Magnetic Interfaces and Nanostructures Division
Room B110-112 - Session MI+2D+TF-ThM

2D Magnetism and Superconductivity

Moderators: Markus Donath, Muenster University, Germany, **Valeria Lauter**, Oak Ridge National Laboratory

8:00am **MI+2D+TF-ThM-1 Heterostructures for Tunneling and Point-Contact Spectroscopy of Two-Dimensional Superconductors**, ***Benjamin Hunt***, *Q. Cao,* Carnegie Mellon University*; E. Telford, C. Dean,* Columbia University **INVITED**

Tunneling spectroscopy is an indispensable experimental tool of modern condensed matter physics. Vertical planar tunneling, which uses a fixed-width tunnel barrier, offers advantages over other spectroscopic tools such as scanning tunneling microscopy (STM). One such advantage is the ability to tunnel in reorientable and very large (≥40 T) magnetic fields at dilution refrigerator temperatures (≤30 mK), a capability that has application in, for example, determining the order parameter symmetry of novel two-dimensional (2D) superconductors. We demonstrate a novel vertical planar tunneling architecture for van der Waals heterostructures based on via contacts, namely, metallic contacts embedded into through-holes in hexagonal boron nitride (hBN). This via-based architecture overcomes limitations of other planar tunneling designs and produces high-quality, ultra-clean tunneling structures from a variety of 2D materials. The physical area of our via-based tunnel contacts is limited only by nanofabrication techniques, and we demonstrate a crossover from diffusive to point contacts in the small-contact-area limit by studying the spectrum of a 2D superconductor, $NbSe_2$. We show that our tunneling technique may enable highly-sought measurements of newly-discovered 2D superconductors such as monolayer 1T'-WTe_2, rhombohedral trilayer graphene, twisted trilayer graphene, and twisted bilayer BSCCO.

8:40am **MI+2D+TF-ThM-3 Ghost States and Topography Inversion in 2D Materials**, ***Mina Yoon***, Oak Ridge National Laboratory, USA **INVITED**

In this talk, I will discuss the challenges associated with characterizing the surface structures of single-atom thick materials, such as graphene and boron nitride, on metallic substrates or the surface of bulk systems, including quantum topological Kagome systems, using scanning tunneling microscopy (STM). The understanding of fundamental properties of two-dimensional (2D) materials and surface properties depends critically on the presence of "ghost" states, which arise due to different decay lengths in the wave function of the underlying layers and surfaces.

The existence of these ghost states, in conjunction with long-lived substrate states or underlying layers, plays a crucial role in interpreting and understanding the surface properties of 2D materials. These ghost states can originate from various sources, such as the bulk or the substrate, and can even arise from the boundary on the opposite side. The appearance of ghost states due to different decay lengths leads to unexpected results in surface structure measurements, including the intriguing phenomenon of topography inversion. Topography inversion refers to the counterintuitive result where the observed topography in STM images is opposite to the expected atomic geometry, as discussed in our recent study [1,2]. This inversion occurs as a consequence of the pervasive substrate states overshadowing the intrinsic states of the 2D materials. As a result, the measurement of the intrinsic properties of 2D materials becomes complicated, with the ghost and substrate states dominating the observed topography. To address these challenges, we employ a combination of first-principles density functional theory calculations and analytical modeling. Through our investigations, we demonstrate the critical role played by these ubiquitous substrate and ghost states in the observed topography inversion in STM images. By unraveling the influence of these states on STM measurements, we provide crucial insights for the accurate interpretation of STM topographies of atomically thin materials.

Our findings not only shed light on the phenomenon of topography inversion, but also contribute to the further development of 2D materials in (opto)electronic and quantum applications. Understanding and characterizing the ghost and substrate states is essential to unlock the full potential of 2D materials and enable their use in various technological advancements.

[1] "Spatially resolved on-dimensional boundary states in graphene-hexagonal boron nitride planar heterostructures", J. Park et al., Nat.Com. 5, 5403 (2014).

[2] "Topography inversion in scanning tunneling microscopy of single-atom-thick materials from penetrating substrate states", C. Park and M. Yoon, Sci. Reports 12, 7321 (2022).

11:00am **MI+2D+TF-ThM-10 Spatially-Resolved Photoemission Studies of Magnetic Weyl Semimetals**, *S. Sreedhar,* University of California, Davis*; M. Staab, R. Prater,* University of California at Davis*; A. Rossi,* Italian Institute of Technology, Italy*; V. Ivanov,* Lawrence Berkeley Lab*; Z. Shen,* University of California at Davis*; G. Conti,* Lawrence Berkeley Lab*; V. Taufour, S. Savrasov,* University of California at Davis*; S. Nemsak,* Lawrence Berkeley Lab*;* ***Inna Vishik***, University of California-Davis **INVITED**

$Co_3Sn_2S_2$ is a magnetic Weyl semimetal below its Curie temperature (T_c) of 177K. I will discuss spatial and temperature-dependent angle-resolved photoemission spectroscopy (ARPES) and x-ray photoelectron spectroscopy (XPS) studies in this system.Across T_c, we observe signatures of a topological phase transition, but also observe changes in bulk bands which are inconsistent with a simple lifting of exchange interactions, suggesting enhanced electronic correlations in the regime without long-range magnetic order.I will also discuss spatial-dependent ARPES and XPS data which quantify the characteristic differences between Sn- and S-terminated surfaces, with relevance for interpreting surface-dominated phenomena.

