for Advanced Materials

BROOKHAVEN NATIONAL LABORATORY
Condensed Matter Physics & Materials Science
and The Center for Functional Nanomaterials

June 24–26, 2026

Managed by Brookhaven Science Associates
on behalf of the U.S. Department of Energy

U.S. DEPARTMENT of ENERGY

INVITED **PRESENTATIONS**

1 **Mingzhao Liu**
2 **David Muller**
3 **Miaofang Chi**
4 **Haimei Zhang**
5 **Meng Li**
6 **Renae Gannon**
7 **Stephanie Ribet**
8 **Michael Zachman**
9 **Steffi Woo**
10 **Peter Denes**
11 **Shelly Conroy**
12 **Yue Yu**
13 **Maureen Joel Lagos Paredes**
14 **Menglin Zhu**
15 **Robert Klie**
16 **Frances M. Ross**
17 **Jianguo Wen**
18 **Joachim Dahl Thomsen**
19 **Naoya Shibata**
20 **Ismail El Baggari**
21 **Cameron Johnson**
22 **David McComb**

POSTER **PRESENTATIONS**

1 Mingzhao Liu

Developing and understanding new material platforms for superconducting qubit scaling up

Superconducting qubits remain a leading platform for quantum computing due to their scalability and compatibility with modern fabrication. However, further scaling faces two central challenges: extending qubit coherence and increasing device density. From a materials science perspective, both challenges are fundamentally linked to losses originating at material interfaces and limitations of current device architectures. In this talk, I will discuss our efforts to develop new material platforms that enable longer-lived and more compact superconducting qubits. First, I will highlight how materials innovation, such as replacing niobium with tantalum, can significantly enhance coherence, and present our work combining advanced materials characterization with resonator and qubit measurements to identify microscopic sources of loss. In particular, we directly resolve the spatial distribution and oxidation states within native oxide layers using advanced electron microscopy techniques and synchrotron X-ray spectroscopy, establishing clear links between interfacial chemistry and qubit decoherence. I will then introduce superconducting transition metal silicides as a promising, CMOS-compatible materials platform for scalable quantum circuits. These materials offer tunable superconducting properties, excellent uniformity, and compatibility with established microelectronics. I will discuss their synthesis, characterization, and implementation in quantum devices, including resonators and Josephson junctions, with an emphasis on pathways toward high-coherence, densely integrated qubit architectures.

Affiliation: Brookhaven National Laboratory

2 David Muller

Three-dimensional, high-resolution and dose-efficient imaging with cryogenic electron ptychographys

With recent advances in detector technology and a new class of ptychographic phase-retrieval algorithms to unscramble multiple scattering, the resolution of the electron microscope is now limited only by the dose applied to the sample, and thermal vibrations of the atoms themselves. With improved detector speeds and drift correction algorithms, cryogenic temperature experiments needed to study phase transitions in quantum materials have become practical. At high doses, these approaches have allowed us to image the detailed vibrational envelopes of individual atom columns as well as locating individual interstitial atoms. The three-dimensional nature of the reconstruction means atomic-scale interface roughness and step edges inside devices can be resolved – including modern gate-all-around transistors and Josephson junctions. Even the location of all atoms in thin amorphous films now seems within reach. The reduced sensitivity to chromatic aberrations also makes these approaches of interest for thick biological sections, polymer samples or battery, where we have been able to demonstrate a fivefold improvement in dose efficiency over conventional cryo electron microscopy.

Affiliations: Cornell University

3 Miaofang Chi

Cryogenic STEM and EELS: New Opportunities for 2D Materials Research

TBD.

Affiliation: Oak Ridge National Laboratory

4 Haimei Zhang

Revealing Atomic Dynamics at Solid–Liquid Interfaces through Liquid-Phase Electron Microscopy and Cryo-EM

Solid–liquid interfaces govern a wide range of phenomena in nanomaterials synthesis, electrochemical energy conversion, corrosion, and environmental processes. However, directly probing atomic-scale dynamics at these interfaces remains challenging because of their buried nature and the complexity of liquid environments. Recent advances in liquid-phase electron microscopy (LPEM) have enabled direct visualization of dynamic materials transformations and solid–liquid interfacial processes with unprecedented spatial and temporal resolution. In this presentation, I will discuss how the complementary capabilities of liquid-phase electron microscopy and cryogenic electron microscopy (cryo-EM) provide unique opportunities to reveal atomic-scale information about solid–liquid interfacial processes. Liquid-phase electron microscopy enables real-time visualization of dynamic phenomena in liquids, while cryo-EM captures transient states through rapid vitrification, preserving atomic-scale interfacial structures and metastable configurations that are often inaccessible through in situ imaging alone. These complementary approaches provide a powerful framework for bridging nanoscale reaction dynamics with realistic operating conditions. Examples from nanomaterials synthesis, electrocatalysis, and energy materials will illustrate how advanced electron microscopy is revealing previously inaccessible mechanisms at solid–liquid interfaces, offering new insights into nanoscale materials transformations and enabling new opportunities for materials design and discovery.

