Electronic structure of exfoliated black phosphorus and black arsenic measured by μ-ARPES

Florian Margot
Simone Lisi, Irène Cucchi, Edoardo Cappelli, Andrew Hunter, Ignacio Gutiérrez-Lezama, KeYuan Ma, Fabian von Rohr, Christophe Berthod, Marco Gibertini, Samuel Poncé, Nicola Marzari, Anna Tamai, Alberto Morpurgo and Felix Baumberger
Departement of quantum matter physics, University of Geneva, quai Ernest-Ansermet 24, CH-1211 Geneva, Switzerland
florian.margot@unige.ch

2D semiconducting materials represent an interesting opportunity to pursue the desired scaling of transistors for the electronic industry. Black phosphorus (BP) and black arsenic (BAs), direct gap semiconductor with strongly thickness dependent anisotropic properties, are two prominent candidates to replace silicon in this application. Experiments have indeed shown that in relatively thin body BP FETs (7-15 nm), mobilities of the order of 1000 cm^2/Vs can be achieved at room temperature, with appropriate on-off ratio of the order of 10^5 and near ideal subthreshold swing [1-3]. However, despite the interest in BP and a large body of transport and optical studies, little is known about its momentum-dependent electronic structure. To date, one thus commonly resorts to electronic structure calculations to interpret a range of measurements. Given the large spread of results from ab-initio electronic structures, the validity of this approach for the precise evaluation of device behaviour and performance is unclear. To remedy this situation, we performed μ-ARPES experiments on very thin encapsulated BP and BAs flakes. Our measurements unveil the layer-dependent quantum well state structure in the valence band of these two materials and allow us to characterise the anisotropy of the quasi-particle band structure near the valence band edge. We further propose an eight parameters tight-binding model that captures the dispersion of the subbands in the relevant portion of the Brillouin zone. Finally, our measurements also uncover satellite peaks, present for all measured thicknesses and for each subband. We tentatively attribute these satellites to electron-phonon coupling.

References

[1] Chen, X. et al., ACS nano, 2018, 12, 5003-5010
[2] Chen, X., Wu, Y., Wu, Z. et al., Nat. Commun 6, 2015, 7315
[3] Liu, X., Ang, KW., Yu, W. et al., Sci Rep 6, 2016, 24920

Figures

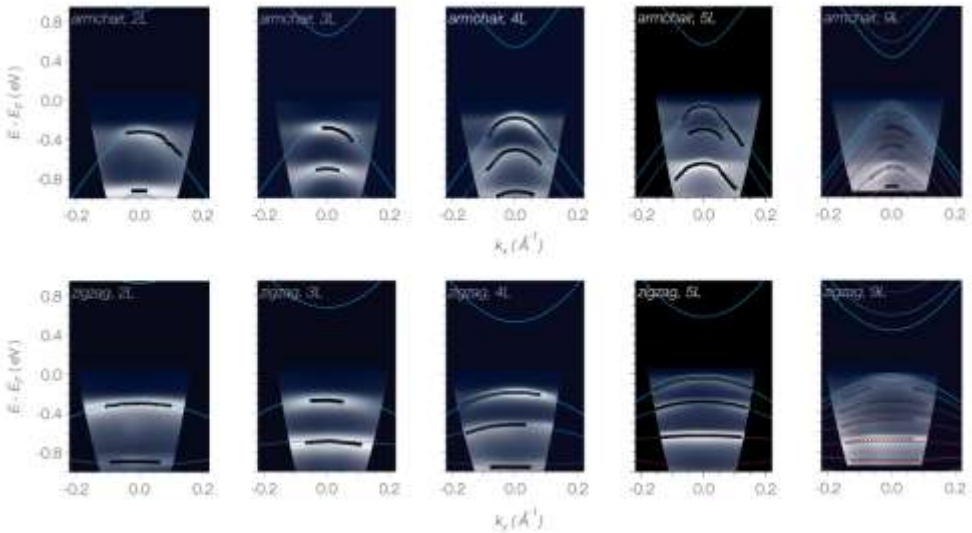

Figure 1: ARPES spectra acquired along the high symmetry directions (armchair, zigzag) of few layer encapsulated BP flakes from 2L to 5L and for a thicker 9L sample. Filled black and hollowed dots are extracted quasi-particle dispersions. The continuous coloured lines are the tight-binding bands obtained by fitting the extracted dispersions.