Laser-Manipulated Iron Applied to Nanofabrication

In magnetism, model systems are required for understanding magnetic interactions and switching behaviors on the nanoscale. Fabrication and analysis of periodic nanostructures can therefore be useful in understanding phenomena such as magnetic photonic bandgaps or ultrahigh-areal-density materials for magnetic data storage. In the October 25 issue of *Applied Physics Letters* (p. 3842), G. Myszkiewicz and E. Jurdik from the group of Th. Rasing of Radboud University Nijmegen in The Netherlands have reported the fabrication and characterization of iron nanolines by atom optics, which is the interaction between an atomic beam and a far-off resonant laser standing wave. Atom optics allows for macroscopic, uniform arrays of well-defined periodic structures necessary for future magnetic data storage technology.

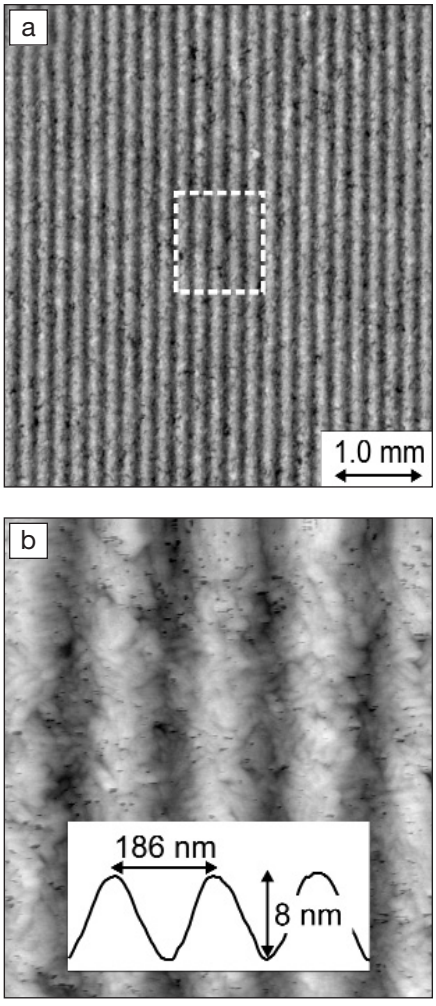

Figure 1. Laser-focused nanolines of iron. Atomic force microscopy scans of (a) 5 μm × 5 μm and (b) 1 μm × 1 μm, corresponding to the surface area encapsulated in the white square in (a); inset is the structure profile averaged over 1 μm along the lines. Reprinted with permission from Applied Physics Letters ***85*** *(17) (October 25, 2004) p. 3842.*

The iron nanostructures were grown by depositing an atomic beam of iron onto a glass–ceramic substrate through a one-dimensional optical standing wave tuned 200 MHz above the relevant optical transition in ^{56}Fe. The optical forces applied to the ^{56}Fe atoms propagating through the optical standing wave caused the atoms to migrate toward the regions of low light intensity. The process does not induce 100% modulation depth of the atoms so that the result is a background layer of deposited metal with a periodically-modulated line structure on top. The macroscopically "corrugated" surface is created with highly uniform Fe nanolines, which have a period of 186 nm, a full-width at half maximum of 95 nm, and a height above the background of 8 nm, as shown by atomic force microscopy (Figure 1). Approximately 8600 iron nanolines were created, each ~400 μm in length. Studies using magnetic force microscopy and magneto-optical Kerr measurements demonstrate ferromagnetic behavior with an in-plane easy axis that is independent of nanoline presence.

The researchers said that future work will involve engineering a material with periodically modulated magnetization, such as selective manipulation of iron during simultaneous deposition of another material, in order to create a nanostructure that is useful for data storage.

ADITI S. RISBUD

High-Contrast Images of Semiconductor Chips Produced by Novel Microscopy Approach

A semiconductor integrated circuit (IC) chip is composed of metals, semiconductors, and dielectrics. In order to accurately identify the defect material in an integrated circuit, several microscopic imaging tools are available, but each has its advantages and drawbacks. V.J. Cemine and colleagues from the University of the Philippines have found that by combining confocal microscopy and optical-beam-induced current (OBIC) imaging, they are able to achieve high-contrast images of semiconductor and metal sites in integrated circuits. By using a semiconductor laser instead of a gas laser as the light source, they increased the efficiency and reduced the costs of this technique over others.