Affiliation: Brookhaven National Laboratory

5 Meng Li

Atomic-Resolution insights into early-stage Oxidation using in situ ETEM

Oxidation plays critical roles in the performance, degradation, and manufacturing of metals and alloys, yet the atomic-scale mechanisms governing the early stages of oxidation remain poorly understood. Direct, real-time observation of oxidation processes is essential for uncovering the dynamic structural and chemical transformations that control oxidation pathways and kinetics. During oxidation, local structural and compositional transformations—such as surface segregation, reconstruction, and short-range ordering—can profoundly influence oxidation kinetics and pathways. However, these processes are often difficult to capture using conventional characterization techniques. In this talk, I will present atomic-resolution in situ ETEM studies of the early-stage oxidation of Cu and Cu-based alloys. By directly imaging surface reconstruction, elemental segregation, oxide nucleation, and interface evolution as they occur, we uncover the dynamic structural and chemical processes that govern oxidation pathways and kinetics. Complementary density functional theory (DFT) calculations and machine-learning-assisted image analysis provide quantitative insight into the atomic-scale mechanisms underlying the experimental observations. These findings advance the fundamental understanding of metal and alloy oxidation and provide guidance for designing oxidation-resistant materials and advanced manufacturing of nano-oxides.

Affiliation: Brookhaven National Laboratory

6 Renae Gannon

Advancing Multiscale Cryo-EM Workflows for Functional Energy Materials

Characterizing complex interfaces in functional energy materials presents a significant challenge, particularly when dealing with beam-sensitive components, volatile elements, or delicate soft-hard material interfaces. Cryogenic electron microscopy (cryo-EM) has emerged as an essential platform for preserving and analyzing these materials in their native states. While cryo-EM is often associated with high-resolution imaging, our group's work emphasizes a multiscale approach that bridges the gap from bulk device architectures to atomic-scale structures. In this presentation, we detail our integrated workflows utilizing cryogenic laser and plasma focused ion beam (PFIB) and cryo-S/TEM techniques. We demonstrate how femtosecond laser ablation, paired with cryo-PFIB polishing, enables the rapid, site-specific extraction of large-volume cross-sections from intact batteries, membranes, and photovoltaics. For evaluating local chemistry and structure, we will discuss cryo- scanning transmission electron microscopy (cryo-S/TEM) techniques. As anyone who has attempted these techniques knows, freezing comes at a cost. Cryo-EM experiments, particularly those requiring complex multiscale preparation, are time-consuming, highly sensitive to environmental factors, and carry an increased risk of artifacts such as frost contamination or ion-beam induced damage, or failure. Thus, when planning characterization for functional energy systems, it is critical to consider whether (and which) cryo-EM techniques are appropriate based on specific research goals and an understanding of beam-sample interactions. Drawing from our collaborative work and the capabilities within our group, we will discuss the practical limitations of current systems and provide insight to the questions of when, why, and how to achieve cryogenic characterization across diverse energy materials.

Affiliation: National Laboratory of the Rockies

7 Stephanie Ribet

At the intersection of cryo- and computational electron microscopy: characterizing soft materials with 4D-STEM

4D-STEM is central to modern materials science scanning transmission electron microscopy (STEM). Small convergence angle nanobeam diffraction experiments provide structural characterization, including short-range order, crystal phase, and orientation mapping. Phase retrieval reconstructions of large convergence angle 4D-STEM datasets enable electron dose-efficient, high-resolution characterization of specimens that is not accessible with conventional dark-field imaging. Despite the benefits of computational approaches for materials characterization, it can be incredibly difficult to study soft, electron beam sensitive specimens with STEM. These challenges can often be mitigated by combining efficient computational approaches with cryo-electron microscopy to reduce damage. In this presentation, I will discuss our 4D-STEM approaches for dose-efficient characterization, spanning both nanobeam diffraction and large convergence angle STEM. I will highlight how machine learning methods can outperform conventional techniques and discuss their implementation in the open-source package quantEM. I will show examples of how coupled cryo- and computational electron microscopy can be leveraged for the characterization of soft materials, including polymers and biological specimens. Finally, I will discuss the growth of cryo-electron microscopy at Lawrence Berkeley National Laboratory through our new cryoEPIC program.

Affiliations: Lawrence Berkeley National Laboratory

8 Michael Zachman

Enabling Multi-scale Cryo-EM of Sensitive and Low-Contrast Interfacial Materials in Electrochemical Devices

Developing next-generation electrochemical devices relies on understanding fundamental processes that occur at interfaces within them. Accurate characterization of features that dictate these interfacial phenomena is challenging, however, as their sizes can extend down to the nano- and atomic-scale while varying across length scales up to millimeters. In addition, the interfacial materials tend to be highly beam-sensitive, may provide little contrast, and must be extracted from the devices. In this talk, I will describe recent efforts to probe the native states of these buried interfaces at high spatial resolutions across large length scales using various cryogenic electron microscopy techniques. I will include discussions of optimal sample preparation methods, automated low-dose experimental workflows, approaches to maximize information utility, and advanced data analysis procedures, which enable statistical measurements of native nanoscale interfacial features across large length scales in these complex systems.

Affiliations: Oak Ridge National Laboratory

9 Steffi Woo

Localized Excitonic Response in van der Waals Semiconductors below 100K

TBD.

Affiliation: Oak Ridge National Laboratory

10 Peter Denes

Towards an Ultra-Stable, Ultra-Cold Transmission Electron Microscope

Electron Microscopy at very low temperatures is essential now to provide the detailed 3D information required to perfect quantum materials and systems. While there has been tremendous recent progress on cold sample holders, to date they are limited to temperatures ~10K – whereas the systems in question operate at temperatures <1K. The key practical limitation has been the incorporation of a cold stage in a hot microscope, which thus limits the ultimate temperature. An all-superconducting microscope provides a suitable thermal environment to achieve the low temperatures desired. In addition, but making the entire microscope superconducting • Mechanical stability is aided, since thermal expansion ◊ 0 as T ◊ 0 • Superconducting magnetic shielding can reduce the effects of external electromagnetic noise sources by more than 4 orders of magnitude over what is possible with the best room temperature shielding o As well as thermally-generated magnetic noise along the electron beam path • Operating the objective lens with superconducting persistent currents means that power supplies can be disconnected from the microscope • Superconducting field emitters are capable of very small intrinsic energy widths, opening new opportunities for spectroscopy At Lawrence Berkeley National Laboratory, we are building a prototype 5 keV all-superconducting microscope with the goal of demonstrating nm/day focal stability. We have already demonstrated persistent current operation of a prototype full-energy objective lens, the improvements possible with superconducting shielding, and a Nb field emitter with 20 meV intrinsic width. The components of the prototype will be complete this summer, and we aim to then demonstrate focal stability, perform initial ptychographic experiments, and complete the conceptual design of a full energy TEM.

