

### Near-Field Optical Microscope Enables Submicron Direct-Write Laser Micromachining of Diamond

Diamond came to the attention of the scientific community as a material that could be useful in microelectronic and microelectromechanical systems applications because of its mechanical, electrical, thermal, and chemical properties. However, diamond is very difficult to work with, due to its hardness. Igor Smolyaninov and Christopher Davis from the Department of Electrical and Computer Engineering of the University of Maryland have developed a technique for microscale processing. Using a standard scanning near-field optical-shear-force microscopy technique, they achieved high-resolution surface ablation of thick chemical-vapor-deposition-(CVD)-grown diamond films.

As reported in the October 1 issue of *Optics Letters*, their method uses nanosecond optical pulses from a Nd:YAG laser operating at 1060-nm wavelength coupled to a multimode optical fiber with an initial core diameter of 150  $\mu\text{m}$  adiabatically tapered to a 100-nm microscope tip and used as a local light source. This arrangement allowed them to deliver a power of  $\sim 100 \text{ MW}/\text{cm}^2$  to a sample region of only 500 nm  $\times$  500 nm during a single laser pulse. This power was sufficient for ablating locally the surface of diamond. The ablation process required multiple laser pulses in a given location and may be mediated by an intermediate step in which the diamond is turned into graphite before being ablated. Patterns written on samples were investigated with a shear-force microscope, which was an intrinsic part of their system. Extended use of the optical fiber showed no damage to the tip from either exposure to the laser light or accumulation of graphite. Calculations indicate that the optimum tip diameter is  $\sim 1/3$ . Thus, even though the diameter for single spots obtained was  $\sim 500 \text{ nm}$ , the spatial resolution of this micromachining method can be further increased to 50–100 nm by using a pulsed UV laser.

CLAUDIU MUNTELE

### Electromagnetic Tweezers Enable Simultaneous Positioning and Viewing of Micron-Sized Magnetic Objects

The advent of nanotechnology has created a need for techniques that are capable of precisely manipulating and positioning objects that range in size from atomic to micrometer dimensions. Optical trapping methods and microelectromechanical systems (MEMS) have been used for manipulating micron-scale objects of biological interest. For magnetic materials, magnetic

tweezers, consisting of permanent or soft coil-wound magnets with macroscopic dimensions, have been employed. Recently, a magnetic material manipulation technique that integrates a low profile magnetic coil and soft ferromagnetic probe has surfaced. This device, which is physically much smaller than other magnetic or optical tweezers, provides several advantages over these other devices, including negligible sample heating, low cost, ability to study particles suspended in a variety of solutions, and simultaneous positioning and optical viewing of samples.

In the September 17 issue of *Applied Physics Letters*, Mladen Barbic and co-workers of the University of California—San Diego described a scanning probe electromagnetic tweezer system that utilizes a microcoil and a magnetic microtip for localized positioning of micron-sized magnetic objects. Their technique also incorporates an optical illumination scheme that allows the magnetically trapped objects to be viewed without the interference that often arises due to light scattering from the magnetic manipulator tip. The device can position magnetic objects with submicron resolution up to operating distances of more than 40  $\mu\text{m}$ .

The scanning probe electromagnetic tweezers were fabricated by winding 25- $\mu\text{m}$ -diameter copper magnet wire around a 50- $\mu\text{m}$ -diameter soft-ferromagnetic wire (two coil layers with 6–8 turns each). The soft-ferromagnetic wire was electrochemically etched into a sharp probe in aqueous 40% sulfuric acid solution at 3 V. In addition to keeping the device small, by minimizing the coil diameter and the ferromagnetic tip size, the researchers gained in magnetic field strength and field gradient, respectively. The microcoil and microtip, which measure 1  $\text{mm}^3$  in size (see figure), were installed on a Nikon Diaphot inverted optical microscope such that the microtweezers tip rested on a mechanical translation stage above the microscope's viewing lens.

Superparamagnetic, 2.8- $\mu\text{m}$ -diameter beads and 1- $\mu\text{m}$ -diameter (nonmagnetic) polystyrene (PS) beads were placed inside a rectangular cross-section quartz capillary tube with inner dimensions of 50  $\mu\text{m}$   $\times$  500  $\mu\text{m}$  and a uniform wall thickness of 40  $\mu\text{m}$ . The capillary tube was placed between the tip and the microscope lens, and the microtip was brought to within several microns of the outer capillary wall. White light from a xenon lamp was coupled to the capillary tube through an optical fiber to allow for optical viewing. The capillary holder prevented spurious light scattering from the microtip. Due to differences in the index of refraction



Figure. The micro-manipulator (microcoil and microtip), which measures 1  $\text{mm}^3$  in size, offers an alternative to the optical tweezers method. The micron-scale coil diameter and ferromagnetic tip allow these electromagnetic tweezers to be fabricated with dimensions that are much smaller than traditional magnetic tweezers.

between the capillary and air, light was confined to the capillary due to total internal reflection, and magnetically trapped particles were clearly viewed without scattering interference. Furthermore, the magnetic samples were suspended in a liquid solution, and thus the capillary provided a container that both held the liquid and prevented the microtip from contacting the sample.

