



Figure 1 | Light bending and stretching. Simmons *et al.*¹ make the conductivity of carbon nanotubes responsive to light by adding molecules of the azo-based Disperse Red 1 dye to the nanotube walls. These dye molecules undergo photoisomerization, with their molecular conformation shifting around their central nitrogen double bond: from the *trans* to the *cis* form under ultraviolet light of wavelength 254 nm, and back again under blue light of 365 nm. The changes cause significant, reversible shifts in the molecules' electrical dipole moments (unit: debye, D; arrows indicate direction), and thus in the electrical conductance of a nanotube transistor as a whole.

interactions involve, for example, hydrophobic, van der Waals and electrostatic forces, and are efficient when used at short range between molecular building-blocks, but are too weak to cause intermolecular changes or form actual bonds.

Such interactions implicitly require the physical adsorption of suitable molecules onto the side walls of the nanotubes. The non-covalent immobilization of numerous polycyclic aromatic species — most notably, conjugated polymers⁵ and small molecules such as pyrene^{6,7} — onto a nanotube surface has been at the forefront of research so far. Such additions have emerged as versatile building-blocks that can be used to modify nanotubes' solubility, fine-tune their electronic properties and exfoliate individual nanotubes from the initial bundles.

Simmons and colleagues' functionalizing addition is the commercially available Disperse Red 1 dye. Like many other azo-based dyes (that is, dyes centred around a nitrogen double bond), Disperse Red 1 undergoes a highly reversible '*cis-trans*' molecular reconfiguration, or isomerization, when exposed to light of different wavelengths. This photoisomerization involves the rearrangement of the dye's outlying molecular groups around the double bond, which cannot itself rotate. Ultraviolet light of wavelength 254 nm initiates the conversion from the *trans* to the *cis* form, whereas blue light of 365 nm brings about the back-conversion from *cis* to *trans* (Fig. 1).

Importantly, the reconfiguration of the dye molecule causes a significant change in the electrical dipole moment along its principal axis. Simmons *et al.* document impressively that this shift also modifies the local electrostatic potential in the nanotube and, in turn, modulates its conductance by shifting the threshold voltage at which current flows. With a dye coverage of 1–2%, the photoisomerization induced a shift in the threshold voltage of up to 1.2 V. In particular, a carbon-nanotube transistor exhibiting p-type behaviour (that is, the flow of holes, carriers of positive electric charge) saw its threshold voltage increase

by 1 V to higher, positive gate voltages.

As far as integrating single-walled carbon nanotubes into transistors is concerned, the technology described by Simmons and colleagues² has several advantages. First, the functionalized transistors show repeatable switching for many cycles and a modest switching time of around 2 seconds. The authors believe that decreasing the dye concentration could further accelerate the switching. Second, the low light intensities (about $100 \mu\text{W cm}^{-2}$) needed to modulate the functionalized transistors are in stark contrast to those required to induce intrinsic nanotube photoconductivity (typically 1 kW cm^{-2}). Finally, the authors' synthesis technique is versatile enough to immobilize different dyes onto the nanotubes. That should allow the tuning both of the wavelengths that initiate the photoisomerization and the magnitude of the switching, independently of the nanotube's electronic structure.

In that light, the work is surely a breakthrough in implementing carbon nanotubes in optoelectronic devices — technologies from photovoltaic cells to flat-panel displays that have a bright future. ■

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Correction

In the News & Views article "Computing: The security of knowing nothing" by Bernard Chazelle (*Nature* **446**, 992–993; 2007), an error crept into reference 2. The correct reference is Barak, B. & Sahai, A. *Proc. 46th IEEE Symp. Found. Comput. Sci.* 543–552 (2005).



50 YEARS AGO

A note released recently by the Rockefeller Institute in New York describes a small radio-transmitting capsule which can be swallowed like a medicinal pill and, as it passes through the body, signals the activity of the digestive tract. This 'radio pill', as it is termed...comprises a plastic capsule, $1\frac{1}{8}$ in. long and $\frac{4}{10}$ in. in diameter, containing a tiny transistor oscillator... In one end of the capsule is housed a minute replaceable storage battery which supplies the small amount of electrical power required and has a life of fifteen hours... When the 'pill' is swallowed by a patient and pursues its course through the gastrointestinal tract, it transmits signals the frequency of which is varied by the pressure changes in the tract. These signals from the capsule are picked up on a suitable receiver with an antenna held close to the body.

From *Nature* 4 May 1957.

100 YEARS AGO

Dr H. Charlton Bastian re-affirms his conviction that living organisms continue to arise from not-living material... In the first part of his book he points out that inorganic evolution (recently studied in ways not a little upsetting) has not stopped, and argues against the dogmatism of those who, while admitting that archeobiosis probably occurred very long ago, refuse to discuss the possibility of its occurrence now. Because it has been shown that maggots are not really produced by the flesh in which they crawl, it does not follow that minute specks of living matter may not arise *de novo* in suitable not-living fluids... In a fluid believed to be quite not-living, minute living creatures appear, but observation cannot decide whether they arise from invisible germs or pre-existing organisms, or "whether they have come into being in the mother liquid as a result of life-giving synthetic processes."

From *Nature* 2 May 1907.

50 & 100 YEARS AGO