Affiliation: Lawrence Berkeley National Laboratory

11 Shelly Conroy

Cold Correlations: Microscopy from Liquid Nitrogen to Liquid Helium

Cryogenic workflows combined with liquid cell electrochemistry, operando light microscopy, transmission electron microscopy, and hard X ray synchrotron imaging provide new opportunities for investigating dynamic processes in complex functional materials. These approaches enable electrochemical behaviour to be probed across multiple length scales and imaging modalities, while preserving transient states through rapid cryogenic fixation. A central focus of this work is the development of site specific workflows for cryogenic atom probe tomography (APT) and cryogenic transmission electron microscopy (TEM). By linking liquid cell experiments with cryogenic APT and TEM, operando electrochemical behaviour can be directly correlated with nanoscale structure and local chemistry, while maintaining sensitive electrochemical and hydrated structures with high spatial and chemical fidelity. The talk will also discuss recent work at liquid helium temperatures, including electron ptychography, electron energy loss spectroscopy, and in situ experiments on ferroic materials in their low temperature phases. Particular focus will be placed on the experimental challenges associated with imaging and spectroscopy in the liquid helium regime, and on exploring structural and electronic phase behaviour that only emerges at extreme cryogenic temperatures.

Affiliations: Imperial College London

12 Yue Yu

Laser phase plate for phase-contrast imaging

TBD.

Affiliations: Chan Zuckerberg Institute for Advanced Biological Imaging

13 Maureen Joel Lagos Paredes

Electron spectroscopy studies of collective excitations in quantum materials

TBD.

Affiliation: McMaster University

14 Menglin Zhu

Dynamic Antiferroelectric Transformations Revealed by In Situ Microscopy

Structural phase transformations are tightly coupled to functional properties in polarizable dielectrics, where temperature- and field-driven changes in polarity underpin memory and energy applications. While these transformations are well established in ferroelectrics, analogous behavior in antiferroelectric (AFE) remains less explored. Here, by combining in situ temperature control with TEM diffraction and multislice electron ptychography, we reveal a multi-stage paraelectric (PE) to AFE transformation in Pb^2MgWO_6 (PMW) governed by dynamical fluctuations of polar configurations.

Cryogenic TEM diffraction shows superlattice reflections associated with antiparallel dipole ordering, which disappear upon heating as AFE order collapses. Comparison with simulations based on canonical PE and AFE models, however, reveals additional weak reflections and diffuse scattering from experiment, indicating that the transformation deviates from the expected first order AFE–PE transition. Temperature-dependent diffraction further shows a gradual strengthening of short-range ordered features upon cooling, followed by an abrupt transition into the AFE phase near −30 °C.

The diffuse scattering resembles that observed in ferroelectric relaxors and is commonly associated with polar disorder. Ptychography, however, reveals a centrosymmetric structure with near-zero polar displacements at room temperature and 100 °C. We resolve this contradiction by considering dynamical polar-domain fluctuations faster than the STEM temporal resolution, which on average resembles an PE structure. This behavior is further captured with Monte Carlo simulation of domains and first principle calculations of the phase transformation. Low temperatures stabilize AFE order, while near the critical temperature, competing interactions promote rapidly switching among nearly degenerate polar variants, giving rise to diffuse scattering and a PE structure on average.

Affiliations: Massachusetts Institute of Technology

15 Robert Klie

Analyzing Functional Materials using Aberration-Corrected Cryo-STEM

Recent advances in cryo or in-situ cooling holder development have enabled analysis of materials over a wider range of temperatures with increased stability and spatial resolution. In my presentation, I will discuss our approach to developing cryo-TEM workflows, from sample preparation to multi-modal analysis. I will cover our recent results from hybrid-MXenes analysis using atomic-resolution STEM, to cryo-FIB/SEM imaging of NbHx precipitates in superconducting RF cavities using for transmon qubits.

Affiliations: University of Illinois, Chicago

16 Frances M. Ross

Opportunities for cryo-electron microscopy in beam-induced defect engineering

The electron beam is often used, intentionally or not, to displace the atoms in a sample. But by improving the precision with which we place and steer the beam [1], we find that we can drive deterministic motion, controlling atomic column displacement and final location throughout the thickness of an irradiated crystal [2]. We have fabricated large arrays of identical vacancy-interstitial defect columns in few nm-thick CrSBr, a van der Waals crystal whose electronic structure suggests exciting applications in scalable quantum technologies. We expect that performing these atomic manipulations at cryogenic temperatures will offer further opportunities: directing atomic motion in a greater variety of materials, correlating structure with properties measured in situ at low temperature, and increasing our basic understanding of beam-solid interactions. In this presentation we will first describe the algorithm and conditions required for deterministic defect engineering at scale, then speculate on the possibilities when combined with cryo-EM. We will finally discuss more general applicability of the beam steering algorithm itself to improve data collection under cryogenic conditions.

