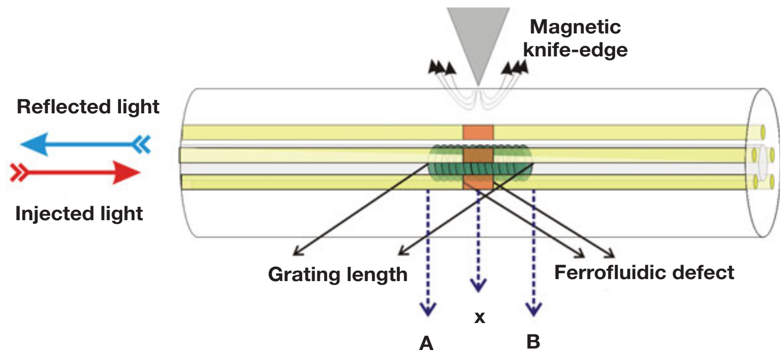
Magnetofluidics used for tuning optical fibers

Microstructured optical fibers make for a versatile photonic platform which combines tailored optical mode propagation properties with microfluidic functionality. For instance, microfluidic channels running through a fiber can permit the movement of small plugs of liquid whose own optical properties alter the passage of light in a controllable way. A report published in the July 1 issue of *Optics Letters* (DOI:10.1364/OL.36.002548, p. 2548) demonstrates how this emerging technology can employ magnetosensitive liquids to create optical fiber devices whose spectral transmission is tunable with a magnetic field.

S. Pissadakis and his team from the Foundation for Research and Technology, Institute of Electronic Structure and Laser, in Greece, developed these magnetofluidic devices in collaboration with the group of W. Margulis from Acreo AB in Sweden, which fabricated silicate optical fibers incorporating five axial microfluidic channels. Using deep ultraviolet laser radiation, they inscribed a 2.4 cm length of the fiber with a region of alternating refractive index known as a Bragg grating, which reflects and transmits specific wavelengths of light.



A schematic of the microfluidic optical fiber in which an infiltrated ferrofluid (orange) alters the spectrum reflected from a Bragg grating (green). Reproduced with permission from *Opt. Lett*. **36**(13)(2011), DOI:10.1364/OL.36.002548, p. 2548. © 2011 Optical Society of America.

A "ferrofluid" dispersion of magnetite (Fe_3O_4) nanoparticles in an isoparrafinic solvent was infiltrated into the microfluidic channels as a 2 mm long plug which acts as a phase defect when overlapping with the grating. This shows up as a dip in the reflected bandwidth whose position and magnitude can be altered by using an external magnetic field to displace the fluid.

A more powerful effect was seen when applying the same principle to a "chirped" Bragg grating, which includes a linear variation in the period of the alternating refractive index. In this case, the ferrofluid plug causes an asymmetrical chopping of the Bragg grating reflected spectrum, narrowing the bandwidth and shifting it to higher wavelengths. In this instance, the sections of grating on either side of the plug are no longer in resonance, and therefore only the illuminated side interacts with the reflected spectrum.

"Such magnetofluidic optical fiber components could be the precursors to developing ultracompact and high-performance photonic devices, serving diverse sensing applications in medicine and electrical power delivery," Pissadakis said.

Tobias Lockwood

Energy Focus

Lithiation highway in Si nanopillars contributes to anisotropic shape changes

Because of its high theoretical specific capacity, silicon is a promising candidate material to use as anodes in lithium-ion batteries. One major challenge for silicon in this context is its large volume expansion upon lithium insertion, up to 400%, which leads to anode pulverization and decreased performance. The use of various Si nanoarchitectures has been instrumental in improving performance due to increased ability to accommodate large volume changes. Though Si nanomaterial electrochemical performance has been studied extensively, mechanistic understanding of volume change upon lithium insertion in these materials is limited. S.W. Lee and colleagues at Stanford University report on anisotropic shape changes of silicon nanopillars induced by electrochemical lithiation as published in the June 9 online edition of *Nano Letters* (DOI: 10.1021/nl201787r).

The researchers used scanning electron microscopy (SEM) to study silicon nanopillars in varying states of lithiation. The nanopillars of distinct axial orientations are fabricated using deep reactive-ion etching on Si wafers with SiO_2 nanospheres as an etch mask. This study includes nanopillars with axial orientations of <100>, <110>, and <111>. Lithiation is accomplished by using the nanopillars as the working electrode in electrochemical half cells with Li metal foil as the counter electrode.

Upon lithiation, surprising cross-sectional shape differences are observed between the different types of nanopillars. The circular cross sections of the pillars develop into "plus" sign shapes in the <100> pillars, ellipses in the <110> pillars, and rough hexagons in the <111> pillars. In the most extreme case, the <110> pillars expanded 245% along the long axis of the final ellipse and only 49% along the short axis.

