Mode-Locking Method Shows Stable Output, Potential for Tiny Lasers

(Left to right) Marco Peccianti, Jose Azana, Alessia Pasquazi, Roberto Morandotti and David Moss developed a compact laser with a new passive mode-locking method that provides stable output and narrow linewidths at high repetition rates.

Courtesy of M. Peccianti

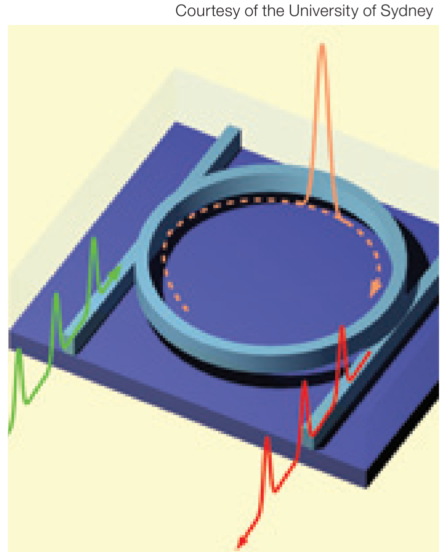
An international team of researchers used a microcavity ring resonator as both a laser filter and mode-locker. The laser emits pulses of light with unusually stable operation at repetition rates as high as 200 GHz while maintaining very narrow linewidths below 130 kHz (Nat. Commun., DOI: 10.1038/ncomms1762).

Passive mode-locking produces much shorter pulses than can be achieved with active (i.e., electronic) control. Many applications that use mode-locked lasers could benefit from the faster, more stable pulses allowed by this new technique.

The team included scientists from Institut National de la Recherche Scientifique (INRS, Canada), Istituto per i Processi Chimico-Fisici (part of the Consiglio Nazionale delle Ricerche, Italy), Infinera Corporation (U.S.A.) and the University of Sydney (Australia).

The new mode-locking method, filter-driven four-wave-mixing (FD-FWM), is in some ways similar to dissipative FWM schemes: A filter is inserted into the cavity of a fiber laser to suppress unwanted modes. "The real achievement," says researcher David Moss of INRS and University of Sydney, "is that we managed to generate an extremely stable output whereas dissipative FWM lasers very often suffer from what is known as supermode instability." The fiber must be long to get the gain and nonlinearity required for sustained lasing in dissipative FWM-based lasers, but a long laser cavity allows many closely spaced modes. This means that multiple modes are within the filter's passband, and these modes interfere with each other, creating beats of low-frequency noise that cause unstable operation.

Courtesy of the University of Sydney



A monolithically integrated 4-port microring resonator acts as both a filter within the laser cavity and as a nonlinear gain medium within the erbium-doped fiber-based laser. The waveguide is made of high index doped silica glass.

Alternatively, the group's laser design puts the nonlinearity and gain into the same microresonator that acts as the filter. While the erbium-doped fiber amplifier is still part of the laser, the required fiber length is much shorter (3 m)—which increases the spacing between modes and therefore increases the stability of the laser output. Moss adds, "The microcavity is a glass-based integrated ring resonator where the laser light modes are generated and locked extremely efficiently, because we've engineered the resonator to have ideal qualities, particularly nonlinear optical properties."

Ultimately, the researchers want to develop an entirely integrated laser that can provide ultrafast pulses. Such an optical system could offer fast processing, low cost and lower energy consumption. This laser isn't entirely integrated, but it is quite small: The microresonator is integrated on a chip made using CMOS-compatible methods, and the fiber can be wound on a spool about 1 cm in diameter.

