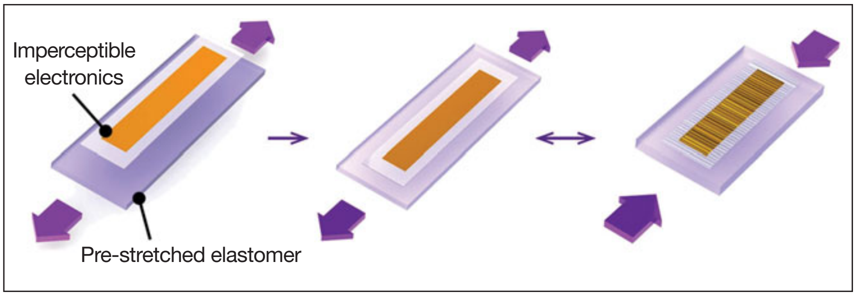
Energy Focus

Design of imperceptible plastic electronics make flexible electronic devices promising

The inside of a computer or a mobile phone contains a stiff circuit board that is green in color, is crammed with chips, resistors, capacitors, and sockets, and is interconnected by a suburban sprawl of printed wiring. What if the circuit board was not rigid, but flexible enough to fold?

Now, Michael Drack of Johannes Kepler University in Austria, T. Sekitani of the University of Tokyo and their colleagues have designed a highly reliable, flexible, and stretchable sub-2-μm sensor using organic conductors with similar electrical resistance as metals. Metals are excellent conductors, but are mechanically mismatched to polymer substrates. Polymer conductors, on the other hand, have elastic moduli comparable to those of thin-film poly(ethylene terephthalate) (PET) substrates, making them interesting for stretchable and elastic conductors.

As reported in the January 7 issue of *Advanced Materials* (DOI: 10.1002/adma.201403093; p. 34), the researchers used a 1.4-μm-thick PET foil temporarily attached to a reusable support substrate foil—125-μm-thick PET covered with a thin poly(dimethylsiloxane) adhesion layer (see Figure)—to allow all-planar device fabrication and avoid subsequent defect-free peeling or transfer of the completed device to a pre-stretched elastomer. The researchers prepared samples of thin-film conductor strips of an organic conductor made of poly(3,4-ethylenedioxythiophene):poly(styrene sulfonate) (PEDOT:PSS) and various metals (silver, gold, and copper) on the ultrathin PET foil with 3 nm adhesion layers of various metals and ultrathin PET. The samples were stretched up to 50% with a strain rate of 0.94%/s while continuously recording the resistance. All the metal conductors where cycled up to 1000 times (Ag, Au, and Cu) or until failure (Al, ca. 400 times); the conducting polymer PEDOT:PSS was fatigued up to 10,000 cycles. Au, Cu, and PEDOT:PSS were found to be highly reliable, withstanding 1000 stretch cycles for the metals, and 10,000 for the polymer conductor without failure. In addition, the resistance slightly increased by 30% over the course of 10,000 cycles. However, the researchers found no indication of fracture of the PEDOT:PSS. The resistance increase may be attributed to the operation in ambient air and the potential water uptake during fatigue.



The electronic foil is transferred onto a pre-stretched elastomer (left, middle) forming out-of-plane wrinkles upon release (right). Reprinted with permission from Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim. © 2014.

"The main advantage of our approach is the planar fabrication of our stretchable interconnects and the easy transfer on mechanically stretchable substrates," says Drack. This work "is just a first step toward a novel technology platform with the thinnest and most flexible circuit boards," he says.

Such highly reliable transparent electrodes form the basis of new avenues for the design of complex, hybrid rigid-island stretchable-interconnect electronic devices such as light-emitting diode strips that can be stretched and twisted without impairing their function. Such materials are in demand in applications in textiles, wearable as glasses, and inner organs like hearts where flexibility, compliance, weight, and softness are important to next-generation electronic devices.

Jean L. Njoroge

Energy Focus

Large grain size may improve efficiency of perovskite solar cells

A research team from Los Alamos National Laboratory (LANL) has created large grain perovskite photovoltaics that have power-conversion efficiencies of up to 18%. The films are defect-free, have high crystallinity and, significantly, show hysteresis-free device operation.

