AgCl resulted in a gray coating on the electrode, comprising nanoparticles of about 100 nm in diameter. This electrode, with a film thickness of catalytic material, termed H_2-CoCat, of about 2 μm, was then transferred to a Co-free electrolyte where its electrocatalytic properties for H_2 evolution were measured. The minimal overpotential required for H_2 evolution was 50 mV, which is significantly lower than the 500–700 mV overpotentials required by other recently reported molecular Co catalysts. A H_2-evolution turnover frequency of 80 h^{-1} per Co center at 385 mV overpotential was also demonstrated.

Characterization of the H_2-CoCat material using methods including x-ray diffraction, x-ray photoelectron spectroscopy, energy-dispersive x-ray spectroscopy and x-ray absorption spectroscopy, suggested that H_2-CoCat is amorphous, and that it is composed of nanoparticles with a cobalt oxo/hydroxo phosphate component that is principally located at the particle surface, with metallic cobalt in the bulk.

Remarkably, anodic equilibration of the H_2-CoCat resulted in its conversion to the OER catalyst O_2–CoCat, which catalyzes O_2 evolution. The switch between these two forms was fully reversible, and corresponded to a progressive and local transformation between two morphologies on the surface of the electrode. The coating therefore demonstrates a Janus-like activity, behaving as a switchable catalyst.

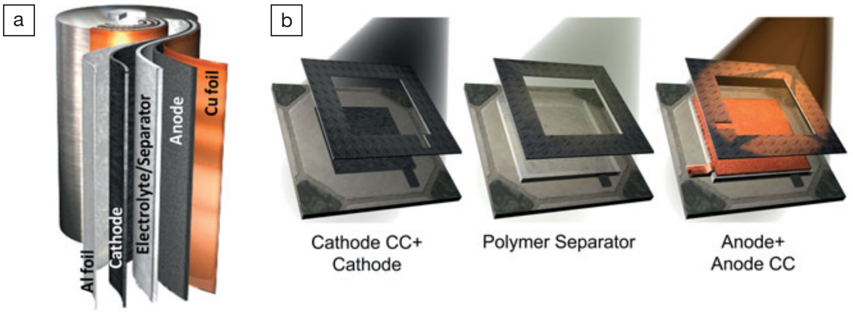
The researchers said that their approach could be applied to the fabrication of "an artificial-leaf device" for light-driven water splitting "even in the absence of a proton-conducting membrane separating (photo)anode and (photo)cathode," as well as to "photoelectrodeposition [of catalysts] on heterogeneous semiconductor nanoparticles."

Steven Trohalaki

Energy Focus

Li-ion batteries fabricated by spray painting

Li-ion batteries have high energy and power density, although their design, wherein sandwiched battery components are "jelly-rolled" into metal canisters (see Figure), puts constraints on the ultimate form factors of the devices they power. Flexible batteries, stretchable textile energy storage, and paper batteries are some of the unconventional battery designs that were devised for devices without form-factor constraints, although their seamless integration remains a challenge. Self-powered electronics with integrated energy storage also require batteries that can be directly incorporated into the device design.



(a) A jellyroll assembly of the layered components of a conventional Li-ion battery; and (b) direct fabrication of a multilayer battery achieved by sequential spraying of component paints, using stencil masks tailored for a desired geometry and surface.

Moving toward these goals, P.M. Ajayan and a team of researchers from Rice University have fabricated multilayer Li-ion batteries by sequentially coating their components onto commonly encountered materials by spray painting, as reported in the June 28 issue of *Scientific Reports* (DOI: 10.1038/srep00481). Component materials were formulated into liquid dispersions (paints), and the researchers chose lithium cobalt oxide (LCO, $LiCoO_2$) as the cathode and lithium titanium oxide (LTO, $Li_4Ti_5O_{12}$) as the anode, for which the effective cell voltage is about 2.5 V. While a commercially available conductive Cu paint was used for the negative current collector (analogous to Cu foil in Li-ion batteries), Al paint could not be employed for the positive current collector because Al micro-powders form explosive aerosols. In its place, the researchers made a viscous, highly consistent ink containing high concentrations (0.5–1% w/v) of single-walled carbon nanotubes (SWNTs) that was suitable for spray painting. Using commercial polymers, the researchers were also able to make a spray-paintable separator with a morphology that allowed optimal electrolyte uptake and formation of a microporous gel electrolyte with sufficient adhesion to adjacent layers to ensure mechanical stability.

After preheating nonconducting substrates (glass, ceramics, and polymer sheets) to 120°C, the researchers spray-painted the component paints layer by layer, starting with the SWNT (cathode charge collector) paint, then the LCO (cathode) paint. After drying and preheating to 105°C, the polymer separator was sprayed on in several light coats up to a final thickness (~200 μm) that prevented internal shorting from solvent penetration from the LTO (anode) layer, which was deposited after preheating to 95°C. The Cu (anode current collector) paint was then deposited. After drying the cell in vacuum, it was transferred to an Argon-filled glove box, soaked in electrolyte, and then packaged with laminated poly(ethylene)-aluminum-poly(ethylene terephthalate) sheets.

For a typical cell, the SWNT layer is ~25 μm, the LCO layer ~120 μm, the polymer separator ~180 μm, the LTO layer ~90 μm, and Cu layer ~5 μm. Pla-

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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.

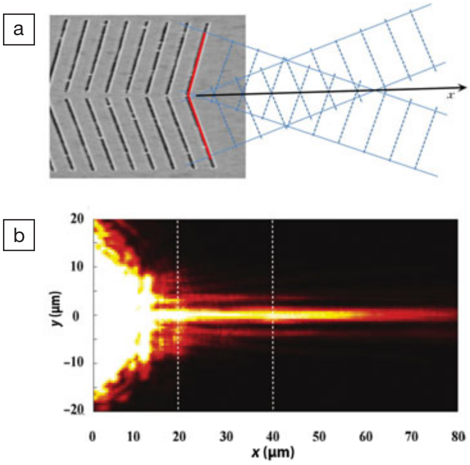
Federico Capasso of the Harvard School of Engineering and Applied Sciences (SEAS); Patrice Genevet, a research associate in Capasso's group; Jean Dellinger of the Laboratoire Interdisciplinaire Carnot de Bourgogne, CNRS, in France; and their colleagues have characterized and created this needle beam, 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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