Affiliations: Massachusetts Institute of Technology

17 Jianguo Wen

Direct Cryo-EM Observation of Non-Equilibrium Ice Phase Transformations

Ice exhibits rich interfacial and phase-transition behavior far from thermodynamic equilibrium. Using cryogenic electron microscopy, we investigate three unusual ice phenomena at the nanoscale. First, we directly observe a quasi-liquid premelting layer between solid ice and water vapor near the sublimation regime around −150 °C. Second, we reveal an unusual melting pathway of ice nanograins, where individual grains progressively coalesce and recrystallize into larger crystalline domains prior to melting, highlighting strong size-dependent stability and interfacial effects at the nanoscale. Third, we study nucleation and growth from supercooled water and observe unexpected eight-branched ice morphologies rather than the conventional six-fold symmetry, associated with the nucleation of cubic ice. These findings provide new insights into ice surface dynamics, phase transformations, and crystallization pathways under extreme non-equilibrium conditions.

Affiliations: Argonne National Laboratory

18 Joachim Dahl Thomsen

Cryo-TEM of quantum materials and electrically contacted devices

Correlating nanoscale structure with quantum phenomena is central to understanding and engineering quantum materials and devices, where defects, strain, and interfaces can strongly influence macroscopic properties such as magnetism and superconductivity. In the first part of this talk, we discuss electrical transport measurements of niobium nitride superconducting devices performed inside a transmission electron microscope using a side-entry continuous-flow liquid-helium sample holder [1]. A thermal radiation shield reduces radiative heat exchange, enabling an estimated sample temperature of 8-9 K, as inferred from the superconducting transition temperature. We also show that both electron beam irradiation and objective lens excitation perturb the superconducting state of the devices. In the second part of the talk, we describe recent work using cryo-TEM to quantify magnetic coupling between van der Waals ferromagnets in cross-sectional lamellae of Fe3GeTe2 (FGT)/graphite/FGT heterostructures, in which two bulk FGT crystals are vertically separated by graphite spacers of controlled thickness [2]. Using Lorentz TEM and electron holography, we image the magnetic domain structure in each FGT crystal and reconstruct the local magnetic fields within and between the crystals. These measurements allow us to extract a dipolar coupling length scale and identify surface-related modifications of the magnetization that are relevant to practical device geometries. Finally, we show that electron dose and beam energy must be carefully considered in in-situ experiments on van der Waals ferromagnets, as electron beam irradiation can modify or degrade their magnetic properties.

Affiliation: Forschungszentrum Jülich

19 Naoya Shibata

Recent Progress in the Development of Magnetic-Field-Free Cryogenic Atomic-Resolution Electron Microscope

Scanning transmission electron microscopy (STEM) is a powerful technique for directly visualizing atomic-scale structures inside materials and devices. By using elaborate detectors with recent phase contrast STEM imaging techniques, we may not only image atoms, but can also image atomic-scale electric and magnetic field distribution.

However, atomic-resolution observation of magnetic materials is essentially very difficult because high magnetic fields (>2T) are always exerted on samples inside the magnetic objective lens. In recent years, we have succeeded in developing a novel magnetic objective lens system that realizes a magnetic field free environment at the sample position. Using this new objective lens system in combination with differential phase contrast imaging technique, real-space visualization of intrinsic magnetic fields of an antiferromagnet has been achieved. This electron microscope (Magnetic-field-free Atomic Resolution STEM: MARS) is expected to be used for research and development of many magnetic materials and devices. In this talk, I will show some resent material application using the MARS and also introduce the status of our new development project (MAgnetic field-free Cryogenic Atomic resoLUtion electron microscope: MACALU) supported by JST ERATO, which aims to introduce a cryogenic stage into the magnetic-field-free objective lens.

Affiliation: University of Tokyo

20 Ismail El Baggari

High resolution electron microscopy with liquid helium: status, updates, and applications

Scanning transmission electron microscopy (STEM) techniques hold immense promise for advancing quantum materials research. However, progress has been hindered by the lack of low-temperature capabilities, which are essential for studying quantum systems. In this talk, I will highlight our efforts to enable novel cryogenic measurements, including the use of liquid helium. The vast majority of scientifically interesting and technologically relevant phenomena in quantum materials, however, occur below 77 K, and often far lower, which requires the use of liquid helium cooling. I will describe the approach undertaken by our team in designing and constructing stable liquid helium STEM inserts, which have opened new lines of inquiry into a variety of novel materials and systems [1]. The liquid helium-cooled inserts provide access to temperatures down to ~20 K while maintaining atomic-resolution performance with sub-angstrom information transfer [1-3]. The instrument further enables extended operation durations over 12 hours, low drift, and temperature stability in the millikelvin range at both base and intermediate temperatures. Variable temperature capabilities enable tracking of the evolution of order and disorder. These capabilities are now available across microscope platforms and institutions. I will discuss visualizations of nanoscale polar textures in a so-called quantum paraelectric [4].

