of soft scanning force microscope cantilevers. These cantilevers have oscillations perpendicular to the surface of the order of 10^{-10} m, while a particle in an optical trap can fluctuate as much as several hundred nanometers in any direction. In this manner, the particle is able to scan over an area becoming a "natural 3-D mechanism".

Scientists from the European Molecular Biology Laboratory in Germany obtained 3-D images of an agar gel by means of this technique, as they describe in the November 26, 2001, issue of *Applied Physics Letters*. An agar gel is a transparent substrate used for biological cultures and chromatography. In this case, liquid agar was mixed with latex beads with a nominal diameter of 216 ± 8 nm. The beads were added at a concentration of 1/20 μm^3. A photonic force microscope, which is a scanning force microscope based on optical tweezers, was used to conduct the experiments. It included a 1064-nm laser beam and a three-dimensional detector. This detector consists of a quadrant photodiode where the scattered laser light from the particle produces an interference pattern. The position of the optical trap is measured with <1 nm error; the position of the center of the particle is measured with nanometer resolution.

A position histogram was calculated after recording the position of a particle for 0.8 s. The thermally induced particle fluctuations allowed it to scan a volume of 300 × 120 × 120 nm^3. It was also possible for the particle to scan areas around an object. When the optical trap was moved along the agar network in 80-nm steps, the variations on the position of the particle showed indications of the presence of the network filaments. The same effect was observed when the optical trap was moved along the *x*- and *y*-axes of the agar network in 80-nm steps and along the z-axis in 160 nm steps. After scanning a volume of 600 × 600 × 300 nm^3, three filaments of the agar network were detected: two of them located inside this volume and one at the edge. The size of the particle affects the resolution which, in these experiments, is ~20 nm.

SIARI S. SOSA

Micro-Optical Devices Dry Etched into Diamond

Diamond has the widest optical transparency window and highest thermal conductivity of all known substances. Consequently, it is a very versatile material for use in optics. Diffractive optical elements (DOEs) are interesting for many applications, including the shaping of CO_2 lasers and Nd:YAG lasers. As reported in the November 15, 2001, issue of *Optics Letters*, M. Karlsson, K. Hjort, and F. Nikolajeff fabricated continuous-relief blazed gratings and diffractive Fresnel lenses in diamond of optical quality at the Angstrom Laboratory in Sweden. The DOE pattern was first written in an electron-sensitive resist by direct-write electron-beam lithography, then transferred from the resist into the diamond by dry-etching in an inductively coupled plasma. The researchers used electronic-grade O_2 and Ar gases for etching of the diamond substrate, and the surfaces were polished to a root-mean-square (rms) roughness of <15 nm.

The transfer of the DOEs from the electron-beam resist into diamond was made in an inductively coupled plasma (ICP) etching system. ICP etching is a high-density system with plasma-etch rates of 1900 nm/min in resist and 190 nm/min in diamond. The researchers reported that to their knowledge, this is the first time that dry etching has been used to transfer continuous structures into diamond. Both blazed gratings and diffractive Fresnel-type lenses were created. The transferred blazed grating was carefully inspected with both an optical microscope and with atomic-force microscopy (AFM) to measure the height of the structure, the surface morphology, and the accuracy of the transfer process. The blazed grating was found to have a period of 45 μm and a grating depth of 3 μm. By using AFM data from the original structure, researchers simulated a diffraction efficiency of 71.5% for the e-beam-exposed structure with a theoretical value of 100%. After etching, the final diamond structure had a diffraction efficiency in the first order of 68.2%, measured with a solid-state laser.

The group now intends to proceed with a more fundamental study of transferring micro-optical elements into diamond by using ICP etching. They also plan to fabricate diffractive and refractive elements for use with Nd:YAG high-power lasers. In this study, the researchers were unable to design optical elements for wavelengths larger than ~700 nm. However, they believe that replicating DOEs in photoresist might lead to optical elements for the infrared region, facilitating applications for 10.6-μm CO_2 lasers.

JENNIFER BURRIS

Reduction in Roughness of Waveguides Leads to Ultralow Transmission Loss

By reducing the sidewall roughness of Si/SiO_2 waveguides, researchers at the Massachusetts Institute of Technology and the University of Wisconsin—Madison have achieved ultralow transmission losses of 0.8 dB/cm by using oxidation smoothing and anisotropic etching techniques. They believe this to be the smallest loss for a high-index-difference system reported to date.