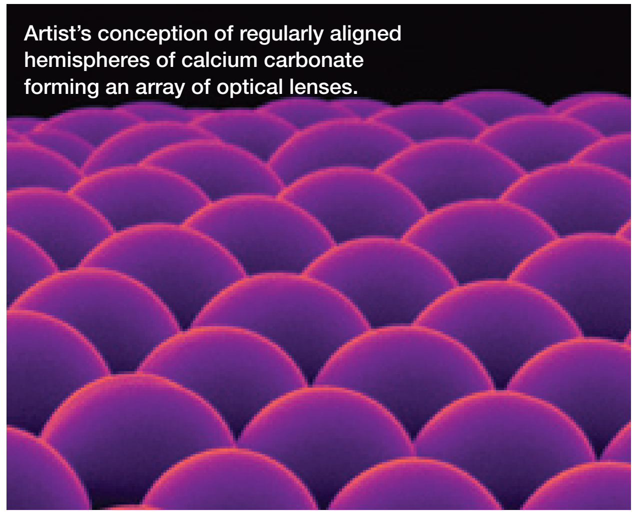
—Yvonne Carts-Powell

Self-Assembling Microlenses Inspired by Starfish

Microlenses are becoming increasingly useful in advanced optical applications, but they are complicated to make. Scientists in Germany recently made good-quality calcium carbonate microlenses by precipitating them out of solution (Nat. Comm. **3**, 725).

The team at the Max Planck Institute of Colloids and Interfaces in Potsdam got inspiration for the experiment from *Ophiocoma wendtii*, a reef-dwelling brittlestar whose body is covered with tiny calcium carbonate lenses that act as the lenses for compound eyes. Brittlestars and other sea creatures build biological structures from calcium carbonate and other minerals in ocean water.

Peter Fratzl, Kyubock Lee and their colleagues mixed up an aqueous solution of calcium hydroxide in water with a surfactant, polysorbate 20, and exposed it to the carbon dioxide found in air. Calcium carbonate quickly agglomerated on the surface of the solution—the tiny hemispheres grew up to 2.7 µm in diameter within the first two minutes. After an hour, they formed a surface film of hexagonally packed microlenses about 6 µm across.


Artist's conception of regularly aligned hemispheres of calcium carbonate forming an array of optical lenses.

Kyubock Lee, Max Planck Institute of Colloids and Interfaces

Next, the team investigated the optical properties of these microlenses. A scanning electron micrograph of a single shape viewed through the lenses revealed an array of tiny images of the shape. The researchers used confocal microscopy to measure the focal length of the tiny lenses as 7.2 ± 0.3 µm. Interestingly, the tiny lenses do not exhibit the birefringence usually found in calcium carbonate.

Raman spectroscopic imaging of the amorphous calcium carbonate lenses showed that they had grown in two steps, with the first 4 or 5 µm of width self-assembling in the first 10 to 20 minutes, and the rest coming in the remaining 40 or 50 minutes. The researchers think that the presence of the surfactant helped the lenses grow into a uniform size and shape.

By using chitosan, a polysaccharide derived from shellfish, the team could affix the microlens films to curved surfaces. Such arrays of inexpensive microlenses could be useful in cell research and other applications.

— *Patricia Daukantas*

Laser Fabricates Silver Dots in a Polymer Matrix

Harvard graduate student Kevin Vora examines a sample in the lab. Vora and colleagues in professor Eric Mazur's group developed a fabrication process that enables the creation of nanostructures patterned in 3-D.

Eliza Grinnell, Harvard University School of Engineering and Applied Sciences

Scientists have made great strides in femtosecond (fs) direct laser writing to make nanoscale patterns of dielectric media, such as glasses and polymers. Now a team at Harvard University (U.S.A.) has extended the fabrication technique to create arrays of silver nanodots in a firm polymer matrix (Appl. Phys. Lett. **100**, 063120).

Previous studies that used fs lasers to pattern metals at the submicron scale had several shortcomings, says Kevin Vora, a Ph.D. candidate in applied physics and the lead author of the paper. Reduction reactions in ethanol-and-polymer suspension systems led to uncontrolled growth of silver particles outside of the laser-irradiated region, and a water-based system gave no solid support for a pattern of silver dots.

Fortunately, one day the group ran out of ethanol and experimented with a mix of silver nitrate, water and a polymer called polyvinylpyrrolidone. "It was a bit of a stroke of luck when we figured out the chemistry and then it was a matter of finding the right laser parameters to do the fabrication," Vora says.

