Best nanowire transistors yet

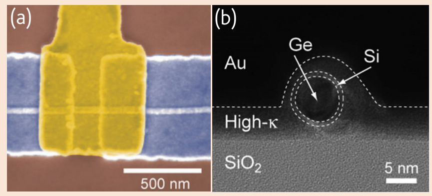
NANOTECHNOLOGY

Charles M. Lieber's group at Harvard University have reported the best nanowire field-effect transistors (FETs) to date. Using standard benchmarks from the semiconductor industry, they demonstrate that their nanowire devices have a clear advantage over conventional planar FETs [Xiang *et al.*, *Nature* (2006) **441**, 489].

Nanowire transistors have been touted as alternatives to metal-oxide-semiconductor FETs (MOSFETs) because of their unique electronic structure and reduced carrier scattering. Partly because of problems with contacts to the nanowires, however, it was previously unclear whether the performance of nanowire FETs could indeed outstrip that of MOSFET technology.

"We decided to use the idea of band-structure design and found that a hole gas can be formed in the core/shell Ge/Si nanowire system," explains Lieber. "This has proved to be an ideal system with reliable ohmic contacts and high mobility."

The team fabricated transistors consisting of Ge/Si heterostructure nanowires combined with Ni source and drain electrodes, HfO_2 or ZrO_2 high-*k* dielectrics, and a metal top gate



(Left) Color scanning electron micrograph of a Ge/Si nanowire transistor. The nanowire rests on a SiO_2 substrate (brown) with source and drain (purple/blue) at either end and the gate (gold/yellow) in the middle. (Right) Cross-sectional transmission electron micrograph of the device. (Courtesy of Charles M. Lieber.)

electrode. The top-gate structure, which wraps around the nanowire, produces a much more efficient gate response than the nanowire transistors studied previously.

The devices work as *p*-type depletion-mode FETs, as expected from the band structure of the Ge/Si core/shell nanowires. A nanowire FET with a 190 nm channel length shows a scaled on-current value of 2.1 mA μm^{-1}. Furthermore, the intrinsic switching delays of the nanowire FETs show a significant speed advantage over Si *p*-MOSFETs.

"We have used the same benchmarks typically used by the semiconductor industry in characterizing the on current and intrinsic delay properties of transistors," says Lieber. "By this method, we show that our current Ge/Si nanowire transistors perform 3-4 times better than Si CMOS."

Lieber believes these results demonstrate that there is great potential for such nanowire devices. The ability to prepare high-performance nanowire FETs with close to 100% yield could find use in high-frequency electronics on plastic substrates, nanosensors with greater sensitivity, and even extend the roadmap for high-performance logic.

The researchers hope to improve the performance of their transistors and scale them to smaller sizes. They are also about to report the development of a different nanowire material system to form a carrier gas of electrons as required for making complementary high-performance devices. That just leaves the large-scale assembly and interconnection of the nanowire devices into integrated systems, on which the team is also now working.

Jonathan Wood

Laser excites Si-H bonds to breaking point

ELECTRONIC MATERIALS

Researchers have selectively desorbed hydrogen from a Si surface by tuning an infrared laser to the vibrational excitation energy of Si-H bonds [Liu *et al.*, *Science* (2006) **312**, 1024]. The achievement by the team from Vanderbilt University, the University of Minnesota, Oak Ridge National Laboratory, and the University of Tennessee could have significant technological applications in the microelectronics industry, by reducing the temperature at which Si devices are grown. In the past, the selective breaking of bonds has been difficult to achieve by vibrational excitation. "Usually, the vibrational energy tends to be redistributed very rapidly within the molecule since huge numbers of low-frequency modes can accept the energy," explains Phil I. Cohen of the University of Minnesota.

A Si(111) surface uniformly covered with H atoms was exposed to infrared illumination from a free-electron laser (FEL) at Vanderbilt University. The partial pressure of the desorbed H_2 was measured over time for different FEL wavelengths. The desorption yield peaked at a wavelength corresponding to 0.26 eV, the energy of the vibrational stretch mode of Si-H bonds.

"While it was immediately clear that there was resonant absorption of the radiation, it was not obvious whether there was resonant desorption," says Cohen. For example, the laser energy could be redistributed to heat the sample locally resulting in H_2 desorption. The team checked this possibility by repeating the experiment with a mixture of hydrogen and deuterium absorbed on the Si surface. "If the process were local heating, then desorption of D_2 and H_2 should be seen," continues Cohen. "Instead, little D_2 was detected, indicating that there was resonant desorption of the H_2."

The researchers also measured the dependence of the resonant desorption on excitation energy. They found an unusual quadratic dependence on the infrared laser intensity. Further work will be needed to understand the exact mechanism of desorption.

Although the process is not yet wholly understood, the desorption of hydrogen from Si is of immediate interest to the semiconductor industry. Hydrogen is used to passivate surfaces to keep Si from oxidizing. However, the hydrogen has to be removed as further layers of Si are added during growth. This is normally achieved by heating to high temperatures, which can create defects in the chips. "By using infrared to remove the hydrogen, it may be possible to lower the growth temperature of device-quality Si," says Cohen.

It also may be possible to remove hydrogen selectively from energetically different sites. Cohen suggests that there are other possibilities too. "If we can preferentially remove hydrogen from step edges, as opposed to terraces on the Si surface, it might be possible to obtain step-flow growth at very low temperatures. Or it might be possible to make use of the wavelength and polarization of the infrared light to direct the growth of Si nanoparticles into wires. Or it might be possible to control chemistry at Si surfaces by removal of hydrogen from active sites," he says. It could be extended to other materials too.

Jonathan Wood