Nanoscale Science and Technology
Room 205 ABCD W - Session NS-WeA

Recent Advances in Nanoscience

Moderators: Deep Jariwala, University of Pennsylvania, **Nikolai Klimov**, NIST

4:15pm **NS-WeA-9 The Role of Defects in Ion Induced β-Ga2O3 to γ-Ga_2O_3 Conversion***, Umutcan Bektas, Oskar M. Liedke,* Helmholtz-Zentrum Dresden - Rossendorf, Germany*; Huan Liu,* helsinki University of Technology, Finland*; Fabian Ganss, Nico Klingner, René Hübner,* Helmholtz-Zentrum Dresden - Rossendorf, Germany*; Ilja Makkonen,* helsinki University of Technology, Finland*; Andreas Wagner, **Gregor Hlawacek**,* Helmholtz-Zentrum Dresden - Rossendorf, Germany

Gallium oxide (Ga2O3) is a highly versatile material with applications in power electronics, optoelectronics, and battery technologies. Among its polymorphs, monoclinic β-Ga2O3 is the most chemically and thermally stable phase. However, controlling the metastable polymorph phases remains challenging, and fabrication technologies for nanoscale structures are still under development. This study aims to enhance the understanding of polymorph conversion mechanisms and to establish novel fabrication techniques for single-phase polymorph films, buried layers, multilayers, and various nanostructures of Ga2O3.

We investigate β-Ga2O3 samples irradiated with different ions and fluences, as well as α- and κ-Ga2O3 thin films. Broad beam (BB) ion irradiation was employed to induce phase transformations in the near-surface region. The irradiated samples were characterized using transmission electron microscopy (TEM) and X-ray diffraction (XRD) to analyze structural changes. Complementary experiments using Positron Annihilation Lifetime
Spectroscopy (PALS) and Doppler Broadening Variable Energy Positron Annihilation Spectroscopy (DB-VEPAS) provided insights into defect types and concentrations.

Our results reveal the evolution of defect types and densities based on DB-VEPAS and positron lifetime measurements. During the phase transition from β- to γ-Ga2O3, a significant reduction in positron trapping sites is observed, indicating a decrease in defect density in the newly formed γ-Ga2O3 layer compared to the highly irradiated β material [1]. This observation aligns with previously reported high radiation hardness of Ga2O3 [2].

Additionally, we employed Neon-based helium ion microscopy to investigate the minimal achievable polymorph feature size, exploring the feasibility of future polymorph-based devices (see Figure 1).

This work is supported by the m-era.net project GoFIB and funded by the Saxonian government. Additional support from the COST Action CA19140 FIT4NANO is gratefully acknowledged.

References

[1] U. Bektas, M. O. Liedke, H. Liu, F. Ganss, M. Butterling, N. Klingner, R. Hübner, I. Makkonen, A. Wagner, and G. Hlawacek, Defect analysis of the β– to γ–Ga2 O3 phase transition, submitted (2025), arXiv:2505.03541 [cond-mat].

[2] A. Azarov, J. G. Fernández, J. Zhao, F. Djurabekova, H. He, R. He, Ø. Prytz, L. Vines, U. Bektas, P. Chekhonin, N. Klingner, G. Hlawacek, and A. Kuznetsov, Nature Communications 14, 4855 (2023), arXiv:2303.13114 [cond-mat.mtrl-sci] .

4:30pm **NS-WeA-10 Development of Heavy Noble Gas Field Ion Sources Using an Iridium Coated Single Crystalline Tungsten Emitter***, **Amina ZID**,* Helmholtz Zentrum Dresden-Rossendorf, Germany

Gas Field Ion Sources (GFIS) have already demonstrated their efficiency in nano imaging and patterning due to their high brightness, high current density and superior spatial resolution [1]. This type of ion source typically employs light noble gases such as helium and neon. In the first case, negligible sputtering and fast diffusion enables image resolution as low as 0.5 nm, while the latter allows high resolution milling of small nanostructures with resolutions better than achievable with a conventional Liquid Metal Ion Source (LMIS). GFIS suffers from limitation in terms of material removal rate due to low achievable maximum current. Another limitation comes from the light ion species used, as well as bubble formation due to deep noble gas implantation making GFIS less efficient than LMIS for larger volume or high aspect ratio milling application with only shallow end of range defects. To overcome those limitations, we investigated the GFIS performance in a Focused Ion Beam (FIB) using heavier noble gases, namely argon and xenon.

In addition, we consider an alternative emitter configuration. Commercial GFIS emitters are based on single-crystal tungsten tips, while we employ an iridium coated tungsten tip. Among noble metals, iridium confers the strongest bond with tungsten [2]. That particularity would allow the overall tip structure to withstand higher electric field than with any other noble metal coating. As a result, iridium coated tips enable higher beam currents without endangering the emitter stability. We also work with a single emission point opposed to the typical trimer configuration traditionally used in Helium Ion Microscopy (HIM).

In this work we will present the first FIB evaluation and performances based on this particular emitter using argon and xenon. Comparison to helium and neon based GFIS used in traditional HIM setups will also be covered.

