Novel Trends in Synchrotron and FEL-Based Analysis Focus Topic
Room: 112 - Session SA-MoA

New Insights in Correlated Materials, Organic Materials and 2D Solids
Moderator: Herrmann Dürr, Stanford University, Petra Rudolf, University of Groningen

2:20pm **SA-MoA1 Operando Soft X-ray Spectromicroscopy on Electronic States of Graphene Transistors**, ***Hirokazu Fukidome***, Tohoku University, Japan

Graphene, the tiny monolayer honeycomb, is promising for high-speed communication owing to excellent electronic properties, such as carrier mobility and saturation velocity, arising from a linear band dispersion, and vanishment of short-channel effects owing to ultrathinness of graphene. The ultrathinness, on the other hand, deteoriates device performances because the ultrathinness easily induces interface modulation of electronic properties of the graphene channel in the graphene transistor. This produces a gap between material properties of graphene layers and device performances of graphene transistor.

To bridge the gap, we have developed operando observation, i.e. observation under operation (gate-bias application in this work), of electronic states using soft x-ray spectromicroscopies with spatial resolutions of 20-100 nm, such as photoemission electron microscopy (PEEM) [1] and three-dimensional scanning photoelectron microscopy (3D nano-ESCA) [2]. This operando PEEM reveals gate-bias-dependent modulation of electronic states of the lateral interface between the graphene channel and contact metal. This interface modulation is brought about by the charge transfer between the graphene channel and the metal contact in the lateral direction. The charge transfer region is relatively large owing to a limited density of states near the Dirac point of graphene. In addition, the operando 3D nano-ESCA directly evidences the linear band dispersion of the graphene transistor in operation by doing a pinpoint C 1s core-level spectromicroscopy at the center of graphene channel, followed by analyzing the shift of the graphene peak by the gate bias.

In conclusion, these operando spectroscopies provides valuable information on graphene transistors. Further operando spectromicroscopy study is in progress to clarify the reason for degradation of high-frequency performances of the graphene transistor [3].

Profs. Oshima, Horiba and Kotsugi and Dr. Nagamura and staff members of BL17SU and BL07LSU of SPrinb-8 are gratefully appreciated for the operando spectromicroscopy. This work has been done partly as the projects of BL07LSU and BL17SU at SPring-8 and also as the academic-industry alliance NEDO project.

[1] H. Fukidome et al., Sci. Rep. 4 (2014) 3713.

[2] H. Fukidome et al., Appl. Phys. Exp. 7 (2014) 065101

[3] M.-H. Jung, H. Fukidome et al., Proc. IEEE 101 (2013) 1603.

2:40pm **SA-MoA2 Micro-metric Electronic Patterning of a Topological Band Structure using a Photon Beam**, ***Nick de Jong***, *E. Frantzeskakis, B. Zwartsenberg, Y. Huang, B.V. Tran, P. Pronk, E. van Heumen, D. Wu, Y. Pan*, University of Amsterdam, *M. Radovic*, Paul Scherrer Institute, *N.C. Plumb, N. Xu*, Paul Scherrer Institut, *M. Shi*, Paul Scherrer Institute, *A. de Visser, M.S. Golden*, University of Amsterdam

We discuss a method of "writing" spatial micro-metric patterns in the electronic surface band structure of the topological insulator (TI) $Bi_{1.46}Sb_{0.54}Te_{1.7}Se_{1.3}$. Due to fine-tuning of the bulk stoichiometry this material is truly insulating, making it a promising candidate for applications where the special transport properties of the topological protected surfaces states are necessary. However despite the insulating character bulk in transport experiments, the spectroscopic fingerprint of $Bi_{1.46}Sb_{0.54}Te_{1.7}Se_{1.3}$ is not that of an insulator. Due to band bending, the conduction band is partly occupied at the surface of the material. We present a way to counteract the occupation of the conduction band in both global and local spatial scales. Namely, we make use of an extreme ultra violet photon beam with superband gap energy and a flux exceeding 10^{21} photons/(s m^2) as a "writing tool". This is a three-step process. First an area of approximately 500 mm x 500 mm is mapped out by angle resolved photoemission spectroscopy (ARPES), taking a spectrum of the topological surface state at each sample location. Secondly, we expose selected sample locations to a higher fluence photon beam. These locations form a pre-defined pattern. Finally, the first map of the area is then again by ARPES. In this way we are able to shift the electronic surface band structure and drive the bulk conduction band to the unoccupied part of the spectrum. This shift is observed to be very local and in our case is only limited by the size of the beam and not by the approach itself.

3:00pm **SA-MoA3 Switching 2D Materials Properties with Light**, ***Alessandra Lanzara***, University of California, Berkeley **INVITED**

Understanding how superconductivity emerges from other competing phases and how this balance evolves through the phase diagram is one of the biggest challenges in the field of high Tc superconductors. By using high resolution time- and angle- resolved photoemission spectroscopy (tr-ARPES) we are able to directly probe the effects of optical excitation on the electronic structure of cuprate superconductors, and study the resulting quasiparticles, superconducting gap, and Cooper pair formation dynamics near their natural time- scales. Direct measurements of these and other non-equilibrium spectral phenomena through the phase diagram further illustrate the power of this unique time- and momentum-resolved spectroscopy. These results reveal new windows into the nature of the pairing interaction in high Tc superconductors.

