Nanocantilevers for small-scale sensors

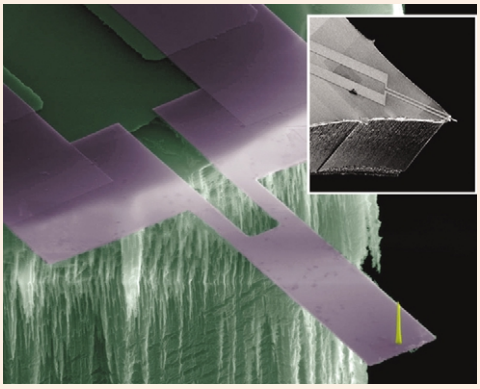
NANOTECHNOLOGY

Nanomechanical devices offer considerable potential for sensor applications requiring exquisite sensitivity. However, difficulties in measuring displacement at the nanoscale have limited efforts to scale-down microcantilever sensors. Researchers from California Institute of Technology have now shown how self-sensing nanocantilevers could provide the answer (Li *et al.*, *Nat. Nanotech.* doi: 10.1038/nnano.2006.208). Displacements of microscale cantilevers are typically measured optically by bouncing a laser off the back of the sensor. Diffraction effects make it far more difficult to use this method at the nanoscale, so the researchers used piezoresistivity instead. They deposited a Au film 30 nm-thick onto SiC nanocantilevers, and monitored strain-induced changes to resistance.

"Techniques from MEMS often do not scale well, or directly apply, to nanodevices. This drives us back to reconsider what is most important and how to achieve it at the nanoscale," says Michael L. Roukes, who directed the research.

Measurements were made using four self-sensing SiC/metal cantilevers with varying lengths (600 nm-30 μm) and widths (400 nm-5 μm). The smallest device had a resonant frequency of 127 MHz. All cantilevers maintain a high resonance quality factor when operated in air at room temperature and pressure.

The next challenge will be integrating the nanoscale cantilevers into large-scale microelectronic systems, says Roukes. Collaborations with industry and fabrication centers have already begun. Work is also underway to explore the devices' potential as sensors. Applications could include gas sensors, electromechanical 'noses' for human breath analysis, and even pacemaker components.



A self-sensing SiC nanocantilever. (Courtesy of Michael L. Roukes, California Institute of Technology.)

For chemical and biological sensing applications, the team hopes to tailor multiple cantilevers to sense specific target species, and then put these together into an array. "A reliable method to selectively coat and functionalize each nanoscale device is still lacking. We need to cooperate closely with chemists to resolve this issue," Roukes notes.

Paula Gould

STM backs up semiconductor theory

CHARACTERIZATION

The increasing miniaturization of semiconductor electronics has prompted researchers to probe the precise mechanism of charge carrier dynamics. The smaller a semiconductor device is, the greater the significance of atomic-scale interactions. Physicists from the University of Tsukuba, Japan, have now visualized the movement of minority carriers across a *p-n* junction with nanoscale resolution [Yoshida *et al.*, *Phys. Rev. Lett.* (2007) **98**, 026802].

Diffusion of carriers across a *p-n* junction under an applied voltage has previously only been characterized using macroscopic current measurements. The Tsukuba team opted instead to image the charge carriers directly using a modified scanning tunneling microscopy (STM) method.

STM of semiconductors is typically hampered by band bending caused by the bias voltage applied between the probe tip and the sample surface. So, although STM can detect dopant atoms, it cannot measure charge carrier density accurately. However, illuminating the semiconductor surface with a sufficiently energetic laser releases additional charge carriers, causing a measurable change in surface voltage (the surface photovoltage, or SPV).

"The larger the SPV, the lower the carrier density," explains lead author Hidemi Shigekawa. "Since we can measure SPV by using our method, we can get information about the local carrier density under the STM tip."

Shigekawa and colleagues applied the technique, known as light-modulated scanning tunneling spectroscopy, to visualize the dynamics of minority carriers in a GaAs *p-n* junction. On increasing the forward applied voltage to the *p-n* junction from 0.5 V to 0.9 V, they observed recombination, drift, and diffusion with ~10 nm spatial resolution.

The same technique could be applied to other semiconductor materials and devices, says Shigekawa. The team plans to study the influence of each dopant or atomic-level defect on the carrier transport properties of samples. They also hope to examine local carrier dynamics in more detail by combining STM with a femtosecond pulsed laser.

Paula Gould

How durable are nuclear waste stores?

CERAMICS

A good solution has yet to be found for the disposal of heavy, α-emitting radioactive materials, such as Pu and certain actinides. Current thinking is that this class of α-emitter should be extracted from nuclear waste and incorporated into mineral-based ceramics. Researchers from the University of Cambridge, UK and Pacific Northwest National Laboratory have now found a way to predict the long-term durability of potential ceramic hosts [Farnan *et al.*, *Nature* (2007) **445**, 190].

The process of α-decay and nuclear recoil will, over time, disrupt the crystalline structure of a ceramic matrix. This has previously been observed as a reduction in density or as changes to X-ray diffraction peaks. Nuclear magnetic resonance (NMR) techniques can provide a more precise measure of structural damage by counting the number of atoms in the crystalline or amorphous regions.

"This does not depend on the density decreasing. NMR is more sensitive and can detect radiation damage at an early stage," says Farnan.

The team applied their method to actinide-containing zircons ($ZrSiO_4$), and a highly radioactive ^{239}Pu-doped zircon. They determined that zircon doped with 10 wt.% Pu would be completely amorphous within 1400 years. The findings have significant implications for nuclear-waste management. Materials are sought than can immobilize ^{239}Pu for ten half-lifes, or 241 000 years. "The positive aspect of this work is that we can put some real numbers on the future behavior of a material," says Farnan. The team now plans to look at alternative matrices for ^{239}Pu, such as titanate and zirconate pyrochlores.

Paula Gould