Scattering losses in waveguides—as calculated by the commonly used method of Marcuse, Payne, and Lee—are proportional to the root-mean-square (rms) surface roughness. Typical rms roughness values for waveguides fabricated by conventional photolithography and reactive ion etching (RIE) techniques are about 10 nm, which yield scattering losses of about 32 dB/cm. By following the photolithography and RIE steps with wet oxidation smoothing or anisotropic etching, the researchers were able to reduce the sidewall roughness to 2 nm.

As reported in the December 1, 2001, issue of *Optics Letters*, K. Lee, D. Lim, and L. Kimerling at MIT, and J. Shin and F. Cerrina at Wisconsin first fabricated waveguides using standard methods. Starting with wafers consisting of a 0.2-μm-thick layer of Si on 1-μm-thick SiO_2, they patterned the surface using UV photolithography, and etched it with SF_6 gas. This produced straight waveguides with widths in the range of 0.5 μm–8 μm. For the oxidation-smoothing sample, the Si layer of the starting wafer was 0.34 μm thick. After photolithography and RIE, the waveguide core was subjected to wet oxidation by H_2O and O_2 at 1000°C for 43 min followed by an HF dip to remove the oxide.

The anisotropic-etching sample fabrication was more complicated. Again starting with a 0.34-μm-thick Si layer on a 1-μm-thick SiO_2 wafer, they oxidized the Si top layer to produce a 0.3-μm-thick SiO_2 layer on a 0.2-μm-thick Si core, leaving the 1-μm-thick Si base layer intact. The top SiO_2 layer was subject to photolithography and RIE to make a hard mask for the core of the waveguide, then the sample was immersed in a 25-wt% aqueous solution of NH_4OH at 80°C for 1 min to etch away the Si from the non-waveguide area. The oxide hard mask was removed, leaving a Si waveguide core.

Atomic force microscopy revealed rms surface roughness values of 2 nm for both the oxidation-smoothed and the anisotropically etched samples, versus 10 nm for the conventionally fabricated waveguide. Transmission-loss measurements versus waveguide width were performed using cutback, IR capture of scattered light, and Fabry–Perot resonance measurements. The reduced transmission loss due to smoother surfaces in the oxidation-

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smoothed and anisotropically etched samples was evident throughout a wide range of waveguide widths. According to the researchers, this smoothing technology could lead to significant improvements in practical waveguide design for optical devices.

TIM PALUCKA

Dynamics Study of Polymer Chains Shows Reduction in Atomic Diffusion Coefficients at a Free Surface

In the November 12, 2001, issue of *Physical Review Letters*, researchers from the State University of New York—Stony Brook reported the relationship between structure and dynamics of polystyrene (hPS) by dynamic secondary-ion mass spectrometry (DSIMS). Their experimental results confirmed the chain-conformation calculation at the free surface by mean-field theory.

In order to understand how the center of mass diffusion of polystyrene related to its different molecular weight as a function of distance from the vacuum interface, a special multiple-layer sample used in the DSIMS experiment was designed. It had two parts, each consisting of a 200-nm layer of matrix hPS followed by a 25-nm layer of 20% monodisperse deuterated analogue (dPS) and 80% matrix hPS. From the relationship between the concentration of the tracer polymer (hPS or dPS) volume and the distance from the free surface for the four-layer sample, the diffusion coefficients for diffusion into a semi-infinite and an infinite medium for the top layer and the middle layer were both reduced relative to the bulk value within the distance from the surface.

The researchers found that "a purely enthalpic argument" cannot explain the experimental result. They had previously reported a large slowing down of dynamics when polymer chains were oriented parallel to the surface by rubbing the surface. They then hypothesized that the stringent confinement imposed by the large surface tension at the vacuum interface was inducing the chain orientation. This type of orientation was also plausible from the theoretical work of Kurt Binder, who demonstrated that the fluctuation times at the surface of a polymer film were anisotropic—namely, those parallel to the sample surface were much faster than those in the perpendicular direction. To test this hypothesis, self-consistent field theory was used and a one-dimensional equilibrium lattice method was designed, in consideration of the small system size. This method identified the segmental distribution at the surface, that is, the number of segments a chain has near the surface as a function of its position from the surface. After comparing the theoretical calculation with the experiment results of the chain dynamics, the researchers confirmed that asymmetric segmental fluctuations at the surface resulted in decreased mobility at the surface. This result overturned the long-held assumption that a large enhancement in mobility would be found at the surface, in analogy to monomolecular systems where this effect was observed as a result of the reduced potential.