The OBIC imaging method can be used to generate two-dimensional images of the semiconductor sites in an IC because only semiconductors produce OBIC signals. A serious drawback with the OBIC images, though, is their poor resolution in the direction perpendicular to the chip surface, which makes images look similar even if they are taken at different depths. Confocal reflectance microscopy, on the other hand, yields high-contrast images, but metal and semiconductor sites are difficult to distinguish from each other because both materials exhibit relatively high reflectivity.

As reported in the November 1 issue of *Optics Letters* (p. 2479), the researchers acquired a pair of confocal and OBIC images simultaneously with the same focused beam by scanning the IC sample longitudinally relative to the stationary optical beam. The semiconductor laser used in these measurements is responsive to the reflected optical signals from the IC samples. This optical feedback mechanism helps to reduce threshold current and improve quantum efficiency of the laser. Three-dimensional distributions of semiconductor and metal sites in an IC are constructed by post-detection processing of image pairs taken at different depths.

"This is an inexpensive technique for high-contrast imaging of semiconductor and metal sites in an integrated circuit," said the researchers. "When combined with existing data sampling technologies employed in VCD players, rapid failure analysis of ICs can be performed economically."

SHIMING WU

Protein Nanopatterning Technique Combines Nanoimprint Lithography and Molecular Self-Assembly

A major challenge for the development of bioengineered surfaces is the ability to immobilize proteins on scales ranging from the submicron to the nanometric. A critical criterion for biomolecular nanopatterns is the ability to deter nonspecific biomolecular binding, including nonspecific binding in the non-interactive areas of the pattern, to insure a low background signal. Patterning methods fall into two categories: serial and parallel. Serial techniques—like electron-beam writing, focused ion beam, and scanning probe-based lithography—are typically expensive and time-consuming but can generate virtually any type of pattern. Parallel techniques that produce regular, submicron patterns include microcontact printing, colloidal lithography, dip-pen nanolithography, and nanoimprint lithography (NIL). These methods are inexpensive compared to serial techniques but have substantially less pattern-shape flex-

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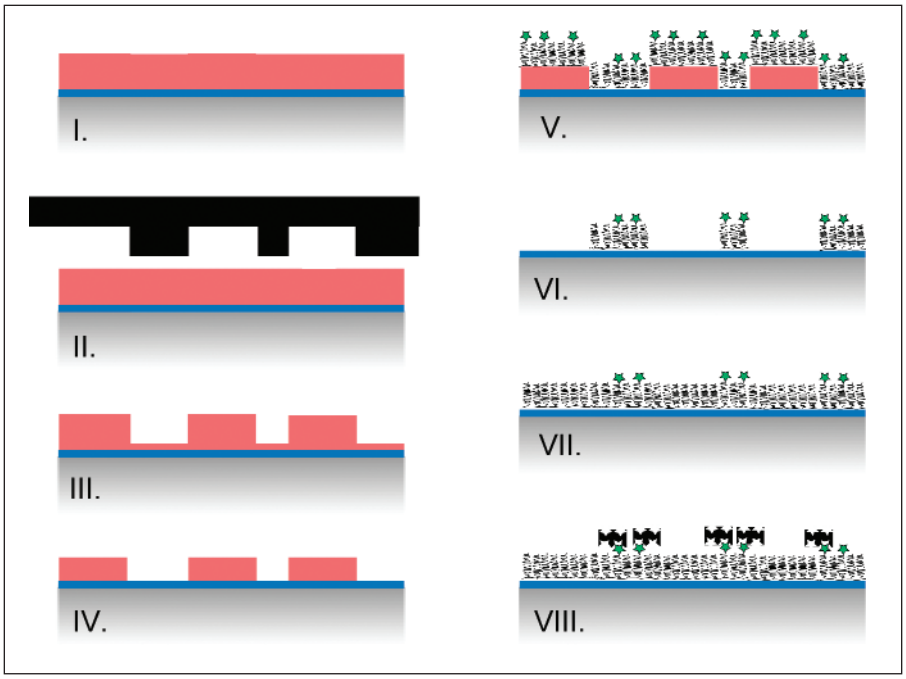

Figure 1. The protein nanopatterning technique combines nanoimprint lithography (Steps I–IV) with molecular-assembly patterning by lift-off (Steps V–VIII). Reprinted in part with permission from Nano Letters **4** *(10) (October 13, 2004) p. 1909. © 2004 American Chemical Society.*

ibility. Recently, however, M. Textor from the Swiss Federal Institute of Technology and colleagues from the Paul Scherrer Institute, the University of Siena, and the Centre Suisse d'Electronique et de Microtechnique have demonstrated a parallel process that is both versatile and economical to pattern proteins onto surfaces with nanoscale resolution.

