teau potentials of about 2.4 V for charge and about 2.3 V for discharge were observed in the galvanostatic charge-discharge curves, with a discharge capacity of about 120 mAh per g of LTO. After 60 cycles the battery retained 90% of its capacity with about 98% Coulombic efficiency, which suggested that all integrated components were working efficiently.

The researchers also demonstrated the versatility of their battery design by connecting nine of them in parallel for a total energy of about 0.65 Wh. The research team glued an inexpensive polycrystalline silicon solar-cell array to the top of one cell and connected it with a current-limiter circuit. When fully charged—with white light illumination for the single cell and with a galvanostat for the other eight—the device powered 40 red light-emitting diodes for more than 6 h (at 40 mA) and could be easily reconfigured to supply different voltages and current capacities.

Steven Trohalaki

"Needle beam" propagates without diffraction

An international team of researchers have demonstrated a new type of light beam that propagates without spreading outwards, remaining very narrow and controlled over an unprecedented distance. This "needle beam," as the team calls it, may greatly reduce signal loss for on-chip optical systems such as used in nanophotonics, and may eventually assist the development of a more powerful class of microprocessors.

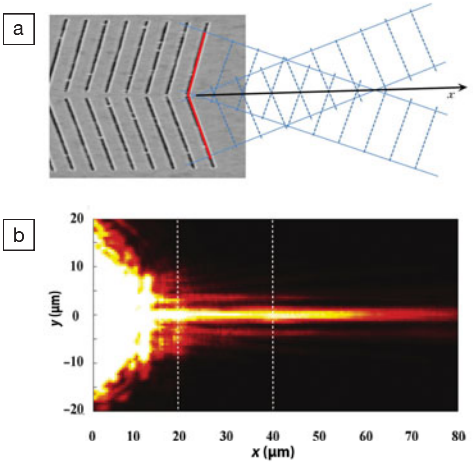
Federico Capasso of the Harvard School of Engineering and Applied Sciences (SEAS); Patrice Genevet, a research associate in Capasso's group; Jean Dellinger of the Laboratoire Interdisciplinaire Carnot de Bourgogne, CNRS, in France; and their colleagues have characterized and created this needle beam, which travels efficiently at the interface of gold and air. Their findings were published in the August 31 online edition of *Physical Review Letters* (10.1103/PhysRevLett.109.093904).

The needle beam arises from surface plasmons, a special class of quasiparticles, which travel in tight confinement with a metal surface. The metallic stripes that carry these surface plasmons have the potential to replace standard copper electrical interconnects in microprocessors, enabling ultrafast on-chip communications.

One of the fundamental problems that has so far hindered the development of such optical interconnects is the fact that all waves naturally spread laterally during propagation, known as diffraction. This reduces the portion of the signal that can actually be detected.

"We have made a major step toward solving this problem by discovering and experimentally confirming the existence of a previously overlooked solution of Maxwell's equations that govern all light phenomena," said Capasso, the Robert L. Wallace Professor of Applied Physics and Vinton Hayes Senior Research Fellow in Electrical Engineering at SEAS. "The solution is a highly localized surface plasmon wave that propagates for a long distance, approximately 80 microns in our experiments, in a straight line without any diffraction."

The so-called needle beam, the technical term for which is a cosine-Gauss plasmon beam, propagates in tight confinement with a nanostructured metal surface. The researchers sculpted two sets of grooves into a gold film that was plated onto the surface of a glass sheet. These tiny grooves intersect at an angle to form a metallic grating. When illuminated by a laser, the device launches two tilted, plane surface waves that interfere constructively to create the nondiffracting beam.



A cosine-Gauss plasmon beam, dubbed a "needle beam," propagates without diffraction; (a) a micrograph and diagram of the metallic gratings that produce the needle beam and (b) experimental results. *Courtesy of Patrice Genevet.*

Slot-die coating may enable continuous printing of light-emitting electrochemical cells

Since the arrival of organic light-emitting diodes (OLEDs), the possibility of being able to economically print off rolls of electronic newspaper has become an exciting prospect. However, the continuous production of OLEDs under ambient conditions has been frustrated by the requirement for low-work-function cathode materials and a thin active layer. A promising alternative that suffers from neither of these constraints is the light-emitting electrochemical cell (LEC), and an article in the August 14 edition of *Nature Communications* (DOI: 10.1038/ncomms2002) describes how continuous ambient fabrication of these devices has recently been realized.

A. Sandstrom at Umeå University, Sweden, H.F. Dam at the Technical University of Denmark, and their co-workers used a slot-die roll coater, in which

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ink is injected onto a continuous roll of material, to print a simple layered device structure onto a flexible, transparent cathode material—poly(terephthalate) coated with ZnO-on-indium-tin-oxide. An active layer of a conjugated polymer (superyellow) and electrolyte (KCF_3SO_3) was first spread to a (dried) thickness of 1 μm, before coating with a similar thickness of poly(ethylenedioxythiophene): poly(styrenesulfonate) to serve as an anode. Despite the relatively thick and rough nature of the resulting layered LEC, they could achieve a brightness of 150 cd m^{-2} at 10 V.