These directions of increased expan-

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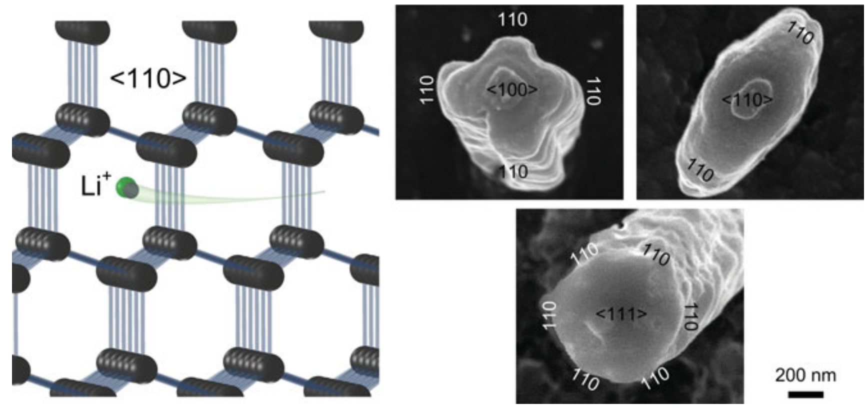
sion can be mapped to <110> directions in the Si crystal structure, a direction that provides large space between Si atoms allowing for ion diffusion to take place. The researchers propose fast lithium ion diffusion along the <110> directions and plastic deformation of the Li-Si alloy are responsible for the anisotropic growth behavior.

Unexpectedly, <100> and <111> pillars first exhibit a marked decrease in height, up to 9.5%, before ending within 1–2% of the initial height upon full lithiation. The <110> nanopillars increase in height throughout lithiation ending about 4% taller than they started. The researchers explain this height behavior by considering the relative effects of two processes: growth in <110> directions as just described versus decreased plane spacing between <111> planes due to broken Si–Si bonds where Li ions are inserted at tetrahedral sites.



Upon lithiation, the initially circular cross sections of crystalline Si nanopillars with <100>, <110>, and <111> axial orientations expand into cross, ellipse, and hexagonal shapes, respectively. A high-speed lithium ion diffusion channel along the <110> direction causes preferential volume expansion along this direction. Reproduced with permission from *Nano Lett*. (DOI: 10.1021/nl201787r). © 2011 American Chemical Society.

An understanding of the structural evolution of Si nanostructures during electrochemical lithiation is important for guiding development of higher performance Si anodes. According to the researchers, this work describes mechanistic insights into nanopillar expansion during lithiation that can be used as experimental handles to continue improving upon existing Si anode architectures.

Alia P. Schoen

Nano Focus

Micro drum chilled to quantum ground state

Showcasing new tools for developing quantum circuits made of mechanical parts, a team of researchers has demonstrated a flexible, broadly applicable technique for steadily damping the vibrations of a mechanical object down to the quantum "ground state," the lowest possible energy level.

As described in the July 6 online edition of *Nature* (DOI:10.1038/nature10261), experiments conducted by J.D. Teufel of the National Institute of Standards and Technology (NIST); K. Lehnert of JILA, a joint institute of NIST and the University of Colorado; and their colleagues nearly stop the beating motion of a microscopic aluminum drum made of about 1 trillion atoms, damping its motion below a single quantum, or unit of energy, and so placing the drum in a realm governed by quantum mechanics. Like a plucked guitar string that plays the same tone while the sound dissipates, the drum continues to beat 11 million times per second, but its range of motion approaches zero. According to the researchers, the cooling technique and drum device together promise new machinery for quantum computing and tests of quantum theory, and could help advance the field of quantum acoustics exploring the quantum nature of mechanical vibrations.

The research team used the pressure of microwave radiation to calm the motion of the drum, which is embedded in a superconducting circuit. The circuit is designed so that the drum motion can influence the microwaves inside an electromagnetic cavity. The cooling method takes advantage of the microwave light's tendency to change frequency, if necessary, to match the frequency, or tone, at which the cavity naturally resonates.

"I put in the light at the wrong frequency, and it comes out at the right frequency, and it does that by stealing energy from the drum motion," said Teufel, who designed the drum.

The drum can store individual packets of energy, or quanta, for about 100 μs without change, much longer than conventional superconducting quantum bits can maintain information. The drum, thus, might serve as a short-term memory device for a quantum computer as well as a platform for exploring complex mechanical and quantum states for tests of theories such as quantum gravity. The apparatus also allows researchers to measure the position of the drum directly, which is useful for force detection, with a precision closer to the ultimate limit allowed by quantum mechanics.

To make engineered bulk objects obey the rules of quantum mechanics, typically observed only in atoms and smaller particles, scientists must lower an object's temperature beyond the reach of conventional refrigeration. The drum experiments used a technique analogous to the way lasers are used to cool individual atoms to near absolute zero, lowering the drum temperature to below 400 μK, or just one-third of one quantum.

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