As reported in the October 13 issue of *Nano Letters* (p. 1909), Textor and coworkers created this method by combining a "top-down" approach—NIL—and a "bottom-up" approach—molecular assembly patterning by lift-off (MAPL). Textor, with other colleagues from his institution, previously published a description of MAPL in *Advanced Functional Materials* (August 2004, p. 749).

To begin the eight-step process of the combined method (see Figure 1), substrates were prepared by sputter-coating silicon wafers or Pyrex plates with 12 nm of transparent niobium oxide (Nb_2O_5). In the NIL component, substrates were then spin-coated with 125 nm of poly(methyl methacrylate) (PMMA) and baked for 1 min at 170°C (Step I). Silicon nanopatterned stamps, which were prepared by electron-beam writing and reactive ion etching, were replicated by imprinting into the substrate (Step II). The stamp was demolded from the substrate in Step III. A nanostructured surface with PMMA/Nb_2O_5 contrast was then obtained by etching the residual PMMA of the nanoimprinted regions (Step IV).

In the MAPL component, which transforms the PMMA/Nb_2O_5-contrasted surface into a biologically functional nanopattern, the method begins by dipping the sample into a solution of biotin-functionalized copolymer—polycationic poly(L-lysine)-graft-poly(ethylene glycol)/poly(ethylene glycol)-biotin (PLL-*g*-PEG/PEG-biotin; about every fourth lysine had a grafted PEG chain and half of all PEG chains were biotinylated)—that adsorbs onto both the PMMA and Nb_2O_5 surfaces (Step V). The remaining PMMA was stripped with acetone (Step VI) and the newly exposed Nb_2O_5 surfaces were backfilled with nonfunctionalized copolymer, PLL-*g*-PEG, that resists adsorption of proteins (Step VII). The substrate was dipped into a buffered solution of fluorescently labeled streptavidin (a protein that has a high affinity for the biotin ligand), which bonds specifically to the biotinylated areas (Step VIII).

The researchers characterized the nanostructures at each fabrication step. For example, atomic force microscopy showed that 100±10 nm PMMA/Nb_2O_5 stripes (with a regular line pattern of 400 nm periodicity) resulting from Step IV had widths comparable to those initially imprinted in Step II. The fluorescently labeled streptavidin that adsorbed onto the stripes were imaged with scanning near-field optical microscopy, verifying the selective adsorption onto the biotin-functionalized-polymer pattern. The researchers also used their technique to fabricate similar biopatterns on the micron scale.

The researchers said that the surface density of bioactive molecules can be quantitatively controlled by diluting the functionalized copolymer with nonfunctionalized copolymer in Step V. In addition, the researchers said that the "PEG polymer can be functionalized with a variety of bioactive groups and thus allows a great flexibility in terms of surface chemistry."

STEVEN TROHALAKI

Optical Waveguiding Observed in CdS Nanowires

Among many other potential applications, nanotechnology is believed to have promise for developing new photonic materials. C.J. Barrelet, A.B. Greytak, and C.M. Lieber from Harvard University have recently characterized cadmium sulfide (CdS) nanowire structures that are employed as photonic circuit elements. As reported in the October 13 issue of *Nano Letters* (p. 1981), the CdS nanowires can be used as subwavelength optical waveguides with exciting properties. Smooth CdS nanowires were synthesized using gold nanoparticles as catalysts, and by employing either molecular precursors or laser ablation of a solid CdS target. Optical studies were performed by locally injecting photoluminescence light along the nanowire, using a diffraction-limited laser spot to excite the CdS bandgap. Spatial maps generated by scanning optical microscopy reveal the efficiency with which the nanowire waveguides light from input to output. For a relatively straight 50 µm nanowire, there is no measurable loss. This demonstrates that semiconductor nanowires can act as extremely efficient subwavelength waveguides.

Charles Lieber's team also demonstrated that nanowires can provide a waveguide medium able to guide light around sharp bends having a radius of curvature much smaller than the wavelength with little loss. "Quantitative analysis of intensity versus position shows a low loss of about 1 dB associated with guiding light through acute angle structures," Lieber said.

Furthermore, the researchers made a nanowire-based electro-optic modulator whereby the intensity of the light being carried in an active waveguide can be varied by applying a voltage across the waveguide. Also, Lieber said that they achieved an electronically controllable

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