Twist-controlled resonant tunnelling in graphene/boron-nitride/graphene heterostructures

J. R. Wallbank, A. Mishchenko, J.S. Tu, Y. Cao, R.V. Gorbachev, M.T. Greenaway, V.E. Morozov, S.V. Morozov, M.J. Zhu, S.L. Wong, F. Withers, C.R. Woods, Y.-J. Kim, K. Watanabe, T. Taniguchi, E.E. Vdovin, O. Makarovsky, T.M. Fromhold, V.I. Falko, A.K. Geim, L.Eaves, K.S. Novoselov.

Department of Physics, Lancaster University, Lancaster, LA1 4YB, UK
j.wallbank@lancaster.ac.uk

Abstract

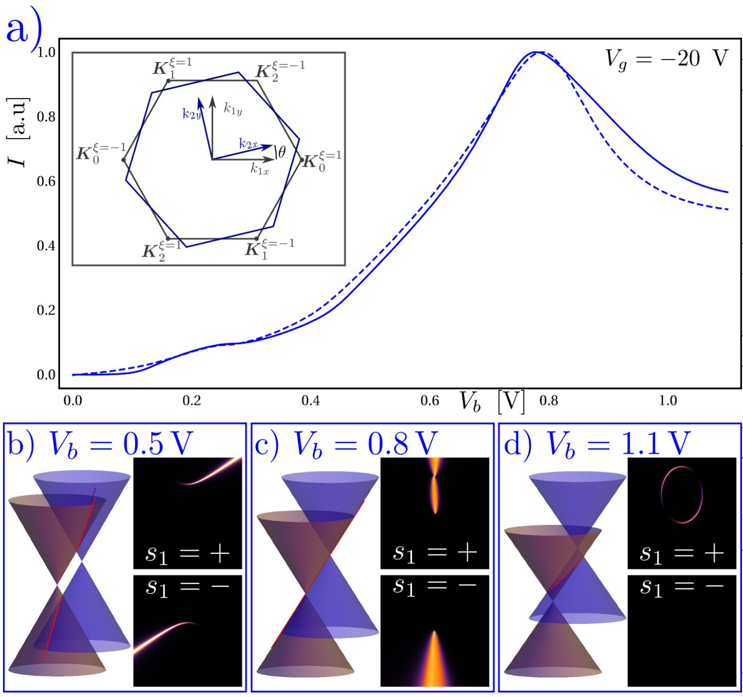
Recent developments in van der Waals heterostructures made from stacks of two-dimensional crystals have already led to the observation of new physical phenomena, such as the metal-insulator transition and Coulomb drag, and to the realisation of functional devices, such as tunnel diodes, and tunnel transistors. An unprecedented degree of control of the electronic properties is available not only by means of the selection of materials in the stack, but also by adjusting the relative orientation of the component layers.

In this talk I shall discuss how careful alignment of the crystallographic orientation of two graphene electrodes, separated by a layer of hexagonal boron nitride (hBN) in a transistor device, can achieve resonant tunnelling with conservation of electron energy, momentum and, potentially, chirality [1]. This leads to resonance peaks and negative differential conductances in the device characteristics, which, in turn, can be used to induce a tuneable radio-frequency oscillatory current. Also, the application of a magnetic field in the plane of the two graphene layers can be used to reveal the effects of graphene's chirality on the tunnelling current, and may lead to valley polarised currents. Finally, I note that the momentum and velocity distribution of the tunnelling electrons is highly anisotropic, which may lead to interesting effects in a ballistic device.

References

[1] A. Mishchenko, J. S. Tu, Y. Cao, R. V. Gorbachev, J. R. Wallbank, M.T. Greenaway, V. E. Morozov, S. V. Morozov, M. J. Zhu, S. L. Wong, F. Withers, C. R. Woods, Y.-J. Kim, K. Watanabe, T. Taniguchi, E. E. Vdovin, O. Makarovsky, T. M. Fromhold, V. I. Falko, A. K. Geim, L. Eaves, K. S. Novoselov, Nature Nanotechnology **9**, 808 (2014).

Figures



(a) The measured (solid curve) and theoretically calculated (dashed curve) tunnelling currents, displaying the resonant peak at a bias voltage of V_b≈0.8V.
(b-d) The conditions of energy and momentum conservation, which enable the tunnelling of Dirac electrons, are visualized in the left panels by the line of intersection (red) of the Dirac cones in the two graphene layers. The shift of these in momentum is set by the misalignment of the Brillouin zones of the two graphene layers (see inset of (a)), while the displacement along the energy axis is controlled by the applied bias voltage. Importantly, panel (c) displays the conditions for which the main resonant peak occurs. The tunnelling probability for an electron is also modulated by the interference between the electron amplitudes on graphene's A/B carbon sites (right panels).