PHYS ORG

Brittle silicon shows exceptional plasticity on the nanoscale

August 26 2011, by Lisa Zyga

(PhysOrg.com) -- On the macroscale, silicon is a brittle material that cannot be easily molded into a desired shape. But scientists have found that a piece of silicon just 3 nm long can be stretched to more than 20 times its original length without breaking. If researchers can take advantage of the plasticity of nanoscale silicon, they could potentially mold the material into nanostructures of different shapes for technological applications.

The scientists, Tadashi Ishida from the University of Tokyo and coauthors from other institutions in Japan and France, have published their study on the nanoscale plasticity of silicon in a recent issue of Nanotechnology.

Although some researchers have predicted that macroscopically brittle materials like silicon and other covalent materials (whose atoms are held together by strong covalent bonds) should show plasticity at the nanoscale, measuring the properties of nanosized materials is difficult for technical reasons. Some of the main difficulties include finding ways to securely clamp the material's ends and monitoring the properties during testing.

To overcome these difficulties, the scientists used a novel method involving a microelectromechanical system and a transmission electron microscope, which they call MEMS-in-TEM. With this set-up, the researchers could simultaneously manipulate the silicon using the MEMS device while observing the results in real time with the microscope.

Starting with a cylindrical piece of silicon with a length of 3 nm and diameter of 50 nm, the researchers pulled the silicon at a quasi-static speed, causing it to elongate. Over a time period of 30 minutes, the silicon elongated from 3 nm to 61.6 nm, while the diameter gradually decreased. The researchers performed the experiment on seven samples until the silicon "nanobridges" finally reached the fracture point.

"A slow tensile loading gave sufficient time to diffuse silicon atoms into the silicon nanobridge and gradually deform the amorphous structure in the bridge," Ishida told *PhysOrg.com*. "The superplasticity was induced by the combination of stress-induced surface diffusion and intergranular amorphous deformation, including crystalline silicon nano grains."

In stress-induced surface diffusion, the first of the two factors, the silicon atoms spread across the surface to increase the length of the nanobridge, which occurs due to mechanical tension and stress. The second factor, intergranular amorphous deformation, can be described as a "creep-like" flow of the intergranular material in the silicon, and the nanocrystals adjusting to this flow. The scientists' observations suggest that, when the diameter of the nanobridge becomes comparable to the average size of the nanocrystals, the nanobridge reaches its critical yielding point and cannot elongate any further.

This ability to elongate nanoscale silicon, which is done at room temperature, could have implications for many silicon-based electronics, since the silicon could be molded into specific shapes.

"With this technique, you can precisely modify the surface of nanostructures and enhance their performance," Ishida said. "This technique can be applied to all mechanical, electrical and optical devices, such as nanoscale wirings and joints, nanowire gas sensors, and photovoltaic devices, for improving their performance."

More information: Tadashi Ishida, et al. "Exceptional plasticity of silicon nanobridges." *Nanotechnology* 22 (2011) 355704 (6pp)
[DOI:10.1088/0957-4484/22/35/355704](DOI:10.1088/0957-4484/22/35/355704)