Rapid time-controlled emission of single Dirac fermions from graphene quantum dots

M. R. Connolly[1,2], K. L. Chiu[2], S. Giblin[1], M. Kataoka[1], J. Fletcher[1], C. Chua[2], J. P. Griffiths[2], G. A. C. Jones[2], V. I. Fal'ko[3], C. G. Smith[2], T. J. B. M. Janssen[1]

[1]National Physical Laboratory, Hampton Road, Teddington TW11 0LW, UK
[2]Cavendish Laboratory, Department of Physics, University of Cambridge, Cambridge, CB3 0HE, UK
[3]Department of Physics, Lancaster University, Lancaster, LA1 4YB, UK

mrc61@cam.ac.uk

Electrical transport measurements are traditionally used to uncover the properties of a conductor by driving randomly generated electron wavepackets through a device and extracting information about scattering, quantum interference, and localization from the time-averaged current density. Control over the trajectory and emission time of individual wavepackets provides a more direct way to explore and manipulate the quantum nature of single electronic excitations [1]. Given that low energy electron wavepackets in graphene have the same linear energy dispersion relation as massless Dirac fermions, time-controlled release in graphene also allows fundamental questions about quantum measurement to be explored in a relativistic setting. Multiple emitters, for instance, could spatially separate and control the collision of pairs of Dirac fermions to assess how the valley or layer degree of freedom affects particle indistinguishability.

Here we describe graphene single electron emitters which work by adiabatically transfering single charges between two series coupled quantum dots [Fig. 1(a) and Ref. [2]]. The application of phase-shifted radiofrequency signals to all-graphene side-gates results in a single charge being transferred between the dots each cycle, and generates a net current equal to the fundamental electronic charge times the drive frequency [3]. We discuss the role played by the geometry of the quantum dots on pumping, the experimental conditions required to achieve good pump performance, and the conformity of the experimental data to theoretical models based on pumping through metallic islands [4]. We also explore the quantization accuracy and robustness of the pumped current as a function of drive frequency. Quantized pumping is observed up to GHz frequencies, an order of magnitude higher than previously achieved using conventional metallic or semiconductor adiabatic pumps.

References

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Figures

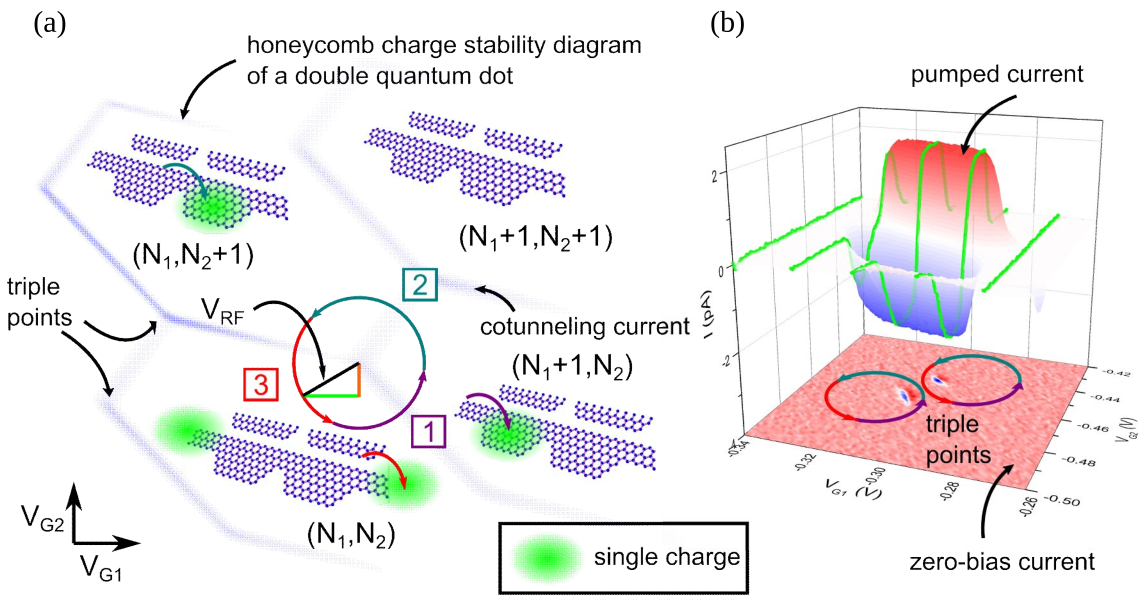

Fig. 1 (a) Schematic showing the process of transferring a single charge per cycle through a graphene double quantum dot: (1) The plunger gate attracts an electron on to the left quantum dot , changing the number of charges on the dots from (N_1, N_2) to (N_1+1, N_2), (2) the right plunger gate increases, shifting the electron on to the right quantum dot [(N_1+1, N_2) to (N_1, N_2 +1)], (3) the plunger gates return to their original values, and the electron is pumped out to the drain contact. Charges are thus pumped when the loop makes an excursion enclosing a triple point. (b) Plot showing the relation between the triple points in the DC zero-bias current and the plateau in the pumped current obtained by rapidly modulating the gate voltages at a frequency of 12 MHz. The same cycle of gate voltages generates current with opposite polarity when the rotation is centred on different triple points because electrons are pumped in the opposite direction [1].