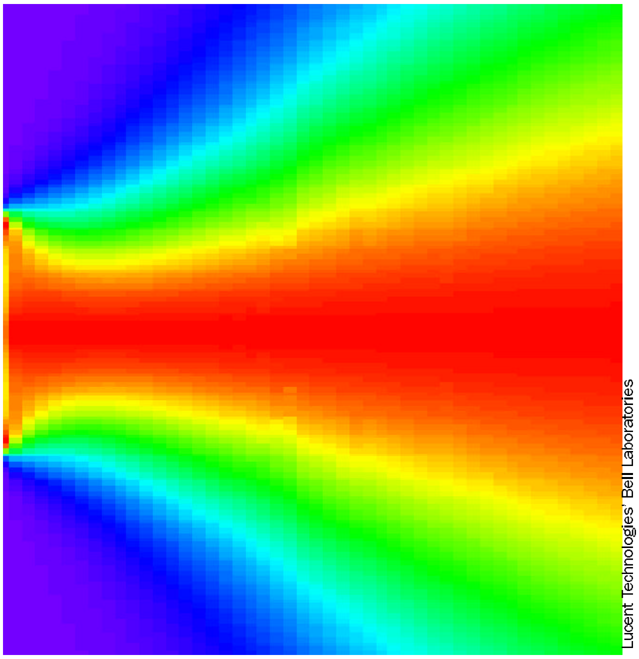
by Eric J. Lerner

Tiny, Powerful Laser for Optical Recording

Sometimes, the most obvious and best way to solve a problem is overlooked for a while. This observation applies to near-field optics, a burgeoning area of research. Near-field optics uses the fact that light can pass through apertures much smaller than a wavelength wide, although only for short distances from the aperture—an area called the near field. The technique has now been widely applied as a new form of microscopy. When near-field optics was first developed, it also appeared to be applicable in optical recording to create bits smaller than light wavelengths and, thus, to increase data density. But the power supplied by existing near-field light sources was too small to record data at high rates. When light was sent from a laser down a tapered fiber tip, most of the power was converted to heat and lost before the light exited through a small aperture at the end.



Lucent Technologies' Bell Laboratories

Calculated beam shape for polarized light of 980-nm wavelength transmitted through a 200-nm aperture shows the decay of electric field energy density with distance from the aperture.

At Lucent Technologies' Bell Laboratories (Murray Hill, NJ), Afshin Partovi and colleagues conceived a simpler and seemingly obvious idea. They just punched a tiny hole in the mirrored end of a laser diode, which let the light out directly through the small aperture (*Appl. Phys. Lett.* 1999, *75*, 1515). By eliminating the tapered tip, they greatly reduced power loss. The laser power density (power per unit area) through the aperture was comparable to that of a nonmirrored laser, and the power that did not escape through the aperture was recycled within the laser cavity and not lost as heat. In a single jump, the researchers increased the power delivered to a near-field spot by 10,000-fold over previous methods.

The Lucent team used a focused ion beam to punch a hole 250 nm on a side in the metal-coated facet of a small diode laser. With the resulting very-small-aperture laser (VSAL), they could write and read optical data with a density of 7.5 Gb/in.^{2}, three times that of a digital video disk. Ultimately, this technology could yield apertures as small as 30 nm across, which would increase data density to more than 500 Gb/in.^{2}, about 100 times greater than the best magnetic or optical-data-storage technology on the market today. Equally important, the VSAL achieved a read/write speed of 18 Mb/s, which is very competitive with existing systems, and rates as high as 100 Mb/s are within reach.

Lucent has licensed the technology to Siros Technologies, Inc. (San Jose, CA), a start-up company in which Lucent and EMC Corp. (Hopkinton, MA) hold equity. Siros intends to develop the VSAL for optical-data-storage technologies in various applications. The size of the VSALs—less than 1 mm on a side—is particularly important to the company. "Up to now, you haven't had any really miniaturized technology for optical recording," says Barbara Grant, Siros's president and chief executive officer. "Now with VSAL, we do, and we hope that we'll be able to compete not only with existing optical technologies, but with magnetic disks as well for products such as hard drives."

Transparent conductors

Metals are highly reflective because they are good electrical conductors. Electric fields cannot penetrate far into metals before the electrons rearrange themselves to cancel the fields out. Indeed, at optical frequencies, the skin depth of most metals—the depth at which the radiation falls to $1/e$ of its original intensity—is only 10 to 15 nm. A 40-nm layer of silver will block 93% of the light falling on it. So making a metal thick enough to carry substantial currents and thin enough to be transparent was generally regarded as a theoretical impossibility.

