aqueous suspensions of graphene oxide (which is one type of CMG) to produce relatively large platelets on substrates, and then mapped their optical properties before and after heat treatment¹¹. A compelling reason for interest in such colloidal suspensions is that all the graphene oxide platelets in the suspension seem to be individual layers. Alas, this heavily oxidized form of graphene is electrically insulating, but the platelets can be made electrically conductive by exposing them to chemical reductants or heat.

The 'chemistry part' of the graphene story has only just begun and because of the extraordinary number of levers that chemistry affords, there will be a growing dialogue between chemists and researchers in other fields (such as physics, materials and processing) who, otherwise, might only have worked with graphene in its pristine form. As an example of a first step, teams led by Richard Kaner of UCLA¹², Klaus Kern of the Max Planck Institute in Stuttgart and the EPFL¹³, and myself (I. Jung, D. Dikin, R. Piner & R.S.R, manuscript in preparation) have recently deposited graphene oxide platelets onto

substrates and then converted them to electrically conductive CMG that allowed for voltage gating. Individual platelets were identified by light microscopy, and their electrical properties were studied as a function of temperature or prior exposure to hydrazine or hydrogen plasma.

This work is still at an early stage and some questions remain to be answered. In converting graphite to graphite oxide, have significant defects been introduced into the individual layers? Are unwanted defects introduced when making the aqueous suspension of graphene oxide platelets? If one is able to keep the basic carbon skeleton intact without too many defects, will it be possible to manipulate the surface chemistry, and perhaps even 'return' to pristine graphene, albeit by a rather circuitous route?

Although it should be possible to position the larger CMG platelets¹¹ where needed on a silicon wafer for further processing, and to perhaps create 'striped' graphene platelets (see Fig. 1) that could also be assembled on silicon wafers through appropriate patterning, it is not yet clear if this approach will be of

interest to the nanoelectronics industry. Nevertheless, whatever happens, graphene and chemically modified graphene will remain of interest for fundamental research. It may be that pristine graphene is essential for applications in nanoelectronics. However, it could be that some degree of chemical functionalization may be tolerated, or perhaps even found to be beneficial.

References

1. Novoselov, K. S. *et al.* *Science* **306**, 666–669 (2004).
2. Lu, X. K., Yu, M. F., Huang, H. & Ruoff, R. S. *Nanotechnology* **10**, 269–272 (1999).
3. Geim, A. K. & MacDonald, A. H. *Physics Today* **60**, 35–41 (August 2007).
4. Min, H. K., Sahu, B., Banerjee, S. K. & MacDonald A. H. *Phys. Rev. B* **75**, 155115 (2007).
5. Berger, C. *et al.* *Science* **312**, 1191–1196 (2006).
6. Celzard, A., Mareche, J. F. & Furdin, G. *Prog. Mater. Sci.* **50**, 93–179 (2005).
7. Chernozatonskii, L. A., Sorokin, P. B. & Brünig J. W. *Appl. Phys. Lett.* **91**, 183103 (2007).
8. Stankovich, S. *et al.* *Nature* **442**, 282–285 (2006).
9. Watcharotone, S. *et al.* *Nano Lett.* **7**, 1888–1892 (2007).
10. Dikin, D. A. *et al.* *Nature* **448**, 457–460 (2007).
11. Jung, I. *et al.* *Nano Lett.* **7**, 3569–3575 (2007).
12. Gilje, S., Han, S., Wang, M., Wang, K. L. & Kaner, R. B. *Nano Lett.* **7**, 3394–3398 (2007).
13. Gómez-Navarro, C. *et al.* *Nano Lett.* **7**, 3499–3503 (2007).
14. Sofo, J. O., Chaudhari, A. S. & Barber, G. B. *Phys. Rev. B* **75**, 153401 (2007).

NANOMETROLOGY

Island hopping

Developing new measurement standards that are based on the fundamental physical constants, such as Planck's constant and the mass of the electron, is a top priority in metrology laboratories around the world. However, the unit of electrical current, the Ampere, is still defined in terms of the forces acting on wires carrying currents, which is why a number of groups are working on alternative standards.

A central element in some of these approaches is a 'turnstile' that opens and closes at a well-defined frequency, f , allowing a well-defined number of electrons, N , to pass through the turnstile every time it opens, leading to a current $I = Ne f$, where e is the charge of the electron. Writing in *Nature Physics*, Jukka Pekola and co-workers at the Helsinki University of Technology and Stony Brook University report a new type of turnstile based on a hybrid single-electron transistor (*Nature Phys.* doi:10.1038/nphys808; 2007).

The hybrid device consists of an island of superconducting aluminium that is separated from copper source and drain electrodes by aluminium oxide

tunnel barriers. The electrons must tunnel through these barriers to enter or leave the island. The device is controlled by a d.c. voltage across the source and drain, and a combination of a.c. and d.c. voltages that are applied to a metal gate electrode.

Pekola and co-workers measure the current through the turnstile as these voltages are varied, with the plateaux in the data (left) demonstrating that they are able to control N . In both figures the vertical axis is the current and the horizontal axes are different components of the voltages. The figure on the far

left, which was recorded at a frequency of 12.5 MHz, shows N increasing from zero up to ten. The plateaux in the other image, which was recorded at 20 MHz, correspond to $N=1$, 0 and -1 (that is, a current flowing in the opposite direction).

A quantum standard for current would bring it into line with the standards for resistance and voltage, which are based on the quantum Hall effect and the Josephson effect respectively, thus completing a metrological triangle for electrical units based on Ohm's law.

Peter Rodgers