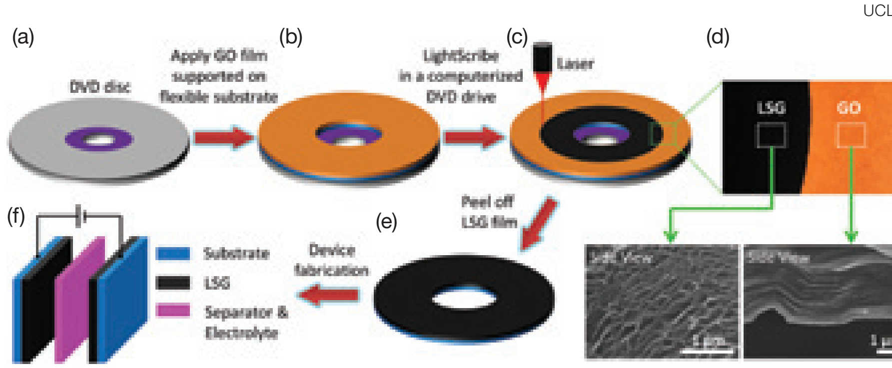
To stimulate growth of the silver dots, Vora used a 795-nm Ti:sapphire laser with 50-fs pulses and focused it with a microscope objective to increase the beam's fluence and intensity. In spots where the polymer mix is irradiated, the photons reduce the Ag^{+} ions to metallic silver. The team was able to build silver dots about 300 nm in diameter.

The chemistry in the technique is simple and readily available, and fs lasers are becoming more popular, according to Vora. The next step is to improve the resolution and quality of the silver nanodot arrays to make them more useful as potential metamaterials. For example, coupled metal nanorods might be used for invisibility cloaks, and nanorods and dots could be arranged into optical antenna arrays.

—Patricia Daukantas

Better Super-Capacitors from Laser-Scribed Graphene

UCLA



(a, b) A graphite oxide film on a flexible substrate is attached to a DVD and inserted into a LightScribe drive. (c, d) The IR laser in the LightScribe drive removes oxygen from the film, converting it to a thin layer of graphene with a large surface area. The color changes from brown to black. (e, f) The graphene film is used as an electrode in a flexible supercapacitor with power and energy densities comparable to batteries.

Researchers from the University of California, Los Angeles (U.S.A.) used a common computer optical drive to convert thin layers of graphite oxide into graphene, which was then incorporated into flexible electrochemical capacitors (ECs, also called supercapacitors or ultracapacitors). The ECs with these laser-scribed graphene electrodes offer better—possibly breakthrough—performance that could make them competitive with batteries. Researchers Maher F. El-Kady, Veronica Strong, Sergey Dubin and Richard B. Kaner used a standard LightScribe DVD optical drive to make electrodes for ECs that demonstrated high energy densities, high conductivity and good physical and electrical stability (Science **335**, 1326).

Plenty of desktop computers have LightScribe DVD drives, which incorporate a laser for printing labels directly onto optical disks. The drives are commercially available for roughly $20 USD. The labeling laser (as opposed to the data-writing laser) provides an IR 788-nm beam with 5 mW power. In its conventional use, the LightScribe laser traces a computer-generated image onto the label side of the disk, which is equipped with a dye that changes color when the laser hits it. The researchers used this laser to reduce graphite oxide (an electrical insulator) to graphene (an electrical conductor).

After coating a flexible substrate with a thin film of graphite oxide and affixing it to an optical disk, the laser beam drives oxygen out of the film and rearranges the bonds. Patterning the entire area took about 20 minutes. Each pass by the laser over the surface changes the conductivity. After six passes, the material had changed from graphite oxide to graphene with an excellent conductivity of 1738 S/m—an order of magnitude better than the conductivity of the activated carbon materials in commercially available ECs. Also, the low oxygen content (3.5 percent) contributes to the high-cycling stability of the ECs.

ECs store more charge than conventional capacitors and charge faster than batteries. In the past, however, they have not been able to match the energy density of batteries. Graphene's high conductivity, which improves with increased surface area, makes it an attractive material for EC electrodes. The laser-scribing method creates a layer less than 8 μm thick with an exceptionally high surface area.

The ECs made with laser-scribed graphene electrodes exhibited high energy density and high power density values. The researchers also showed that the ECs could be cycled even when subjected to bending.

"Our study demonstrates that our new graphene-based supercapacitors store as much charge as conventional batteries," said Kaner, "but can be charged and discharged a hundred to a thousand times faster."

—Yvonne Carts-Powell

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