That's not so, according to research by physicists Michael Scalora, Mark J. Bloemer, and Charles Bowden at the U.S. Army's Redstone Arsenal (Huntsville, AL). Contrary to intuition, although a single 40-nm silver layer blocks out light, a stack of six layers transmits it. The secret is the well-known quantum mechanical phenomenon of resonant tunneling. In tunneling, a photon can cross an energy barrier because of the uncertainty in its position. Resonant tunneling greatly enhances this phenomenon when the spacing of the barriers is equal to one-half the wavelength of the light. Scalora and colleagues, using 145-nm layers of magnesium fluoride between the silver layers, obtained 50% transmission for a band of light in the green part of the spectrum centered on 500 nm. A solid block of silver of the same thickness as the six layers would be entirely opaque.

By tailoring the spacing between the layers and the thickness of the layers, the band of light that can resonantly pass through can be made broader or narrower. The team's theoretical calculations indicate that reducing the spacing of the first and last layers can dramatically increase transmittance, pushing it above 70% for a broad band from 450 to 600 nm. Equally important, the stack remains opaque to wavelengths well away from the resonance band, so it can be used as a transparent shield against anything from microwaves to soft X-rays.

The conductivity of the stacks is essentially the same as that of a solid sheet with the same total thickness, and thus conductivity can be made very high. Possible applications include transparent, conductive displays (such as “heads-up” displays for pilots or drivers), ultraviolet and electromagnetic interference shielding, and antennas embedded in windows (*Opt. Photonics News*, Sept 1999, 25).

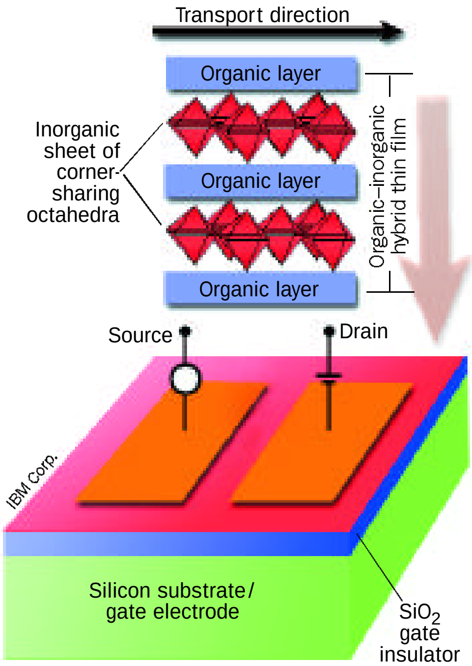
Self-assembly

The pursuit of chemically assembled electronic circuits continues at a hot pace. Only a few months after a University of California, Los Angeles–Hewlett Packard team used organic molecules sandwiched between metal electrodes to make programmable switches (see *The Industrial Physicist*, 12/99, p. 17), researchers at IBM in Yorktown Heights, New York, announced that they had sandwiched inorganic layers between organic layers to produce transistors by a chemical process. The IBM process could radically cut the cost of thin-film transistors, which would allow the manufacture of flexible computer displays and perhaps prepare the way for electronic newspapers and smart cards.

Conventional amorphous-silicon-based transistors are produced by photolithographic processes, which require high temperatures and high vacuums to lay down semiconducting material one layer at a time, guided by lithographic masks. This process precludes laying the circuits down on flexible, soft materials such as plastics, which cannot withstand high temperatures. In addition, photolithography involves sophisticated and expensive equipment, which substantially adds to the cost of large silicon-based displays.

On the other hand, efforts to make organic semiconductors, which can be manufactured at low temperatures, face the problem that organics tend to be poor conductors. In addition, orienting organic molecules into the precise crystalline patterns needed for transistor operation has posed a difficulty until now.

The IBM team, led by Cherie Kagan, approached these two challenges by using a hybrid material that was part inorganic semiconductor and part organic (*Science*, Oct 29, 1999, 945). The semiconducting material is a perovskite, a type of octahedral crystal with a metal atom at the center



IBM Corp.

Self-assembling perovskite semiconductor could be used to produce thin-film transistors, reducing dependence on expensive high-vacuum deposition.

of the octahedron and halogens at the vertices. In the specific type of crystal used here, the metal is tin and the halogen is iodine. Perovskites, which have conductivity and other properties similar to those of amorphous silicon, are being studied as a possible alternative material for transistors. The trick is to get the perovskite to self-assemble into a regular crystalline layer when it precipitates out of solution.

The IBM team achieved this alignment with the help of an organic salt that it mixed with tin iodide in heated acid. The resulting crystals were dissolved again in methanol and spun onto wafers. The organic and inorganic components interact to naturally form alternating layers, with the perovskite neatly arranged into a regular polycrystalline thin film. "The chemical forces between the organic and inorganic components drive the organization of the material toward oriented, alternating layers," Kagan explains.

To form transistors, the films are deposited on arrays of electrodes over a silicon dioxide base. The electrodes have to be generated by conventional lithography, but because the semiconductor layer goes on afterwards,it is not affected by the high lithographic temperatures.