YUE HU

One-Dimensional Metallic Edge States Observed in MoS_2

Researchers at the Technical University of Denmark and the University of Aarhus have found metallic states along the edges of two-dimensional MoS_2 clusters. These edge states are a realization of one-dimensional conducting wires and have been observed in MoS_2 nanoclusters on Au(111) substrates.

M.V. Bollinger, J.V. Lauritsen, and coworkers described their results in the November 5, 2001, issue of *Physical Review Letters*. The researchers performed density functional theory (DFT) calculations on a single layer of MoS_2 and studied the edges in a model system consisting of a stripe of MoS_2 in a supercell geometry. They also reported experimental scanning tunneling microscopy (STM) images of MoS_2 nanoclusters on Au(111) substrates along with simulated STM images calculated from a Tersoff–Hamann model.

The experimental STM images achieve atomic resolution and reveal the detailed structure of these MoS_2 clusters. The images also show a brim of high conductance that extends around the edge of these clusters.

The DFT calculations for MoS_2 edges show two one-dimensional metallic states localized at the molybdenum edge. One of these states (edge state I) is localized at adsorbed sulfur dimers on this edge and is a superposition of p_x orbitals extending in two parallel chains.

To investigate whether these metallic edge states are responsible for the conducting brims seen in experiments, the researchers simulated STM images for MoS_2 stripes with and without an underlying Au(111) substrate. These calculations showed that the brim is due to the p orbital arising from the p–d bond between sulfur and molybdenum.

"The one-dimensional metallic wires existing at the edges of the MoS_2 nanoclusters may provide a template for investigating the properties of coherent electrons on this length scale," said Bollinger.

Another important consequence of this work, according to the report, is a better understanding of the catalytic properties of MoS_2. Bollinger said, "It is generally accepted that catalytically active sites of MoS_2 are localized at edges. Since the electronic structure at edges determines this reactivity, it is certainly possible the metallic edge states play an important role in this context."

CHRISTOPHER MATRANGA

Low-Temperature Aging of Zirconia Ferrules Limits Optical-Connector Reliability

The increased use of optical fibers in uncontrolled environments has recently led to research focused on the durability and reliability of interconnects. Current technology employs flat-end-face connectors where the reduction of reflected light at the fiber end is achieved by physical contact between the optical fibers secured in a stabilized zirconia ferrule. A team of researchers from the Oak Ridge National Laboratory, Rutgers University, and Bellcore in Morristown, N.J. has shown that strict polishing, which ensures physical contact, accelerates the aging of zirconia ferrules by relieving compressive stress, making the resulting phase transformation more thermodynamically favorable. This environmental-aging-induced phase transformation results in a 4–5 % increase in the unit-cell volume, leading to surface roughening and optical losses due to contact problems, thus limiting connector lifetimes.

As reported in the November 2001 issue of the *Journal of the American Ceramics Society*, the research team, led by Michael Lance, aged samples from a variety of manufacturers at temperatures from -10°C to 85°C at 95% relative humidity for 90 days. Studying the results with profilometry, optical, and interferometric microscopy, the researchers found two patterns. In some samples, they observed a significant increase in the surface roughness of polished zirconia ferrules, corresponding to a 1–2 vol% phase transformation. In other samples, they saw a flattening or deformation of the zirconia surface, corresponding to an increased volume content of monoclinic transformed zirconia, up to 40 vol%.

Raman spectroscopy equipped with a confocal aperture was used to control the sampling depth and to quantify the tetragonal–monoclinic phase transformation. They reported that the amount of transformation was lower in the vicinity of the optical-fiber-region under compression—and that transformation occurred only at the polished surface of the material. In addition, no monoclinic zirconia was found at the sides of the fer-

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