Affiliation: University of British Columbia

21 Cameron Johnson

Stable Liquid-Helium-Cooled STEM with Double-Tilting

The next generation of instrumentation for scanning transmission electron microscopy (STEM) is emerging, enabling studies of quantum and other low-temperature phenomena, far below what can be reached with liquid nitrogen, together with atomic spatial resolution, and few meV energy resolution. While aftermarket sample cooling systems exist, significant engineering challenges exist to deliver all the multi-modal measurement capabilities from conventional STEM to a cryo cooled sample. The ideal sample cooling system should have long hold times, low drift and shakes, a base temperature of at least 10 K, extensive radiation shielding, an UHV environment, variable temperature operation, and double-tilting. We have designed and built a system targeting these specifications. A liquid helium flow cryostat is rigidly mounted to the side of the column. The sample is introduced via a separate port and coupled to the cryostat via a flexible braid that isolates vibrations from the cryostat. This geometry leaves the central bore of the sample rod clear for a motor-driven tilt mechanism, plus instrumentation wires for heaters, sensors, and biasing. The system also includes thorough in-column cryo-shielding, which both protects the sample from room-temperature infrared radiation and improves the vacuum around the sample beyond the native UHV conditions, likely into the extreme high vacuum range. Additionally, we have developed cryo-compatible single- and double-tilt sample rods that can be tilted about the primary rod axis (alpha-tilt) up to ±20°, and ±30° beta tilt. An overview of this system, its capabilities and recent measurements, as well as a sneak peek to future developments will be presented.

Affiliation: Bruker AXS

22 David McComb

Cryogenic imaging and spectroscopy of solid-liquid interfaces

Cryogenic transmission electron microscopy (cryo-EM) has transformed structural and cellular biology, providing near atomic-resolution structures of proteins and other macromolecules in their native biological environments, as well novel 3D tomographic structural imaging of cellular apparatus. The adoption of such methods to materials science, where spatially resolved chemical and physical information must be delivered alongside structural data has been much slower.

Cryogenic STEM-EELS introduces experimental complexity that demands use multiple detectors and electron-optical configurations can compromise the hard-fought temperature stability in biological cryo-TEM. However, progress is being made, in part driven by the materials characterization challenges associated with understanding solid-liquid interfaces (SLI). SLI control on the atomic scale how matter, energy, and information move between solids and liquids and play a pivotal role in medicine, manufacturing and technology.

Cryo-EM requires cryotransfer of flash frozen samples into the microscope, a capability that, until recently, was not available on advanced STEM-EELS systems capable of ultimate energy resolution. To address this, we have developed a cryo-transfer system for the monochromated aberration corrected (MAC-) STEM at Oak Ridge national Laboratory (ORNL). In this contribution, we will discuss recent investigations on plunge-frozen and cryo-transferred samples to study vibrational EELS of macromolecules in structured fluids. To demonstrate the potential of this approach for the study of structured fluids, we will show that using vibrational STEM EELS it is possible to determine the location of the active species within the sample's vesicle lamella or within the vesicle itself.

Affiliation: The Ohio State University

23 Sanghyo Lee

Domain-Resolved TEM Study of a Potential Two-Phase Transition in Low-Temperature $CuIr_2S_4$s

$CuIr_2S_4$s (CIS) undergoes a metal–insulator transition (MIT) near 230 K, accompanied by the disappearance of magnetic moments and the formation of a spin-dimerized insulating state. This transition has commonly been interpreted in terms of octamer ordering of Ir^{3+} and Ir^{4+} ions within a triclinic (P-1) structure. However, most previous studies relied on bulk-averaged diffraction techniques and therefore could not directly resolve nanoscale structural variations. In addition, several reports have suggested the possibility of further structural evolution at temperatures below the MIT, raising the question of whether the low-temperature state can be fully described by a single triclinic phase. Here, we combine cryogenic TEM and domain-resolved 4D-STEM to investigate the local structure of $CuIr_2S_4$s at liquid-nitrogen (~90 K) and liquid-helium (~20 K) temperatures. Local diffraction information was obtained from 4D-STEM datasets acquired using a direct electron detector. 4D-STEM imaging reveals well-defined stripe domains with characteristic widths of approximately 2 nm along the (001) zone axis. Such nanoscale domains are significantly smaller than the averaging length scale of conventional diffraction techniques and therefore may remain hidden in bulk structural analyses. Analysis of 4D-STEM nanobeam electron diffraction datasets separates individual domains and reveals systematic differences in diffraction intensity distributions and peak positions. Domain boundaries are found to preferentially align along specific crystallographic directions, suggesting an intrinsic relationship between domain formation and lattice distortions associated with dimer ordering. To determine whether the observed structural variations can be explained solely by domain formation within a single triclinic phase, experimental observations were systematically compared with structural models derived from previously reported crystal structures. At liquid-helium temperatures (~20 K), the diffraction patterns are largely consistent with the previously reported low-temperature triclinic structure. In contrast, datasets acquired at liquid-nitrogen temperatures (~90 K) exhibit additional diffraction features that cannot be readily explained by the domain variants identified at 20 K. These observations suggest that the insulating state of $CuIr_2S_4$s may possess greater structural complexity than previously recognized and could involve additional structural evolution within the low-temperature phase. Atomic-resolution STEM imaging provides complementary evidence through analysis of Ir-sublattice elongation. The elongation direction varies systematically between 90 K and 20 K and provides additional evidence for a possible low-temperature phase transition. Comparison between liquid-nitrogen and liquid-helium temperature datasets reveals changes in both diffraction signatures and atomic distortion patterns, indicating that the underlying local structural motifs are not identical. These observations are consistent with temperature-dependent modifications of dimer ordering and associated lattice distortions. Our results establish a combined atomic-resolution and diffraction-based framework for resolving nanoscale structural heterogeneity in $CuIr_2S_4$s. More broadly, this work highlights the importance of domain-resolved electron microscopy for distinguishing local symmetry breaking, phase coexistence, and subtle structural evolution in correlated electron materials.