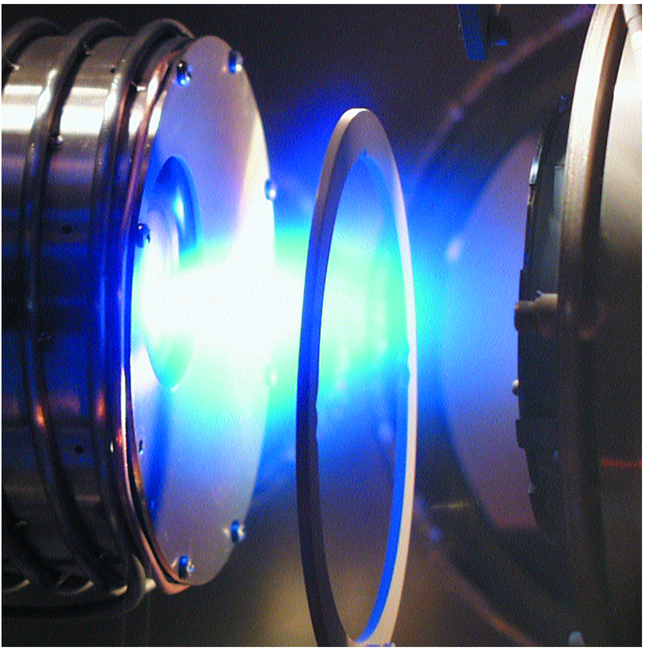
The new method of making thin-film transistors could, in the short run, cut costs for displays such as active-matrix liquid-crystal displays, which provide high-quality images for laptop computers. More advanced applications might take advantage of the flexibility of plastic substrates for uses such as electronic newspapers that, like the paper versions, can be folded. In addition, the work is another step toward building entire circuits with molecular self-assembly, eventually eliminating the need for lithography altogether. Such an advance could pave the way to much smaller and faster molecular-sized circuits.

Laser separation

When hospitals request radioactive isotopes from the U.S. Department of Energy, in many cases the department isolates them by using the venerable Calutron machines left over from the Manhattan Project. These large devices, essentially scaled-up mass spectrometers, put a stream of ions through a powerful external magnetic field, which separates them by magnetic deflection according to their masses—with the paths of more massive isotopes bent slightly less than those of lighter ones.

But P. P. Pronko and colleagues at the NSF Center for Ultrafast Optical Science at the University of Michigan at Ann Arbor have serendipitously discovered a potentially lower-cost and easier route to isotope separation (*Phys.Rev. Lett*. 1999, *83*, 2596). They have produced megagauss magnetic fields with femtosecond laser pulses and used the fields to separate out isotopes in a plasma plume. Because the laser-produced plasmas naturally generate the huge fields required, "it's a simple, direct method with no external magnets needed," explains Pronko. So far, the abundance of less common isotopes has been about doubled for a variety of elements, but multistaged enhancement to much greater purity seems possible.

The University of Michigan team members were not looking for isotope separation when they discovered the effect. They were seeking to use laser ablation as a means of depositing a thin film on a surface. They hit a boron target with a 150-fs laser pulse, producing a plasma plume that moved into a vacuum chamber. When they studied the plasma, they found to their surprise that near the center of the pulse the abundance of boron-10—normally



NSF Center for Ultrafast Optical Science, University of Michigan

In the megagauss magnetic field of a plasma plume generated by femtosecond laser pulses hitting a target at left, isotopes can be separated and caught in a thin film on the substrate at right.

around 20%—had nearly doubled to 40%. After carefully double-checking their instruments, they decided that they had a real phenomenon. The light isotopes concentrated near the center of the plume, and the heavier ones moved to the outside. Later experiments showed similar results with heavier elements.

Pronko believes that his group understands how the separation occurs. “When the plasma plume first leaves the surface, the motion of the charged particles forms a toroidal or smoke-ring-shaped magnetic field,” he says. “But in about a picosecond, the field develops instabilities and turns into a more axial configuration, and the plasma starts to swirl around the axis, perpendicular to the surface.” The interaction of the circular motion and the axial field produces a force pinching the ions toward the center of the plume. The lighter ions are pushed faster than the heavier ones and, thus, accumulate in the center.

While the relative mass differences are less for heavier elements such as copper and gallium than for boron, the increased charges of the ions, which are briefly heated to energies of several kiloelectron volts, compensate for this smaller relative difference and allow for a similar concentration of lighter isotopes. This could make the process useful for separating medically and scientifically needed radioactive isotopes, which tend to have a high atomic mass.

The University of Michigan team thinks that it can scale up its apparatus to the level needed to produce significant (milligram) quantities of radioisotopes. “We have to understand better how to maximize the number of ions in the plume, but we are learning how to adjust that with laser pulse intensity and duration,” Pronko says. He is not, however, concerned that this less costly and faster method of isotope separation could make the production of nuclear weapons materials such as uranium-235 easier. “You need tens of kilograms, not milligrams, for those purposes, and that still would mean a gigantic investment, not something you could do in your garage,” he says.