11:40am **MI+2D+TF-ThM-12 High-Temperature Superconductor FeSe Films Enabled Through Temperature and Flux Ratio Control**, ***Maria Hilse***, *H. Yi, C. Chang, N. Samarth,* The Pennsylvania State University*; R. Engel-Herbert,* Paul-Drude-Institut für Festkörperelektronik, Germany

FeSe, a bulk superconductor with a T_C of 9 K has attracted a high level of attention since a skyrocketing boost in TC was reported for a single unit cell (UC) layer of FeSe grown on SrTiO3(001) by molecular beam epitaxy (MBE) to as high as 100 K. FeSe-SrTiO3 heterostructures have since been fabricated by many groups but the record TC proved difficult to reproduce and thus the mechanism behind it remains concealed. After extensive work in the past, the field appears to agree on certain key "ingredients" in the heterostructure sample preparation that are believed essential for the boost in TC. Those are; 1. an ultra-clean substrate surface of a double TiO_{22} termination realized by a chemical and thermal *ex-situ* and/or thermal *in-situ* substrate preparation; 2. ultra-thin – one UC thickness – limit of FeSe; 3. a high number of Se vacancies in the FeSe film ensured through post-growth annealing steps in ultra-high vacuum (UHV) for several hours; 4. followed by a capping layer growth protecting FeSe against oxidation during *ex-situ* characterization.

We present our findings on FeSe thin film growth by MBE and present a roadmap for high-T_C – 222 % higher than the reported bulk value in *ex-situ* transport measurements – circumventing above mentioned steps 1, 2, and 3 by simple *in-situ* Se/Fe flux ratio and temperature control during FeSe growth. FeSe films of 20-UC-thickness grown at varying temperatures and Se/Fe flux ratios and the structural and morphological properties of the obtained uncapped FeSe films were analyzed. The morphology of the films showed a sensitive dependence on the growth temperature and flux ratio spanning from perfectly smooth and continuous films with atomic terraces at 450 °C growth temperature and a low flux ratio of 2.5 to exclusively disconnected island growth of large height but smooth top surfaces at lower temperatures and/or higher flux ratios. Surprisingly, the tetragonal P4/nmm crystal structure of beta-FeSe was maintained for all investigated films and the *in-situ* observed diffraction pattern in reflection high energy diffraction also maintained the streaky pattern characteristic for smooth FeSe films even for the samples with the most pronounced island growth resulting in a root mean square atomic force microscopy roughness of more than 18 nm. Smaller flux ratios than 2.5 resulted in mixed – beta-FeSe/elemental Fe – phase samples. FeSe films grown under optimized conditions at 450 °C and a flux ratio of 2.5 (but without any post-growth UHV anneal) and capped with the commonly used FeTe (300 °C) and elemental Te (room temperature) layers yielded superconducting onset temperatures of about 30 K and a TC of 20 K.

12:00pm **MI+2D+TF-ThM-13 Unraveling Picosecond Dynamic Material Processes on the Mesoscale by X-Ray Microscopy***, **Thomas Feggeler,*** University of California, Berkeley*; J. Lill, D. Guenzing, R. Meckenstock, D. Spoddig, B. Zingsem,* University of Duisburg-Essen, Germany*; M. Efremova,* Eindhoven University of Technology, Netherlands*; S. Pile, T. Schaffers,* Johannes Kepler University, Austria*; S. Wintz,* Max Planck Institute for Intelligent Systems, Germany*; M. Weigand,* Helmholtz Center Berlin, Germany*; A. Ney,* Johannes Kepler University, Austria*; M. Farle, H. Wende, K. Ollefs,* University of Duisburg-Essen, Germany*; D. Shapiro,* Lawrence Berkeley National Laboratory*; R. Falcone,* University of California, Berkeley*; H. Ohldag,* Lawrence Berkeley National Laboratory

Dynamic processes govern a multitude of phenomena in physical, chemical and material sciences. Time- and spatially resolved element-specific monitoring of such processes is crucial in the understanding of phenomena like magnetization dynamics, battery charging and discharging, and phase transitions of several kinds. Time-Resolved Scanning Transmission X-ray Microscopy (TR-STXM) [1] is a versatile tool fulfilling these demands on the mesoscopic scale, offering element-specific observations with sub 50 nm spatial resolution and picosecond time sampling. By introducing a phased-locked-loop excitation synchronization scheme, TR-STXM also allows to sample dynamics originating from continuous wave excitations. This presentation introduces the TR-STXM technique and its principle of operation, and the setup developed at the Advanced Light Source at Lawrence Berkeley National Laboratory. The presentation is complemented by examples of dynamic magnetic measurements, which allow for local monitoring of magnetization dynamics in fields such as spintronics, magnonics, biomedical and energy related applications. Here we demonstrate TR-STXM results on Py/Co microstructures [2], Py stripe ensembles [3] and magnetite nanoparticle chains inside magnetotactic bacteria *Magnetospirillum Magnetotacticum* [4,5], showcasing localized uniform and non-uniform resonant magnetic responses, supplemented by micromagnetic simulations in good agreement.

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[1] T. Feggeler, A. Levitan, et al. J. Electron Spectrosc. Relat. Phenom. 2023. **267**: 147381.

[2] T. Feggeler, R. Meckenstock, et al. *Sci. Rep.*2022, **12**:18724.

[3] S. Pile, T. Feggeler, et al. *Appl. Phys. Lett.* 2020, **116**(7): 072401.

[4] T. Feggeler, R. Meckenstock, et al. *Phys. Rev. Res.* 2021, **3**(3): 033036.

[5] T. Feggeler, J. Lill, et al. *New J. Phys.* 2023, **25**(4): 043010.

Author Index

Bold page numbers indicate presenter