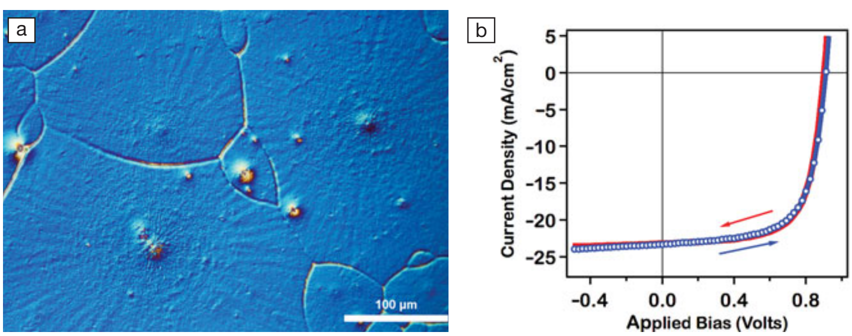
Perovskite photovoltaics are organic–inorganic hybrids such as $CH_3NH_3PbX_3$—where X is a halide—that are in the perovskite crystal phase. They are more attractive than the conventional silicon-based solar cells due to their cost-effective fabrication and high power-conversion efficiency. However, they have issues of stability and reproducibility and exhibit persistent hysteresis during device operation. Therefore, the article published in the January 30 issue of *Science* (DOI: 10.1126/science.aaa0472; p. 522), by lead authors Aditya Mohite and Hsing-Lin Wang and colleagues at LANL, represents a significant development in moving toward cheap, commercially viable perovskite photovoltaics.

To create a uniform perovskite film, an equimolar solution of PbI_2 and methylamine hydrochloride were dissolved in a high-boiling-point solvent such as *N,N*-dimethylformamide (DMF), heated

https://doi.org/10.1557/mrs.2015.102 Published online by Cambridge University Press

to 70°C and cast onto a substrate maintained at 180°C. This was then spin-coated for 15 s. Using this "hot casting" process, the team was able to attain grain sizes as large as 1–2 mm with the required composition and morphology. (The average conventional grain size is 1–2 μm.) A high-boiling-point solvent such as DMF allows excess solvent to be present during substrate heating, allowing for the growth of larger grain sizes. This method may be industrially scalable for the production of large-area crystalline thin films. The solution composition, choice of solvent, and substrate temperature were optimized for best performance.

The highest power-conversion efficiency was observed for grain sizes of 180 μm. Large grain sizes reduce the interfacial area between grains, reducing charge trapping and hysteresis during device performance. They further have low defect concentrations allowing for unimpeded movement of charge carriers for longer durations. "The optical and transport properties of these perovskites are comparable to that of the state-of-the-art high-quality direct bandgap semiconducting materials like GaAs," says Mohite. The researchers further tested these arguments with optoelectronic simulations that confirmed the high crystalline quality of the large grain perovskites. The device modeling used drift and diffusion equations to fit the experimentally observed current–voltage curves under solar cell operation to extract charge carrier mobility.



(a) Optical image of large grain-size organometallic perovskite film; (b) current–voltage sweep of a typical large grain perovskite solar cell showing no hysteresis. Credit: Wanyi Nie, Hshinhan Tsai, and Aditya Mohite.

The short-circuit current density, the open-circuit voltage, and the fill factor measured for the device are close to the upper limit predicted by Shockley-Queisser, demonstrating reduced recombination of photogenerated charge carriers. Henry Snaith of the University of Oxford, who was not associated with this work, said that "this is a very interesting article which demonstrates that perovskite solar cells could evolve toward a multi-crystalline morphology typically seen in silicon solar cells. This approach could ultimately lead to very high efficiencies due to elimination of losses at grain boundaries." Due to innovative fabrication, approaches such as these perovskite solar cells may one day lead to high-efficiency, low-cost solar modules.

Vineet Venugopal

https://doi.org/10.1557/mrs.2015.102 Published online by Cambridge University Press