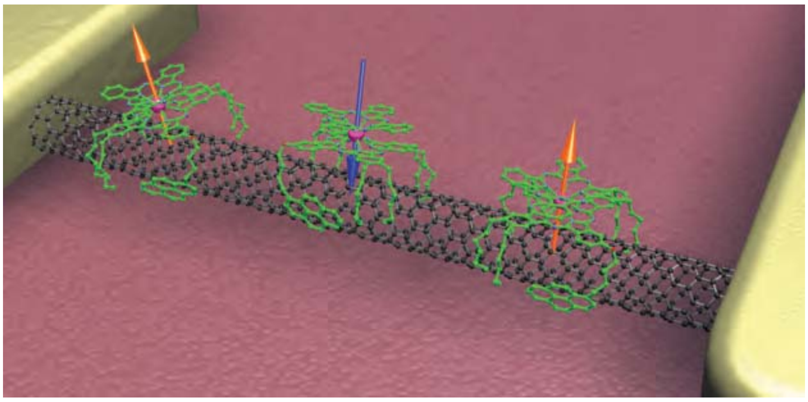
Supramolecular spin valves

The field of Single-Molecule Magnets (SMM) is very promising, since an individual magnetic molecule represents the ultimate size limit for storing and processing information. Magnetic molecules are considered very promising for spintronics – electronics that exploits the spin as well as the charge of the electron – because they can store one bit of information in an extremely small volume. However, in order to use magnetic molecules, one has to find a way to measure their magnetization. Here we show how magnetic molecules could act as building blocks for the design of spintronic devices. A collaboration between experimental chemists and physicists has led to a procedure that combines bottom-up processing techniques with conventional top-down nanofabrication. We have built a novel spin-valve device in which a non-magnetic molecular quantum dot, consisting of a Single-Wall Carbon Nanotube contacted with non-magnetic electrodes, is laterally coupled via supramolecular interactions to a TbPc2 molecular magnet. The localized magnetic moment of the SMM leads to a magnetic field-dependent modulation of the conductance in the nanotube with magnetoresistance ratios of up to 300% below 1 K. Our results open up prospects for new spintronic devices with quantum properties.

A standard Giant Magnetoresistance (GMR) spin valve is an electronic device in which two conducting magnetic layers are separated by a non-magnetic layer. A large modification of the electrical conductance through the device can be achieved by switching the magnetic configuration of the two electrodes between parallel and antiparallel alignments. Under increase of an external magnetic field, because the two layers have different magnetic coercivities, the magnetization of one layer switches at a different field value than the other. That is, the configuration goes from parallel to antiparallel, and finally back to parallel alignment, thus switching the conductance of the device. The resulting Magnetoresistance Ratio is defined by MR = $(G_P – G_{AP})/G_{AP}$, where G_P and G_{AP} are the conductances of the spin valve for parallel (P) and antiparallel (AP) alignment. Typical MR values for metallic spin valves lie in the ten percent range at room temperature. A tunnel barrier between the two layers leads to MR values greater than one hundred percent, as used for instance in commercial spin valves in reading heads.



A spin valve built entirely from soft organic materials rather than the usual inorganics: A lead made of a Single-Wall Carbon Nanotube (black in the Figure) is contacted at each end by non-magnetic electrodes (gold colour). It is coupled laterally to molecular, $TbPc_2$ (Pc = phthalocyanine) quantum magnets (green), the latter acting as localized magnetic moments. Sweeping a magnetic field modulates the conductance through the nanotube, achieving magnetoresistance ratios up to 300% between fully polarized and non-polarized molecular configurations.

Our experiments represent the realization of a suggestion we made in 2008 to use quantum nanomagnets : if a Single-Molecule Magnet is coupled laterally to a contacted Single Wall Carbon Nanotube (SWCNT), its highly anisotropic magnetic moment should influence the current passing through the nanotube, and thus permit readout of the molecule's magnetic state by standard conductance measurements. This idea has now been validated: we have measured high magnetoresistance ratios in such a "supramolecular" SMM-SWCNT geometry, in which single quantum nanomagnets act as both magnetic polarizer and analyzer (see Figure). The results demonstrate magnetization switching detected electrically for a single quantum magnet.

We have also built a similar device using a graphene nanoconstriction decorated with $TbPc_2$ magnetic molecules. In this case, a magnetoconductivity signal as high as 20% is found for the spin reversal, revealing the uniaxial magnetic anisotropy of the $TbPc_2$ quantum magnets. The results show the behavior of multiple-field-effect nanotransistors with sensitivity at the single-molecule level.

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FURTHER READING

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