In their experiment, the researchers prepared an area on the sample that contained two closely spaced (10- $\mu\text{m}$ ) PS beads but no magnetic particles. A nearby magnetic particle was located and, using the manipulator with a 100-mA microcoil current, this bead was moved such that it traced out a figure eight pattern around the PS beads, thereby demonstrating submicron positioning of a micron-sized particle. The researchers estimated that approximately 0.5 pN of force is exerted on the particle per 10 mA of current through the manipulator's microcoil. Coil currents up to 200 mA have been used without instrument degradation, indicating that forces as large as 10 pN could be applied to particles. Even at these higher currents, the low ( $1 \Omega$ ) coil resistance ensures that sample heating does not occur.

"Our technique provides an attractive alternative to the optical tweezers method used in biological studies," said Barbic. "The micro-manipulator, which measures only 1  $\text{mm}^3$  in size, could prove to be a valuable low-cost engineering tool. The device also has potential for further miniaturization and integration into micro-fluidics and MEMS systems."

STEFFEN K. KALDOR

### Switchable SQUID Fabricated in Loop Geometry from $\text{Fe}_{0.1}\text{Co}_{0.9}$ and Pb

J. Eom and Mark Johnson at the U.S. Naval Research Laboratory have fabricat-

ed a switchable superconducting quantum interference device (SQUID) by using novel magnetoquenched superconductor-normal-metal-superconductor (S-N-S) Josephson junctions formed in a loop. This arrangement of superconductor and ferromagnetic films utilized  $\text{Fe}_{0.1}\text{Co}_{0.9}$  and Pb on polished Si substrates.

While the junction properties of most SQUIDs are determined at fabrication, mesoscopic magnetoquenched superconducting valve (MMSV) S-N-S junctions can be switched on and off simply by changing the direction of the stable magnetization state in the ferromagnetic film. The researchers took the MMSV, a bilayer structure that consists of a ferromagnetic film spanning a narrow superconducting bridge, one sizable step further when they formed two superconducting bridges into a loop with one MMSV in each arm. When the MMSV junctions were "on," the researchers were able to observe and study superconducting quantum interference effects in the device by applying a weak, perpendicular magnetic field. By also switching the junctions "off," the researchers demonstrated a switchable SQUID.

As reported in the September 24 issue of *Applied Physics Letters*, Eom and Johnson fabricated samples on polished Si substrates with 100-nm-thick silicon nitride cap layers. Next, they thermally deposited 110 nm of Pb in a mostly evacuated environment and then patterned the superconducting bridge using optical lithography and an Ar ion mill. They used optical lithography to define and open a window for deposition of the ferromagnetic film after the surface of the Pb was oxidized by  $\text{O}_2$  plasma. A 170-nm ferromagnetic layer of  $\text{Fe}_{0.1}\text{Co}_{0.9}$  was deposited by e-beam evaporation on top of the oxide surface. The completed devices consisted of films less than 300-nm thick.

When asked about their device, Johnson said, "The key to our success was simply trying something that nobody thought would work." Now that their design has worked, Eom and Johnson see it potentially reaching fruition in time-dependent magnetization measurements or as nonvolatile circuit elements in digital superconducting electronics.

PAMELA JOHNSON

### Multilayer $\text{Ni}_{80}\text{Nb}_{20}/\text{MgO}$ Mirrors Efficiently Reflect Water-Window X-Rays

An international team of researchers from the Department of Metallurgical Engineering and Materials Science, Indian Institute of Technology in Bombay and from Institut für Materialphysik, Uni-

versität Göttingen has made a multilayered mirror from alloy-ceramic oxide— $\text{Ni}_{80}\text{Nb}_{20}\text{-MgO}$ —for water-window soft x-rays (2.2–4.4-nm wavelength range) by pulsed-laser deposition. As reported in the September 15 issue of *Optics Letters*, the alloy target was prepared from high-purity Ni and Nb powders, while for the MgO target, high-purity single-crystal substrates were used. The mirror was deposited on a silicon substrate, at room temperature, using an excimer laser with 245-nm wavelength, 30-ns pulse width, and 10-Hz pulse rate. A total of 40 bilayers were deposited with a deposition rate of 0.023 nm per pulse for the MgO and 0.0076 nm per pulse for  $\text{Ni}_{80}\text{Nb}_{20}$ . The method used to analyze the resulting multilayered mirror was grazing incidence x-ray scattering with  $\text{Co-K}_\alpha$  radiation.

From the two types of x-ray scattering scans performed (reflectivity and transverse), the researchers obtained information about the growth of the layers and structure of the interfaces. It was found that the thickness of individual layers is  $1.78 \text{ nm} \pm 0.15 \text{ nm}$ , corresponding to a bilayer thickness of 3.56 nm. Also, the roughness of the interfaces was found to be only 0.35 nm. No second-order reflection was observed, consistent with the 1:1 layer thickness ratio. The atomic arrangement within the layers was established to be amorphous using high-angle x-ray diffraction with  $\text{Co-K}_\alpha$  radiation.

The novelty of this research consists in the low value of the roughness at the interface indicating a different type of growth in MgO layers, the high reflectivity (38%) at a wavelength of 0.179 nm and the

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