Affiliation: Brookhaven National Laboratory

24 Lukas Friedrich Worch

Probing Damage Mechanisms in Liquid Electrolyte Battery Materials via Cryogenic Atom Probe Tomography and Electron Microscopy

Degradation in battery electrode materials remains an important issue, whose understanding requires analysis of both the mechanical and chemical changes occurring in the material during cycling. Detailed analysis of these properties has remained difficult. Lithium is not only difficult to image through many conventional microscopy methods, but the liquid electrolyte that is key to many current-generation batteries is difficult to retain for imaging in high-vacuum environments. In solving these issues, most state of the art analysis techniques carry out significant alterations to the in-situ state of the electrode through processes such as washing. We present here a fully cryogenic workflow for use with liquid-electrolyte battery samples, based on the transfer between different instruments using a cryogenically cooled, high vacuum transfer suitcase, allowing for transfer of samples between a dual-beam scanning electron microscope (SEM)/focused ion beam (FIB), atom probe tomography (APT), and transmission electron microscope (TEM). Use of the SEM/FIB allows for not just preparation of samples at cryogenic temperatures, but also macroscopic imaging in three dimensions through slice-and-view tomography. From here, morphological changes occurring during the cycling process can be identified, and regions of high interest in the material picked out. Cryogenic FIB preparation not only prevents loss of high-mobility ions such as lithium [1], but also allows for retention and imaging of the SEI that is otherwise lost through processes such as washing [2]. Through a combination of large scale morphological data from the SEM-FIB, nano-scale chemical composition from APT, atomic resolution structural information from scanning transmission electron microscopy (STEM), and information on chemical bonding environments from electron energy loss spectroscopy (EELS), a much more detailed pictured of electrode material degradation can be obtained than previously possible.

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25 Madison King

Multiscale cryo-EM analysis of liquid metal coated lithium anodes

TBD.

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26 Lopa Bhatt

Preserving Oxygen Stoichiometry in Nickelates with Liquid Nitrogen Cryogenic FIB and STEM

The recent discovery of high temperature superconductivity in bulk bilayer nickelates under hydrostatic pressure and in thin films under bi-axial epitaxial compression has ignited interest in understanding the electronic and structural interplay in this material. Both in bulk and thin film form, the emergence of superconductivity appears sensitively coupled to oxygen sublattice positions and stoichiometry. Specifically, superconducting La2PrNi2O7 (LPNO) and La2SmNi2O7 (LSNO) bilayer nickelate thin films grown on SLAO substrates have been shown to lose oxygen on the time scale of hours at ambient temperature, requiring cryogenic conditions for preservation of the superconducting state. For atomic scale understanding of the structure via scanning transmission electron microscopy (STEM) and its interplay with electronic properties, a full cryogenic workflow, including cryogenic sample preparation via focused ion beam (cryo-FIB) and advanced cryo-STEM techniques of cryogenic electron energy loss spectroscopy (cryo-EELS) and multislice electron ptychography (cryo-MEP), is required. Due to instability and drift, fabricating thin samples in cryogenic conditions is very challenging, limiting later application of advanced techniques of cryo-EELS and ptychography. Here, we leverage recent developments in more stable cryo-FIB stages and cryo-STEM capabilities to obtain microscopic understanding of superconducting bilayer nickelates. We measure subtle changes in the lattice structure of superconducting LPNO and LSNO films by developing a fully cryogenic workflow involving cryo-FIB sample preparation, cryo-ADF, cryo-EELS and cryo-MEP measurements. Cryo-EELS measurements of the Pr/Sm-M4,5 edges reveal preferential occupation of RE in the outer layers of the bilayer structure. Energy loss near-edge structure (ELNES) of the O-K edge is used to map the inherent inhomogeneity of oxygen stoichiometry at the nanoscale, indicating possible routes for further improvement of the growth procedure. The ability to now characterize beam sensitive and metastable quantum materials at atomic resolution via cryo-FIB and cryo-STEM opens access to vast materials domains not previously accessible.

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27 Yosemin Akyol

Cryogenic STEM-EELS for Structured Fluids

Cryogenic transmission electron microscopy (cryo-TEM) is a unique imaging technique that ensures an environment under vacuum to preserve biological samples and soft materials. However, the mechanisms behind electron-beam damage in many soft materials remain poorly understood. A combination of scanning transmission electron microscopy (STEM) with electron energy-loss spectroscopy (EELS) redefines the limits of energy resolved measurements of materials and spatial resolution in nanometer scale. Structured fluids are a part of soft materials and remain to be explored through STEM-EELS. Most of the S/TEMs operate EELS at room temperature, but the nature of structured fluids needs to be preserved at cryogenic temperatures. Using a cryo-transfer system, plunge frozen structured fluid samples can be transferred into side-entry microscopes by minimizing the temperature fluctuations and maintaining the cryogenic temperatures. As a proof of concept, this study utilizes STEM-EELS to monitor cargo deposition within a structured fluid host by evaluating both with and without an active cargo molecule. In this contribution, we aim to present the difference in vibrational energy regions with STEM-EELS for SF host and SF active samples.

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28 Kassandra Weber

Atomic-Scale Characterization of HF-Induced Hydride Nucleation in Superconducting Epitaxial Nb (111) Thin Films at Room and Cryogenic Temperatures

Standard niobium (Nb) based superconducting (SC) qubit fabrication techniques require hydrofluoric acid (HF) chemical etching to remove lossy native surface oxides from the films. Stripping this native oxide removes a critical diffusion barrier, allowing hydrogen to more easily adsorb onto the exposed Nb surface and diffuse into the film. This incorporation leads to α-Nb to β-Nb phase transitions, lowering the critical temperature (Tc) and ultimately performance degradation in the SC qubits when operated at cryogenic temperatures. This study assesses the nucleation, growth and structural evolution of these hydrides in epitaxially grown Nb (111) thin films at ambient and cryogenic temperatures using low and high HF concentrations. To perform this experiment, we utilize SEM, 4D STEM nanobeam diffraction, high-resolution TEM, aberration-corrected ADF/ABF STEM, and EELS to study the structural and chemical evolution of the hydrides in the films, with supplementary ToF-SIMS and XRD measurements. With this research, we provide further insights into the impact of hydride formation on the atomic structure, nucleation, local lattice expansion, and phase transitions in Nb thin films during thermal cycling, thereby optimizing standard SC qubit fabrication protocols.