When a voltage is applied to the device, the mobile electrolyte ions in a LEC form electric double layers at the anode and cathode that promote hole and electron injection into the active layer, respectively. This leads to both *p*- and *n*- doping of the polymer film until the two regions meet, allowing charges to recombine and emit light, even in thick films such as these. The time dependence of this doping process makes turn-on time an important property, measured at 2 s at a current density of 770 A m^{-2} for these devices.

LECs share with OLEDs a need to be kept free from oxygen and water vapor during operation, so resistance to ambient conditions was effectively conferred to the developed device by drying at high temperature and encapsulating it inside adhesive barrier layers. Given that these steps could also be carried out in a continuous process, the researchers see their research as a first step toward cheap roll-to-roll printing of large areas of light-emitting "paper" and said that optimization of the active material may lead to rapid improvements in its performance.

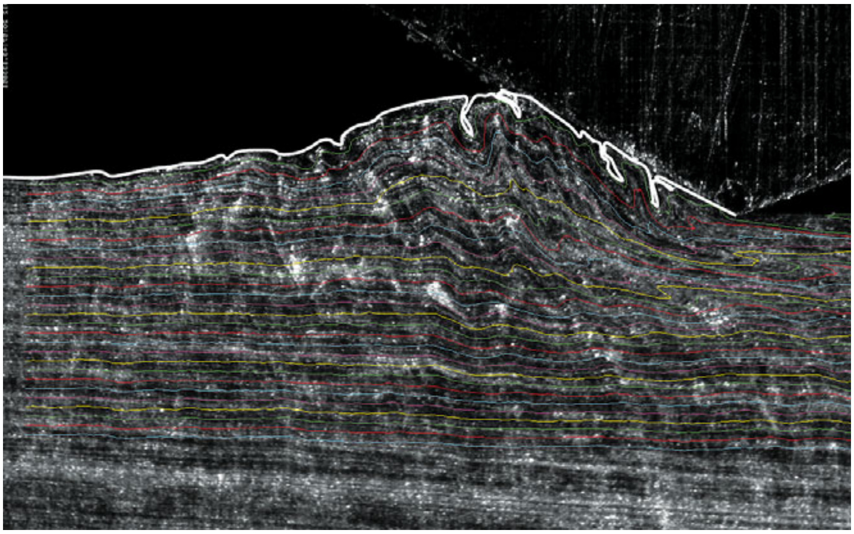
Tobias Lockwood

Sliding metals show fluidlike behavior at the mesoscale

Researchers have discovered a swirling, fluidlike behavior in a solid piece of metal sliding over another, providing insights into the mechanisms of wear and generation of machined surfaces that could help improve the durability of metal parts. Numerous mechanical parts, from bearings to engine pistons, undergo such sliding.

"We see phenomena normally associated with fluids, not solids," said Srinivasan Chandrasekar, a Purdue University professor of industrial engineering who is working with postdoctoral research associates Narayan Sundaram and Yang Guo.

As reported in the September 7 issue of *Physical Review Letters* (10.1103/PhysRevLett.109.106001), the researchers observed what happens when a wedge-shaped piece of steel slides over a flat piece of copper. It was the first time researchers had directly imaged how sliding metals behave at the mesoscale.



This frame from a high-speed camera sequence reveals fluidlike behavior in a solid piece of metal sliding over another (300 μm). The white line is the manually identified surface and superimposed colored lines are streak lines produced from velocity measurements. *Purdue University School of Industrial Engineering image/N. Sundaram and Y. Guo.*

The observations—using a microscope and high-speed camera—show how tiny bumps form in front of the steel piece, followed by the swirling vortex-like movement and then the creation of shallow cracks. The folding and cracking were most pronounced when the steel piece was held at a sharp angle to the copper surface.

The researchers hypothesize that the folding and cracking are due in part to a phenomenon similar to "necking," which happens as a piece of metal is stretched.

The findings were surprising because the experiment was conducted at room temperature and the sliding conditions did not generate enough heat to soften the metal.

"It has been known that little pieces of metal peel off from sliding surfaces," Chandrasekar said. "The conventional view is that this requires many cycles of rubbing, but what we are saying is that when you have surface folding you don't need too many cycles for these cracks to form. This can happen very quickly, accelerating wear."

Metal surfaces that have smaller grains may be less susceptible to the folding and crack formation.

"We need to explore what role grain size plays," Chandrasekar said. "We think there should be some grain size below which this folding mechanism might be less active. We need to explore why—under what conditions—solid metals behave like fluids." □

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