Electronics in optical fibers

OPTICAL MATERIALS

Researchers at the University of Southampton, UK and Pennsylvania State University have successfully deposited crystalline semiconductors within the pores of optical fibers [Sazio *et al.*, *Science* (2006) **311**, 1583].

Fabricating semiconductor devices inside fiber waveguides to enable the manipulation of optical signals should provide a powerful method to couple electronic and photonic processes.

"This fusion of two separate technologies opens the possibility of true optoelectronic devices that do not require conversion between optical and electronic signals," explains Pier J. A. Sazio of Southampton.

The group used the micro- or nanoscale pores in microstructured optical fibers (MOFs) as reaction chambers into which a wide range of semiconductor materials can be deposited by chemical vapor deposition. High pressure flow of the vapor overcomes mass-transport problems to give uniform deposition on the walls of the fiber pores.

High-quality polycrystalline Ge and Si wires can be fabricated inside silica MOFs in this way. Compound semiconductors, such as GeS_2, and heterostructures, such as coaxial SiGe heterojunctions and annular Au/Si Schottky junctions, can also be formed. A field-effect transistor was fabricated based on a continuous Ge wire inside an 11-mm-long silica capillary. Waveguiding of infrared light inside a Si core was also observed.

"This advance is the basis for a technology that could build a large range of devices inside an optical fiber," says John V. Badding of Penn State. It could have applications in areas from computing to medicine and remote sensing devices. "If the signal never leaves the fiber, then it is faster, cheaper, and more efficient," he adds.

Jonathan Wood

Integrated circuit built on single nanotube

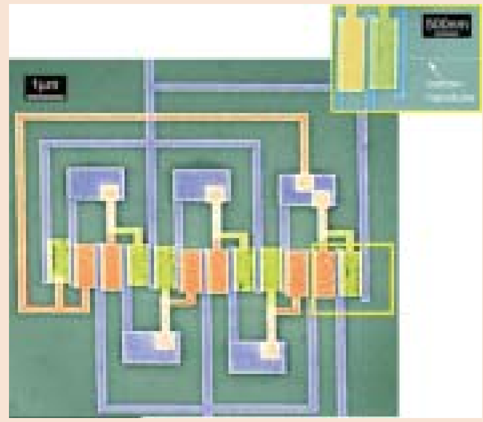
NANOTECHNOLOGY

An integrated logic circuit has been constructed on an individual single-walled carbon nanotube (SWNT) by researchers at IBM T. J. Watson Research Center, the University of Florida, and Columbia University [Chen *et al.*, *Science* (2006) **311**, 1735]. The demonstration of a five-stage ring oscillator is another step that shows SWNTs can be used as a basis for electronics.

In a standard complementary metal oxide semiconductor (CMOS) inverter, an *n*-type and a *p*-type field-effect transistor (FET) are needed. To use the same CMOS approach and obtain both *n*- and *p*-type FETs on the same nanotube, the team used metals with different work functions as the gates. Pd was chosen for the *p*-type FET and Al for the *n*-type FET. The difference in the two work functions shifts the characteristics to give a *p*-/*n*-FET pair. In this way, five inverters involving ten FETs were arranged side-by-side on a single, 1.8 µm long SWNT.

"This successful integration demonstrates the compatibility of carbon nanotubes with conventional circuit architectures," says Joerg Appenzeller of IBM. "The use of nanomaterials does not automatically imply that well-established circuit concepts have to be abandoned."

The inverter characteristics show that the gain of the single nanotube ring oscillator is greater than one. It also works at a frequency of 52 MHz, ~100 000 times faster than previous circuits built by connecting separate nanotube transistors. "This improvement is a result of our compact design, which eliminates parasitic capacitance contributions to a large extent," explains Appenzeller.



Ring oscillator circuit built on a single carbon nanotube consisting of five CMOS inverter stages. Inset shows the nanotube covered by the contact and gate electrodes. (Courtesy of IBM Research.)

The ring oscillator should provide a tool to characterize SWNTs in ac applications. Nanotube performance limits can then be studied, allowing their potential as a platform for nanoelectronics to be assessed.

"Our goal is to ultimately benefit from the intrinsically superior transport properties of carbon nanotubes to enable the predicted terahertz switching speed of nanotube transistors and translate this individual device performance into a high-performance circuit design," says Appenzeller.

Jonathan Wood

Charging up magnetic quantum dots for spintronics

NANOTECHNOLOGY

Chemists at the University of Washington have prepared semiconductor nanocrystals that are both charged and magnetically doped [Liu *et al.*, *J. Am. Chem. Soc.* (2006) **128**, 3910]. This first demonstration of carrier injection into diluted magnetic semiconductor (DMS) quantum dots (QDs) opens up new opportunities for studying carrier-dopant interactions, which are important in spintronics, carrier-mediated ferromagnetism, and spin-based quantum computation. "All potential spintronics applications involving magnetic semiconductors are based on interactions between magnetic dopants and charge carriers," explains Daniel R. Gamelin. "But such interactions are typically very difficult to study, especially on nanostructures, since they involve either magneto-transport or sophisticated magneto-optical measurements." Since the charge carriers are stable indefinitely within the DMS nanocrystals, their properties can now be studied by a broader range of techniques.

ZnO nanocrystals doped with either Co^{2+} or Mn^{2+} and capped with alkyl groups were prepared suspended in toluene. These colloids are reduced photochemically by irradiating with an ultraviolet laser in the presence of ethanol, a hole quencher. Room-temperature electronic absorption spectra confirm the presence of free electrons in the conduction band of the magnetically doped ZnO QDs. Electron paramagnetic resonance spectroscopy of the undoped ZnO QDs show a signal characteristic of electrons in the conduction band. Comparing this spectrum with those for nanocrystals doped with various concentrations of Co^{2+} and Mn^{2+} reveals that interactions between the dopants and the free electrons occur.

Having demonstrated the direct chemical preparation of this new system of charged DMS nanocrystals, and the ability to study them spectroscopically, Gamelin and coworkers now hope to probe the strength of the exchange coupling.

Jonathan Wood