the $E_{\rm F}$ presents opposite spin-polarization than that of the electrodes and carries most of the current (Fig. 1b).

The second consequence of the interaction between the molecule and the electrode is that the molecules' energy levels can be shifted. Again the shift can be spin-dependent, so that a particular spin-polarized molecular orbital can end up at the $E_{\rm F}$ and thus dominates the current. For instance, in Fig. 1c this happens for the majority component of the spin-polarized HOMO, and now the spin current returns to be dominated by majority spins. The strength of the interaction between the molecule and the electrodes also sets the energy scale of the spin-filtering effect. Barraud and co-workers report a dramatic suppression of the magnetoresistance with bias, with the signal halving at only 25 mV (in Fe/MgO tunnel junctions the magnetoresistance halves at about 0.5 V).

Also the temperature dependence is severe with no magnetoresistance beyond 180 K, suggesting that the relevant energy scale for the spin-filtering is around 25 meV.

With this new understanding of how the interaction at a hybrid organic/ inorganic interface alters the spininjection, the next challenge is to engineer it. Indeed, as well as their long spinlifetimes, the ability to alter the properties of organic semiconductors through their structure and make-up is one of the key properties that makes them attractive for building devices. This sets an exciting but demanding agenda for the future. Can we design robust organic/inorganic interfaces that maximize the spin-polarization of the current over a broad temperature range? This might be a complicated affair, but the availability of a practically infinite choice of organic molecules and functioning groups gives us confidence that the task will be successful. Stefano Sanvito is in the School of Physics and the Centre for Research on Adaptive Nanostructures and Nanodevices, Trinity College, Dublin 2, Ireland. e-mail: sanvitos@tcd.ie

References

- Schmidt, G., Ferrand, D., Molenkamp, L. W., Filip, A. T. & Wees, B. J. *Phys. Rev. B* 62, R4790–R4793 (2000).
- Dediu, V., Murgia, M., Matacotta, F. C., Taliani, C. & Barbanera, S. Solid State Commun. 122, 181–184 (2002).
- Xiong, Z. H., Wu, D., Vardeny, Z. V. & Shi, J. Nature 427, 821–824 (2004).
- 4. Barraud, C. et al. Nature Phys. 6, 615–620 (2010).
- 5. Ikeda, S. et al. Appl. Phys. Lett. 93, 082508 (2008).
- Szulczewski, G., Tokuc, H., Oguz, K. & Coey, J. M. D. Appl. Phys. Lett. 95, 202506 (2009).
- Szulczewski, G., Sanvito, S. & Coey, J. M. D. Nature Mater. 8, 693–695 (2009).
- Rocha, A. R. & Sanvito, S. J. Appl. Phys. 101, 09B102 (2007).
- Brede, J. et al. Preprint at http://arxiv4.library.cornell.edu/ abs/1005.4745 (2010).
- 10. Rocha, A. R. et al. Nature Mater. 4, 335-339 (2005).

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SCANNING TUNNELLING MICROSCOPY

Exclusive images

Scanning tunnelling microscopes (STMs) provide fascinating and useful insight into the atomic-scale physical and electronic structure of surfaces. But, although these devices are readily able to resolve isolated atoms on a surface, their ability to image the details of complex chemical structures is limited: conventional STM techniques principally probe the electronic states around the Fermi energy of a sample, whereas most of the information about its chemical structure is contained in the deeper orbital states of its constituent atoms.

Christian Weiss and colleagues, however, have obtained detailed images of the local electron density — and thereby of the bonding structure of complex organic molecules — by adsorbing deuterium molecules onto the end of an STM tip (http://arxiv.org/ abs/1006.0835; 2010).

In previous work (*New J. Phys.* **10**, 053012; 2008), the researchers found that when they collected images of platelet-like organic molecules using an STM tip doused with liquid hydrogen immediately before imaging, it markedly increased the contrast of the images produced (pictured, middle panel), compared with those collected with a bare tip (top panel).





More remarkable, however, was the fact that the shapes that emerged in these images were strikingly similar to textbook drawings of the chemical structure of the molecules being imaged (bottom panel). Yet it wasn't clear what the technique was measuring. To better understand the mechanism that produces this contrast, Weiss *et al.* have repeated the experiment with deuterium molecules, used it to analyse the much simpler structure of a dimer of gold atoms adsorbed on a surface, and performed *ab initio* calculations to try to determine what exactly the tunnelling current is probing.

The experimental images obtained using deuterium were much the same as when using hydrogen. The magnitude of the tunnelling current suggests that the STM tip was covered with a single monolayer of D_2 molecules, and the sharpness of the features in the images obtained (of the order of 0.05 nm) implies that this current flows predominantly through a single molecule at the apex of the tip.

Their analysis suggests that the observed contrast represents the shortrange repulsive force that acts on the D_2 molecule as a consequence of the Pauli exclusion principle. This force is determined by the total electron density in the sample, thereby enabling the distribution of core electrons and, in turn, the overall chemical structure of the surface to be mapped.

ED GERSTNER