Soft X-ray ARPES: From bulk materials to buried impurities and heterostructures

Vladimir N. Strocov*[1], Marius-Adrian Husanu[1], Alla Chikina[1], Jonas Krieger[1], J. Krempaský[1], Leonid L. Lev[2], Claudia Cancellieri[3], and Masaki Kobayashi[4]

[1] *Swiss Light Source, Paul Scherrer Insitute, Villigen-PSI, Switzerland*

[2] *Kurchatov Institute national Research Center, Moscow, Russia*

[3] *Joining Technologies and Corrosion, EMPA, Dbendorf, Switzerland*

[4] *Dept. of Applied Chemistry, University of Tokyo, Tokyo, Japan*

* *vladimir.strocov@psi.ch*

Soft-X-ray ARPES (SX-ARPES) in the energy range around 1 keV benefits from enhanced photoelectron escape depth, sharp definition of 3D electron momentum **k**, and resonant photoexcitation delivering elemental and chemical state specificity. The main challenge of this technique is a drop of the valence band cross-section by 2-3 orders of magnitude which has to be compensated by high flux of incident X-ray radiation. SX-ARPES instrumentation at Swiss Light Source [1] is hosted by the ADRESS beamline delivering soft X-rays in the energy range from 300 to 1600 eV with resolving power E/DE up to 30K. Photon flux above 10^{13} photons/s/0.01%BW combined with optimized endstation geometry overpowers the cross-section problem and allows stretching SX-ARPES to the most photon-hungry cases of buried impurities and heterostructures.

We illustrate applications of SX-ARPES to bulk materials with the perovskite $La_{1-x}Sr_xMnO_3$ where SX-ARPES resolves full 3D topology of its Fermi surface connected with the magnetoresistance [2]. Other cases include charge-density waves in VSe_2 originating from 3D nesting of its Fermi surface [3], Weil semimetals, etc. Applications to buried semiconductor interfaces are illustrated by AlGaN/GaN high electron mobility transistor (HEMT) heterostructures where SX-ARPES resolves Fermi surface, band dispersions and Fourier composition of the interfacial quantum well states [4]. A "drosophila" of buried oxide interfaces is $LaAlO_3/SrTiO_3$. Resonant photoexcitation at the Ti L-edge resolves the interface quantum well subbands, whose peak-dip-hump spectral function manifests a multiphonon polaronic nature of the interface charge carriers fundamentally limiting their mobility [5]. Further cases are multiferroic $BaTiO_3/La_{1-x}Sr_xMnO_3$ interfaces, EuO/Si spin injectors, etc. An example of impurity systems is the magnetic semiconductor GaMnAs, where resonant Mn L-edge photoexcitation identifies the ferromagnetic Mn impurity band as well as its hybridization with the host GaAs bands [6]. Other cases include magnetic V impurities in the topological Bi_3Se_2 competing with the quantum anomalous Hall effect [7], Mn impurities in the ferroelectric Rashba semiconductor GeTe [8], etc. These examples unfold the spectroscopic potential of SX-ARPES in application to the heterostructure and impurity systems in the heart of the present and future electronic and spintronic devices.

References

[1] V.N. Strocov *et al*, Synchr. Rad. News **27**, N2 (2014) 31

[2] L.L. Lev *et al*, Phys. Rev. Lett. **114** (2015)

[3] V.N. Strocov *et al*, Phys. Rev. Lett. **109** (2012) 086401

[4] L.L. Lev *et al*, Nature Comm. (accepted, 2018)

[5] C. Cancellieri *et al*, Nature Comm. **7** (2016) 10386

[6] M. Kobayashi *et al*, Phys. Rev. B **89** (2014) 205204

[7] J. Krieger *et al*, Phys. Rev. B **96** (2017) 184402

[8] J. Krempaský *et al*, Nature Comm. **7** (2016) 13071