Probing ultra-thin high density arsenic delta-layers in silicon with SX-ARPES

Procopios Constantinou, Taylor Stock, Neil Curson, Steven Schofield, Vladimir Strokov, and Gabriel Aeppli

UCL, LCN, UK

We present the first fully three-dimensional mapping of the Brillouin zone of atomically thin doping layers ('delta-layers') in silicon using soft x-ray angle-resolved photoemission spectroscopy (SX-ARPES). We measure the Fermi surfaces and band dispersions of the six conduction band valleys, and demonstrate that the kz dispersion of the out-of-plane valleys provide the most sensitive measurement of electronic two-dimensionality (2D) in silicon delta-layers yet achieved. We show that a fundamentally 2D electronic confinement exists, and that in general, arsenic delta-layers are more 2D than their counterparts fabricated with phosphorous under identical conditions. Our most highly confined arsenic delta-layers exhibits a complete absence of dispersion in kz, and an electronic confinement <1 nm. We also determine the absolute charge distributions within each of the valley sub-bands and show excellent agreement with theoretical calculations. Our results suggest that using arsenic in place of the currently favored phosphorous donors can provide new opportunities for the creation of novel atomic-scale quantum-electronic devices in silicon.