[1]Höflich, K.; et al. Roadmap for focused ion beam technologies. *Applied Physics Reviews **2023***; G. Hlawacek, A. Gölzhäuser, Eds., Helium Ion Microscopy. Springer International Publishing, Switzerland, **2016**.

[2]Oshima, C.; Tomitori, M.; Shimoda, T.; Yasaka, A.; Asai, H.; Rokuta, E. Thermal Stability of Single-Atom Termination at a Pyramidal Apex of an Ir-W Tip. *Surface Science and Nanotechnology **2018***

4:45pm **NS-WeA-11 Unconventional Superconductivity in Quasi-1D $ZrTe_3$ Revealed by Ultra-Low-Temperature Scanning Tunneling Microscopy***, **Laxmi Bhurtel**, Dongwon Shin,* University of Tennessee Knoxville*; Sang Yong Song, Benjamin Lawrie,* ORNL*; Petro Maksymovych,* Clemson University*; Wonhee Ko,* University of Tennessee Knoxville

Quasi-one-dimensional (1D) superconductors possess anisotropic crystal structure and reduced dimensionality that possibly leads to unconventional superconductivity from strong electron correlation. $ZrTe_3$ is a quasi-1D material that displays both charge density waves and superconductivity. In this study, we probe the superconducting behavior of pristine and lightly Ni-doped $ZrTe_3$ with ultra-low-temperature scanning tunneling microscope (STM). The differential conductance (d*I*/d*V*) spectra reveal a clear superconducting gap for both compounds. The height dependence of d*I*/d*V* spectra is not consistent with BCS theory, implying an unconventional pairing mechanism in these materials. Our findings offer microscopic understanding of superconducting pairing mechanisms and electronic behavior in quasi-1D system.

5:00pm **NS-WeA-12 Electronic and Phononic Structure of Doped Graphene/Perovskite Oxide Hybrid Heterostructure Studied by Scanning Tunneling Microscopy***, **Myeesha Mostafa**,* University of Tennessee Knoxville*; Dongwon Shin,* University of Tennessee, Knoxville*; Woo Seok Choi,* Sungkyunkwan University, Republic of Korea*; Wonhee Ko,* University of Tennessee Knoxville

Graphene's interaction with complex oxide opens a new pathway to engineering electronic properties of 2D material. The perovskite oxide $SrTiO_3$ (STO) as a high dielectric substrate along with graphene form a hybrid heterostructure that offers a novel platform to understand the Dirac fermion behavior modified by the unique substrate interaction. Scanning tunneling microscopy (STM) allows us to visualize the impact of complex oxide substrates on graphene's atomic and electronic properties. In this work, the ultra-low temperature STM was employed to investigate the structural and electronic properties of graphene directly grown on STO. The topographic image clearly reveals the honeycomb lattice of graphene with atomic resolution. Differential conductance (d*I*/d*V*)spectradisplay the shifting of Dirac point due to the electron doping effect of substrate.Additionally, the d*I*/d*V* spectra display a gap like feature pinned to Fermi energy, which is associated with a phonon-induced inelastic electron tunneling. This study illustrates how perovskitesubstrates modulate electronic structure of 2D materials and motivates further analysis at lower temperature to resolve strain-induced shifts in phonon energy.

5:15pm **NS-WeA-13 Unveiling High-Temperature Superconducting Pairing Symmetry in Monolayer FeSe via Tunneling Andreev Reflection***, **Dongwon Shin**, Paolo Vilmercati, Norman Mannella,* University of Tennessee, Knoxville*; Petro Maksymovych,* Clemson University*; Wonhee Ko, Hanno Weitering,* University of Tennessee, Knoxville

Recent advances in low-dimensional unconventional superconductors and their unique interface properties require new techniques to probe pairing symmetry, a crucial and often debated aspect of superconductivity. In particular, understanding the pairing symmetry of monolayer FeSe on$SrTiO_3$ remains a central controversy in the study of Fe-based superconductors. Remarkably, monolayer FeSe exhibits a superconducting transition temperature above 60 K, far exceeding that of bulk FeSe (~6 K). While various scenarios have been proposed to explain this enhancement, the underlying mechanism and the nature of the superconducting order parameter remain unresolved. In this study, we grew high-quality monolayer FeSe films on Nb-doped $SrTiO_3$ substrates using molecular beam epitaxy. We also characterized their atomic-scale structure and superconducting properties via scanning tunneling microscopy and spectroscopy (STM/S). Atomic-resolution images confirmed the high crystallinity of the films, and a well-defined superconducting gap was observed at 0.3 K. We further employed tunneling Andreev reflection measurements to investigate the superconducting order parameter. By acquiring spatially resolved STS spectra as a function of tip height z, we extracted the normalized tunneling decay constant $\kappa/\kappa_{0,}$ which reveals nontrivial quasiparticle tunneling characteristics in the superconducting state. This highly sensitive probe of superconducting gap symmetry provides direct insight into the mechanism of unconventional superconductivity, offering quantitative constraints for theoretical models and enabling the identification of possible pairing scenarios in monolayer FeSe.

Author Index

Bold page numbers indicate presenter