A Valley Valve and Electron Beam Splitter in Bilayer Graphene

Jing Li[1], Rui-Xing Zhang[1], Zhenxi Yin[1], Jianxiao Zhang[1], Kenji Watanabe[2], Takashi Taniguchi[2], Chaoxing Liu[1], Jun Zhu[1,3]

[1] *Department of Physics, The Pennsylvania State University, University Park, Pennsylvania 16802, USA.*

[2] *National Institute for Material Science, 1-1 Namiki, Tsukuba 305-0044, Japan.*

[3] *Center for 2-Dimensional and Layered Materials, The Pennsylvania State University, University Park, Pennsylvania 16802, USA.*

Conventional CMOS field effect transistors control current transmission by controlling the charge of carriers. The advent of two-dimensional materials with hexagonal crystal symmetry offers a new electronic degree of freedom, namely valley, the manipulation of which could potentially be exploited to develop new paradigms of electronic applications dubbed “Valleytronics”. I will discuss our work on realizing a valley valve and tunable electron beam splitter in bilayer graphene[1][2].

In high-quality bilayer graphene, the application of a perpendicular electric field opens a tunable band gap, the sign of which can be reversed by reversing the polarity of the applied E-field. Theory predicts the existence of valley-momentum locked one-dimensional conducting channels at the artificial domain wall of two oppositely gapped bilayer graphene regions[3]. Known as the “kink states”, they are hallmarks of the quantum valley valley Hall effect. The helicity of the kink states can be controlled by the polarity of the applied E-field. This unique attribute allows the design of a novel valve and electron beam splitter, where electrically controlled transmission and guiding of the kink states at a four-way intersection have been proposed [4].

Here, we will show our experiments realizing the kink states in bilayer graphene and the operations of a waveguide, a valley valve and beam splitter. The conductance of the kink states exhibits well-developed plateaus with values close to the expected quantization of $4e^2/h$ at zero magnetic field. We will show the transmission of the kink states in the “on” state of the valve and the expected valley blocking effect in the “off” state of the valve. The on/off ratio is about 800% at B=0 and T=1.5 K. The control of the Fermi level in a magnetic field enables a chirality-based beam splitting mechanism. We demonstrate a continuous tuning of the splitting ratio from 0 to close to 100%. The high quality, in-situ electrical control, and scalabilty of the system open the door to many exciting opportunities in valleytronics and fundamental inquiries.

[1] J. Li, K. Wang, K. J. McFaul, Z. Zern, Y. F. Ren, K. Watanabe, T. Taniguchi, Z. H. Qiao, J. Zhu, Nature Nanotechnology, **11**, 1060 (2016)
[2] J. Li, R.-X. Zhang, Z. Yin, J. Zhang, K. Watanabe, T. Taniguchi, C. Liu, and J. Zhu, A valley valve and electron beam splitter in bilayer graphene, arXiv:1708.02311v1 (2017)
[3] I. Martin, Y. M. Blanter, and A. F. Morpurgo, Topological confinement in bilayer graphene, Physical Review Letters **100**, 036804 (2008)
[4] Z. Qiao, J. Jung, Q. Niu, and A. H. MacDonald, Electronic Highways in Bilayer Graphene, Nano Letters **11**, 3453 (2011)