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29 Noah Schnitzer

Liquid helium temperature atomic resolution STEM imaging and ptychography of ferroelectrics

High-resolution real-space characterization at cryogenic temperatures is increasingly important for the study of ferroics and functional oxides, where competing low-temperature electronic and magnetic phases and associated subtle structural distortions require atomically resolved probes to understand, and ultimately control, exotic low-temperature behaviour of both technological and fundamental physical interest [1]. Scanning transmission electron microscopy (STEM) offers unique insight into material structure down to atomic resolution, however in situ under cryogenic conditions reduced mechanical stability presents significant challenges for high-resolution STEM imaging and analysis. Atomic-resolution scanning transmission electron microscopy (STEM) imaging and spectroscopy have previously been extended to ~100 K using liquid-nitrogen cooling, however, phenomena of prime interest emerge only at lower temperatures in many relevant oxide systems, necessitating liquid helium cooling [2,3]. Combining advances in cryogenic hardware with optimized acquisition and data processing approaches, here we demonstrate atomic-resolution STEM imaging and multislice electron ptychography (MEP) at controlled temperatures under liquid helium cooling on two protype ferroic systems [4]. Imaging an epitaxial $SrTiO_3$ thin film grown on (110) $GdScO_3$, we achieve sub-angstrom resolution necessary to resolve octahedral distortions imaging across the film-substrate interface, while in the multiferroic boracite $Fe_3B_7O_{13}I$ MEP reconstructions show improved resolution and strong sensitivity to low-Z boron-oxygen clusters key to locally characterizing inhomogeneity in the system.

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30 Yael Tsarfati

Mapping Local Charging in OMIECs via Cryo-FIB and Monochromated EELS

Organic mixed ionic-electronic conductors (OMIECs) are central to advanced bioelectronics and energy storage devices [1]. However, evaluating their nanoscale charging behavior is heavily restricted by their beam sensitivity and the excessive thickness of standard functional films. To capture transient operational states, we utilize an electro-cryo-EM approach [2] to prepare and vitrify electrochemically doped OMIEC samples. Cryogenic focused ion beam (cryo-FIB) milling is subsequently employed to thin these vitrified films into uniform lamellae ranging from 150-200 nm to meet the thickness requirements for electron energy-loss spectroscopy (EELS). By leveraging the high energy resolution of monochromated EELS, we track localized electronic signatures—specifically low-loss plasmon shifts and core-level fine structures—to map local doping states. Our preliminary measurements offer interesting insights into these electronic environments, indicating spatial heterogeneities in charge carrier distribution throughout the polymer lamellae. These early results highlight the potential of combining electro-cryo-EM and cryo-FIB sample preparation with monochromated EELS to directly link nanoscale charging characteristics with macroscopic electrochemical performance.

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31 Sriram Sankar

Sub nanoscale Visualization of Exciton Localization and Delocalization in WSe2/WS2 Moiré systems

TBD.

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32 Yuxi Zhang

Unveil the Cross-Sectional Microstructure of Halide Perovskites via Cryo-FIB and TEM

Organic-inorganic hybrid perovskites (OIHPs) have attracted intense research attention owing to their outstanding photovoltaic performance. Yet their path to commercialization is still hindered by poor structural stability, as these materials degrade rapidly upon exposure to moisture, oxygen, and heat. Transmission electron microscopy (TEM) offers a route to probe their polymorphism, performance-limiting defects, and degradation pathways at the nanoscale. A key complication is the susceptibility of OIHPs to high-energy beams: under electron or ion irradiation in the microscope, they can decompose almost instantly, leaving behind lead iodide. To sidestep this, the majority of TEM investigations rely on thin films grown directly on TEM grids, thereby avoiding the additional ion damage incurred during focused ion beam (FIB) sample preparation. The drawback is that grid-grown films diverge considerably from the perovskite layers in working photovoltaic devices — in grain size, defect populations, and interfacial strain — which weakens the link between microstructural observations and device-level photovoltaic behavior. In this work, we introduce a low-dose cryogenic-FIB (cryo-FIB) protocol that permits direct, cross-sectional TEM imaging of complete OIHP devices while keeping beam damage sufficiently controlled to preserve the native structure. Monte Carlo simulations of Ga^+ ion interactions with $FAPbI_3$ were used to inform the ion-milling strategy, and an air-free transfer procedure was implemented to suppress phase transitions driven by air exposure. Together, these methods allow direct observation of the pristine photoactive phase of $FAPbI_3$ and enable study of its degradation under ion and electron irradiation. *The authors acknowledge funding from the Department of Energy (DOE) (500000023786).

