Transparent, flexible CNT transistors

CARBON NANOTUBES

A team from the University of California, Los Angeles and Germany's Max Planck Institute for Solid State Research has fabricated transparent and flexible transistors where both the bottom gate and the conducting source-drain channel are carbon nanotube (CNT) networks of different densities and Parylene N is the gate insulator [Artukovic *et al.*, *Nano Lett.* (2005) **5** (4), 757].

Previous transparent transistors have used either polymers (which suffer low mobility) or inorganic oxides (which do not have the desired flexibility and are difficult to manufacture). Here, in contrast, just two materials are used, ensuring simple manufacturing.

Field-effect transistors (FETs) can have conducting channels made from a random network of nanotubes of an appropriate density. Also, flexible transistors can be created by room-temperature fabrication.

Now, highly transparent FETs have been fabricated where CNT networks of different densities provide both the conducting channel and the gate. Simple spray technology is used to deposit 1% sodium dodecyl sulfate (SDS) aqueous solutions of nanotubes, in concentrations of 1 mg/ml for the gate (onto polyester sheet substrate) and 0.35 mg/ml for the channel (onto the parylene gate insulator).

The FETs have a mobility of 1 $cm^2 V^{-1} s^{-1}$ and an on/off ratio of 100. The latter is influenced by the properties of the insulating layer. Characteristics are little affected by repetitive bending and recover fully on release. Transparency is sufficient for use as active matrix displays and smart windows.

The potential to fabricate source and drain from CNT networks makes simple electronic devices possible.

Mark Telford

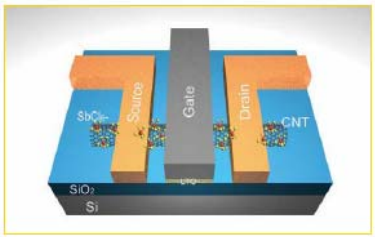
Controlling carriers in CNT transistors

CARBON NANOTUBES

IBM has reported a charge transfer *p*-doping scheme for obtaining stable, unipolar carbon nanotube field effect transistors (CNT-FETs) with a self-aligned gate structure [Chen *et al*, (2005) *Appl. Phys. Lett.* 86, 123108]. The use of triethyloxonium hexachloroantimonate ($(C_2H_5)_3O^+SbCl_6^-$) as a one-electron oxidant for the CNTs and metal contacts modulates both the CNT's carrier density and carrier injection properties at the contacts.

Interaction of a CNT with the doping molecules generates a positively charged CNT stabilized by the negatively charged counter ion $SbCl_6^-$. This doping allows carrier injection to be improved, threshold voltage V_{th} to be tuned, and device performance to be enhanced in both 'on' and 'off' states. Specifically, the transistor is converted from ambipolar to unipolar, drive current is increased by two to three orders of magnitude, device leakage 'off' current is suppressed, and the I_{on}/I_{off} ratio is as much as 10^6.

Further studies involving selective doping of the metal contact area or the bulk of a CNT show that the improved performance is mainly a result of changes at the contacts. Doping leads to an increased local workfunction that favors hole injection at one electrode while suppressing electron injection at the other. The researchers also strongly modulated the carrier density of a CNT by bulk doping, and converted a semiconducting tube to an almost metallic one at high doping density.



A CNT-FET combining electrostatic and chemical gating, with an LTO (low temperature oxide)/W gate stack on part of the CNT channel and chemical doping of the source/drain contacts and exposed channel adjacent to the contacts. (Courtesy of Jia Chen.)

The ability to tune both carrier density and injection properties enables the fabrication of a structure that combines both electrostatic and chemical gating: a W/oxide stack electrostatically gates the bulk of the channel, while the chemical dopants gate the contacts and the adjacent exposed part of the channel. By defining gate and doping in one lithographic step, the electrostatic (W) gate can be aligned with the chemical dopants. This eliminates the large overlap capacitance between gate and source/drain, minimizes the Schottky barriers at the contacts, and maintains a continuous low-resistance channel from source to drain. The method is generalizable to transistors made from both nanotubes and nanowires, and represents a step toward introducing CNT-FETs in logic applications, say the researchers.

Mark Telford

CNT catalysts can quadruple hydrogen storage

CARBON NANOTUBES

A team at the Université du Québec à Trois-Rivières in Canada has used single-walled carbon nanotubes (SWNTs) as catalysts to quadruple the hydrogen sorption kinetics of the reversible storage materials, sodium alanates [Dehouche *et al.*, *Nanotechnology* (2005) **16** (4), 402].

Ti- and Zr-doped sodium aluminum hydride ($NaAlH_4$) was ball milled with additives in three forms: graphite, activated carbon, and SWNTs made by the high-pressure CO conversion process. Tested under pure H_2 at 160°C, hydriding (absorption) and dehydriding (desorption) kinetics were faster than those of $NaAlH_4$ without carbon additives. Those for SWNT-$NaAlH_4$ were four times better.

The researchers believe that the carbon creates new hydrogen transition sites and that its structure plays an important role in enhancing the absorption and release rates. The researchers also suggest that the high hydrogen diffusivity of the nanotubes facilitates hydrogen atom transition. Faster transfer of thermal energy through the carbon nanotubes may also help.

The team aims to clarify the effect of carbon on high-pressure (120 atm) hydriding kinetics; understand the way carbon enhances the hydrogen sorption kinetics of catalyzed $NaAlH_4$ and why the superior performance of SWNTs over graphite and activated carbon is not conserved after 200 cycles; and apply the same doping technique to light Mg- and Li-based alkali-metal Al hydrides, which have greater potential storage capacity.

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