k-resolved electronic structure of buried oxide and semiconductor heterostructures

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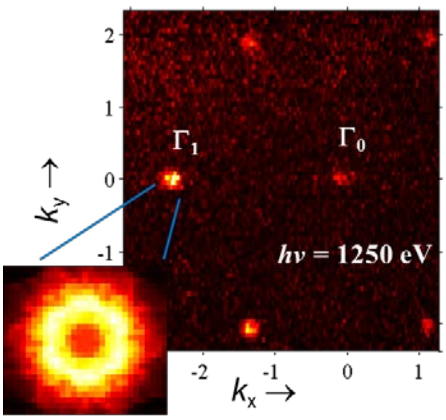
Pushing angle-resolved photoelectron spectroscopy (ARPES) into the soft-X-ray energy range extends its **k**-resolving abilities from the conventional surface physics to buried heterostructures [1] as a result of enhanced photoelectron escape depth and a possibility of resonant photoexcitation delivering an elemental and chemical state specificity.

Oxide interfaces. A "drosophila" buried oxide interface is LaAlO3/SrTiO3 (LAO/STO) embedding mobile 2D electrons. Accentuated with resonant photoexcitation, ARPES signal of the Ti t_{2g} derived interface charge carriers resolves the orbital ordering and band structure in the interface quantum well (QW) states. Luttinger count of the experimental Fermi states identifies phase separation, which is a key element in the percolative superconductivity and weak ferromagnetism of LAO/STO. Furthermore, the temperature dependent peak-dip-hump spectral lineshape manifests polaronic nature of the interface charge carriers [2] where coupling of electrons to the breathing LO3 phonon mode limits their low-temperature mobility, and coupling to the polar TO1 mode, responsible for its giant dielectric constant of STO, causes a dramatic mobility drop with temperature. Doping of the LAO/STO interface with oxygen vacancies, affecting electron-phonon coupling, opens ways to tune the interfacial mobility. The polaronic physics, combining the fast electronic and slow lattice degrees of freedom, is particularly attractive for time-resolved ARPES experiments.

Semiconductor interfaces. Our example of buried semiconductor interfaces is an AlGaN/GaN high electron mobility transistor (HEMT) heterostructure. The soft-X-ray ARPES experiment yields the fundamental band structure characteristics – Fermi surface (Figure), band structure and effective mass – of the QW states in the conducting GaN channel beneath a 4-nm thick AlGaN barrier layer. Overlooked in the transport measurements, the QW states show significant lateral anisotropy resulting from piezoelectrically active atomic relaxation at the interface. This finding suggests technological measures to increase electron mobility in GaN-HEMTs. Periodic oscillations of the ARPES signal as a function of photon energy inform Fourier composition of the QW wavefunctions formed by quantization of the bulk GaN states.



Further examples of **k**-resolved electronic structure studies on buried heterostructures include multiferroic $BaTiO_3/La_{1-x}Sr_xMnO_3$ interfaces, EuO/Si spin injectors, Al/InAs interfaces prototypic of the Majorana fermions, magnetic impurities in GaMnAs, InFeAs [3] and ferroelectric Rashba semiconductor GeMnTe [4] as well as other prototype systems of future electronic and spintronic devices.

[1] V.N. Strocov *et al*, Synchr. Rad. News **27**, N2 (2014) 31
[2] C. Cancellieri *et al*, Nature Comm. **7** (2016) 10386
[3] M. Kobayashi *et al*, Phys. Rev. **B** 89 (2014) 205204
[4] J. Krempaský *et al*, Nature Comm. **7** (2016) 13071