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33 Hsin-Yun Joy Chao

Beam-induced Crystallization at Boron Nitride Nanotube Interfaces during Cryo-EM

Nanotubes such as carbon nanotubes (CNTs) and boron nitride nanotubes (BNNTs) are of high interest in the field of nanofluidic transport as their unique properties with their chemically protective tube core and singular interactions at the interface between nanotube and water recommend themselves as effective nanochannels for applications pertaining to nano sensors and water filtration. [1-4] In particular, the BNNT surface is polar, and dipole interactions can introduce ordering in a water layer at the interface. The rise of cryogenic electron microscopy (cryo-EM) has been driven in part by the ability to characterize biogenic and aqueous structures in a vitreous state, in the absence of damage or diffraction contrast caused by ice crystallization. Nucleation of crystals is also relevant to cryo-preservation and life survival in cold environments. Here, we study the nucleation of crystals of ice into the cubic Ic and hexagonal Ih phases from a low density amorphous (LDA) structure, natively and in the presence of multi-walled BNNT. Observations include transmission electron microscopy (TEM) diffraction contrast and in-situ Raman spectroscopy. We find that the presence of BNNT reduces the dose for nucleation. Numerical molecular dynamics models with and without water polarization show a trend for increasing order of the water molecules at 300 K at the BN interface. We will discuss the agreement between experimental and modeling work, and its implications. [5]

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34 Xiaoyu Song

Transitory Topochemical Tailoring of a van der Waals Superconductor

Topochemical intercalation is widely used to access metastable phases with novel electronic properties, but the reverse reaction (deintercalation) typically restores the original state, limiting practical use. Here, we present a topochemical approach that employs a sacrificial intercalant that thermally decomposes to irreversibly lock in the new electronic state. Using 2-aminobutane as the sacrificial intercalant, we convert the van der Waals (vdW) material 1T-$TiSe_2$ into a superconductor and the vdW superconductor 2H-$NbSe_2$ into a nonsuperconducting metal, while preserving the ability to exfoliate the resulting crystals. We find that this transitory intercalation increases the electron density in both materials and partially suppresses the CDW in $TiSe_2$. By tuning the thermolysis temperature, we can systematically vary the carrier density in $TiSe_2$, enabling us to map its phase diagram. The superconductivity in $TiSe_2$ is retained in exfoliated flakes, although with a lower critical temperature. This transitory topochemical strategy enables access to new electronic states with precisely tuned carrier densities that are otherwise inaccessible through direct solid-state synthesis.

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35 Maya Gates

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36 Alexis Williams

How to Train Your Segmentation Model: Developing Automated Analysis Workflows for Noisy CryoEM Data

CryoEM datasets in materials science are rapidly expanding from single micrographs to multi-terabyte-scale collections comparable to those in structural biology. These datasets can span large fields of view and multiple magnification ranges, while low-dose 40–60 $e^-/Å^2$ and ultralow-dose <10 $e^-/Å^2$ imaging conditions produce inherently noisy images. In many cases, the features of interest are only tens of nanometers in size and must be identified, quantified, or tracked across multiple fields of view. To address these challenges, we have developed ACORN, an automated software platform for training and deploying segmentation models across diverse microscopy datasets. Here I will cover three software-enabled use cases: 1) model training with sparse annotations, 2) autonomous quantification of tens-of-nanometer features across large fields of view, and 3) 3D reconstruction of heterogeneous samples. Together, these examples show how ACORN and related tools can move cryoEM analysis of soft-matter systems beyond manual, single-image interpretation toward automated, large-area, statistically meaningful, and reproducible workflows.

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38 Leopoldo Molina-Luna

Defect-Controlled Domain Dynamics in Functional Oxides Revealed by Cryogenic Operando TEM

Cryogenic electron microscopy is emerging as a powerful platform for investigating functional materials under realistic operating conditions, particularly for systems exhibiting strong coupling between structural, electronic, and ferroic degrees of freedom. In this contribution, we present recent developments in cryogenic in situ and operando scanning/transmission electron microscopy (S/TEM) designed to probe defect-mediated phenomena in functional oxide materials. Our approach combines MEMS-based cryogenic biasing platforms, low-damage plasma FIB sample preparation, and on-chip electrical contacting to enable quantitative operando experiments across a wide temperature range. Using single-crystal $BaTiO_3$ as a model system, we directly visualize dislocation-mediated domain nucleation, domain-wall pinning, and phase-transition-driven domain evolution from the rhombohedral phase at −175 °C to the cubic phase near 200 °C. Cryogenic operando TEM experiments reveal that dislocations strongly influence local polarization switching and domain-wall dynamics under applied electric fields. Atomic-resolution STEM imaging and geometric phase analysis (GPA) uncover localized strain accumulation at dislocation cores, while electron energy-loss spectroscopy (EELS) identifies associated electronic fingerprints linked to oxygen vacancy distributions and local defect chemistry. These results demonstrate how advanced cryogenic operando electron microscopy can bridge structural and functional characterization at the nanoscale, providing new insights into defect-controlled phenomena in ferroic and quantum-relevant oxide materials. The work further highlights the importance of integrating cryogenic methodologies with electrical operando capabilities for the next generation of functional materials research.

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39 Alexander Reifsnyder

Hardware Development for Advanced TEM Sample Transfer

Transmission Electron Microscopy (TEM) is an indispensable tool for materials characterization, enabling direct observation of micro- and nano-scale samples with exceptional spatial resolution. Advances in TEM experiments, however, increasingly depend on how a specimen is prepared, preserved, and introduced into the microscope. Cryogenic and inert-environment transfer workflows have become a critical bottleneck, as many scientifically valuable samples are air-sensitive, stable only at low temperatures, or both. Maintaining specimen integrity from preparation through insertion requires preserving cryogenic conditions or excluding atmospheric exposure throughout the transfer, demands that conventional handling and loading workflows struggle to meet. This presentation examines the requirements and challenges of advanced sample transfer for TEM, with an emphasis on cryogenic workflows. Through three examples, we demonstrate transfer approaches that maintain stable environmental conditions and discuss how improved transfer capabilities expand the range of materials and experiments accessible to electron microscopy.

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