PCSI
Room Ballroom South - Session PCSI-SuE
Probing Exotic Order Parameters with Photoemission Spectroscopy

Moderator: Chris Leighton, University of Minnesota

7:30pm **PCSI-SuE-1 Searching for the Excitonic Insulator State in Quantum Materials***, **Edoardo Baldini,*** The University of Texas at Austin **INVITED**

The excitonic insulator is an electronically driven phase of matter that emerges upon the spontaneous formation and Bose condensation of excitons. Detecting this exotic order in candidate materials is a subject of paramount importance, as the size of the excitonic gap in the band structure establishes the potential of this collective state for superfluid energy transport. However, the identification of this phase in real solids is hindered by the coexistence of a structural order parameter with the same symmetry as the excitonic order. Only a few materials are currently believed to host a dominant excitonic phase, Ta_2NiSe_5 being the most promising. In this talk, I will describe how advanced protocols based on time- and angle-resolved photoemission spectroscopy can shed light on primary order parameter of a candidate excitonic insulator [1]. Finally, I will discuss the opportunities offered by the development of novel momentum microscopy tools to extend these studies to the realm of two-dimensional material flakes that may host similar physics.

[1] E. Baldini et al., Proc. Natl. Acad. Sci. 120, e2221688120 (2023)

8:10pm **PCSI-SuE-9 Comparative Study on Non-Linear and Linear Least Square Analyses Applied to X-Ray Induced Auger Electron Spectroscopy Transitions***, A. Gagliardi,* CNRS, ILV, France*; N. Fairley,* Casa Software Ltd, UK*; **Solene Bechu,*** CNRS, ILV, France

With the exception of the modified Auger parameter, X-ray induced Auger electron (X-AES) transitions aren't exploited to their full potential. Indeed, they can provide as much information (oxidation degree, chemical environment, atomic composition) as the classic photopeaks used in XPS, but their shapes' complexities limit their decompositions.

We offer here to explore the decomposition of Ga $L_3M_{4,5}M_{4,5}$ and In $M_{4,5}N_{4,5}N_{4,5}$ X-AES lines by comparing two approaches: the non-linear [1] and the linear [2] least square analyses. By combining non-linear and linear fitting procedures, PCA, and vectorial method [3], those two analyses have been implemented on the materials $Cu(In_xGa_{1-x})Se_2$ and InSb, to unveil their surface oxidation when exposed to different atmospheres. The growth of oxide phases (Ga_2O_3 and In_2O_3, determined by PCA, vectorial method and by comparison with reference spectra) was monitored on the X-AES lines with non-linear and linear approaches, showing a very good coherence between both, as illustrated in Fig 1 for the In $M_{4,5}N_{4,5}N_{4,5}$ X-AES transition of InSb. We will provide keys to perform non-linear and linear least squares analysis on X-AES lines, to explore new approaches for chemical determination.

[1] J.J. Moré, Numer. Anal. **630**, 105 (1978).

[2]G.H. Golub and C. Reinsch, Linear Algebr. **420**, 403 (1971).

[3] S. Béchu et al., Appl. Surf. Sci. **447**, 528 (2018).

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8:15pm **PCSI-SuE-10 Probing Electrons and Light in Nanomaterials Using the Photoelectric Effect***, **Taisuke Ohta**, A. Boehm, S. Gennaro, C. Doiron, A. Kim, K. Thuermer, J. Sugar, C. Spataru,* Sandia National Laboratories*; J. Fonseca Vega, J. Robinson,* Naval Research Laboratory*; T. Beechem,* Purdue University*; M. Sinclair, I. Brener, R. Sarma,* Sandia National Laboratories

The photoelectric effect is sensitive to both the occupied electronic density of states and the electromagnetic field distribution. Thus, capturing the energy, yield, and spatial origin of photoelectrons from the sample enables us to examine local electronic properties and light-matter interactions concurrently. In this talk, we will describe two case studies using photoelectron emission microscopy (PEEM), revealing the spatial variations of Schottky barrier height between WS_2 and Au, and the local electromagnetic near-field profiles of Si metasurfaces. We will discuss the impact of crystallographic facets of Au grains as well as how the attractive interaction of Au with WS_2 can modify the crystallographic alignment among WS_2 layers. For near-field imaging, we will demonstrate the sensitivity of photoemission yield to the light absorptivity in visible to near infrared range, and evaluate the field profiles around Si meta atoms at the sub-(photon) wavelength scale on and off resonance excitation. Altogether we will discuss the potential of photoelectron imaging to examine the intertwined light-matter coupled phenomena abundant in two-dimensional and quantum materials.

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8:20pm **PCSI-SuE-11 Layer-by-Layer Engineering and Deciphering of Topological Orders in Magnetic Topological Insulators***, W. Lee,* University of Chicago*; S. Fernandez-Mulligan,* Yale University*; H. Tan,* Weizmann Institute of Science, Israel*; C. Yan,* University of Chicago*; Y. Guan, S. Lee, R. Mei, C. Liu,* Pennsylvania State University*; B. Yan,* Weizmann Institute of Science, Israel*; Z. Mao,* Pennsylvania State University*; **Shuolong Yang**,* University of Chicago **INVITED**

The advent of intrinsic magnetic topological insulators enables us to envisage various low-dimensional topological orders, such as the quantum anomalous Hall insulators and the axion insulators, at realistic cryogenic temperatures. These materials are represented by $MnBi_2Te_4$ and its derived superlattices $MnBi_{2n}Te_{3n+1}$. However, it has been controversial whether these materials exhibit the key ingredient for magnetic topological phases: an energy gap due to the time-reversal symmetry breaking. Moreover, the construction of high-quality magnetic topological insulators at the ultrathin limit has met significant challenges. In this talk, I will present a new technique, layer-encoded frequency-domain photoemission spectroscopy, which allows us to decipher the layer origins of various electronic states. By encoding layer indices with intralayer phonon frequencies, we measure the strengths of coupling with layer-specific phonons. This experiment reveals that the topological surface states on antiferromagnetic $MnBi_4Te_7$ are partially relocated to the nonmagnetic layers, reconciling the mystery of vanishing broken-symmetry gaps [1]. Moreover, I will present our recent progress on the "carpet-growth" of Bi_2Te_3 ultrathin films and $MnBi_2Te_4/Bi_2Te_3$ heterostructures using molecular beam epitaxy. These thin films extend coherently across a millimeter spatial scale without disruptions by substrate step edges. Angle-resolved photoemission spectroscopy studies yield unprecedentedly sharp electronic structures in agreement with first-principles calculations layer-by-layer, and suggest opportunities to realize the quantum spin Hall effect and quantum anomalous Hall effect at near-ambient temperatures [2].

[1] W. Lee *et al.*, Nature Physics **19**, 950-955 (2023).

[2] W. Lee *et al.,* Submitted (2023).

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