Bandgap opening in bilayer graphene and 2D magnetic insulators van der Waals interfaces

Giulia Tenasini,[1,2] David Soler Delgado,[1,2] Zhe Wang,[1,3] Enrico Giannini,[1] Ignacio Gutiérrez-Lezama,[1,2] and Alberto F. Morpurgo[1,2]

[1] *Department of Quantum Matter Physics, University of Geneva, 24 Quai Ernest Ansermet, CH-1211 Geneva, Switzerland*
[2] *Group of Applied Physics, University of Geneva, 24 Quai Ernest Ansermet, CH-1211 Geneva, Switzerland*
[3] *MOE Key Laboratory for Nonequilibrium Synthesis and Modulation of Condensed Matter, School of Physics, Xi'an Jiaotong University, Xi'an,710049, China*

The application of a perpendicular electric field can controllably tune bilayer graphene (BLG) into an insulating state, disclosing the possibility of tailoring the material bandstructure with sufficiently large electric fields [1, 2]. Van der Waals (vdW) interfaces can naturally host built-in electric fields perpendicular to the layers, whenever the band alignment between the constituent two-dimensional (2D) materials is such to favor a significant charge transfer. Here, we report the observation of a bandgap in BLG when placed in contact with a 2D magnetic insulator, specifically a chromium tri-halide CrX_3 (X = Cl, Br, I). By means of field-effect measurements in BLG/CrX_3 heterostructures we detect a sharp conductance suppression of over five order of magnitude in the transfer curves below 50 K, indicative of the presence of a robust insulating state in BLG. We attribute the bandgap opening to the considerable charge transfer—as high as 10^{13} cm^{-2}—occurring from BLG to the localized d-bands of CrX_3, that induces a strong hole doping in graphene and generates an electric field at the interface. From the Arrhenius dependence we can extract the activation energies and the corresponding bandgaps for the three vdW heterostructures, which result in good agreement with the theoretical prediction for the displacement fields inferred from the doping charge density measured in BLG. Furthermore, the geometry of our devices allows us to relate a gate voltage change to a shift in chemical potential and to independently estimate the bandgap values from transfer curves. Despite this simple picture works remarkably well for BLG/$CrCl_3$ where the bandgap is $\sim$ 170 meV, the detailed electrostatic equilibrium at the interface has to be considered for a reliable modeling of the gap in the three heterostructures. Our results pave the way for engineering an insulating state in BLG by assembling vdW interfaces of suitably chosen 2D materials.

[1] J. Ostinga et al., Gate-induced insulating state in bilayer graphene devices, Nature Materials 7, 151-157 (2008).
[2] Y. Zhang et al., Direct observation of a widely tunable bandgap in bilayer graphene, Nature 459, 820-823(2009).