3:40pm **SA-MoA5 Science-driven Requirements for Soft X-ray Free Electron Lasers**, ***Fulvio Parmigiani***, Elettra-Sincrotrone Trieste, Italy **INVITED**

Starting from the archetypal FERMI externally seeded FEL, recent theoretical and experimental progress has shown the possibility of producing fully coherent, variable polarization and tunable, soft-X-ray, ultra-short pulses at high repetition rate. This ultimate achievement will unlock the gate for performing X-ray-based experiments that are qualitatively different from those available at any current or planned X-ray source. Here we will review the experiments and the ideas that represent the science frontier in soft X-ray, time-resolved spectroscopy, coherent imaging and scattering experiments. These studies will lead to an understanding of fundamental dynamics, occurring on the ultrafast time and nanometer spatial scales, needed for addressing a broad range of science essential for resolving our complex and long-term energy challenges, environmentally urgent questions and demanding problems in bioscience and novel materials.

4:20pm **SA-MoA7 Revealing Spin Texture Dynamics in Complex Materials via Time-resolved Resonant Soft X-ray Scattering**, ***Robert Schoenlein***, Lawrence Berkeley National Laboratory **INVITED**

Self-organized mesoscale spin textures emerge in complex materials due to coupling between charge, spin, and lattice degrees of freedom, and play a significant role in establishing the exotic properties of these materials. Here we focus on two examples: (1) topologically-protected spin vortices (Skyrmions) in the insulating multiferroic Cu_2OSeO_3 which result from a combination of symmetric spin-exchange interactions, and antisymmetric exchange resulting from a Dzyaloshinskii-Moriya (DM) interaction, and (2) helical spin states in the lanthanide metal Dy which result from competition between spin-orbit coupling, magneto-elastic effects, and long-range exchange coupling mediated by the indirect RKKY interaction.

A key scientific challenge is to understand the origin of these ordered spin textures, and the fundamental mechanisms and time-scales for manipulating these phases, in order to develop a knowledge base for potential technology applications. Resonant X-ray scattering (RXS) is a powerful direct probe of charge, spin, and orbital ordering in complex materials. Current synchrotron X-ray sources and new X-ray free-electron lasers enable RXS to be applied in the time domain. This provides an important new route to disentangle the cause-effect interactions that drive the formation and evolution of spin textures in complex materials.

Optical pump and resonant X-ray scattering studies of the skyrmion phase in Cu_2OSeO_3 reveal six-fold symmetric magnetic peaks that appear as satellites around the (001) Bragg peak. Transient optical excitation at 2.3 eV (above band gap) suppresses the spin ordering on a ~40 ps time scale – significantly faster than from excitation below gap at 1.5 eV, indicating an electronically-driven collapse of the skyrmion phase. We will discuss the fluence dependence of the conical and skyrmion phases and the motion of the ordering wavevector in response to excitation above and below the insulating gap.

We also report on recent studies of an epitaxially grown Y/Dy/Y multilayer film to understand the dynamics of the core-level spin helix in response to excitation of the conduction electrons responsible for the exchange interactions. Ultrafast optical excitation at 1.5 eV results in ultrafast injection of unpolarized spins into the 500 nm Dy film via nonequilibrium diffusion. The subsequent dynamics of the helical phase, revealed by time-resolved resonant X-ray scattering, differ significantly from those observed

in ferromagnetic materials due to the relationship between the core spins and conduction electron Fermi surface nesting.

5:00pm **SA-MoA9 Electronic States of Functional Molecular Materials Probed by Low-energy Excitation**, ***Satoshi Kera***, Institute for Molecular Science, Japan **INVITED**

Understanding the impacts of electron-phonon coupling as well as weak intermolecular interaction on the electronic state is required to discuss the mechanism of charge transport in functional molecular materials. Ultraviolet photoelectron spectroscopy (UPS) is known to be a powerful technique to study the electronic states. However, the experimental study of fine features in the highest occupied molecular orbital (HOMO) state has not been progressed till recently due to difficulty in the sample preparation, damages upon irradiation and so on, though it can offer a variety of key information, that is essential to comprehend charge-hopping transport and small-polaron related transport in the ordered monolayer film [1] as well as to coherent band transport in the molecular single crystal [2,3]. We present recent findings regarding on the precise measurements of electronic states for large aromatic organic molecular materials by using low-energy excitation UPS.

Use of low-energy excitation realizes unique experiments to find out the followings as an advantageous for the organic materials; i) low-kinetic energy of photoelectron may achieve resonance excitation channel to open eyes for many events accessed, e.g. on a degree of electron cloud localization, inelastic scattering phenomena at the interfaces and a breaking the sudden approximation, and ii) high-photoionization cross section and bulk-sensitive probe may detect a quasi-particle state in very narrow HOMO band. Combining all findings above mentioned, characteristics of an electron in the functional molecular material has been embossed.

[1] S. Kera et al., Prog. Surf. Sci. 84 (2009) 135.

[2] N. Ueno et al., Prog. Surf. Sci. 83 (2008) 490.

[3] S. Ciuchi et al., Phys. Rev. Lett. 106 (2011) 166406.

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