metal foils, and enable roll-to-roll manufacturing techniques. However, previous attempts at this approach have foundered on the inability to dope CdTe with Cu, as is required to achieve high hole density. The efficiencies of inverted devices have therefore remained stuck at around 8%.

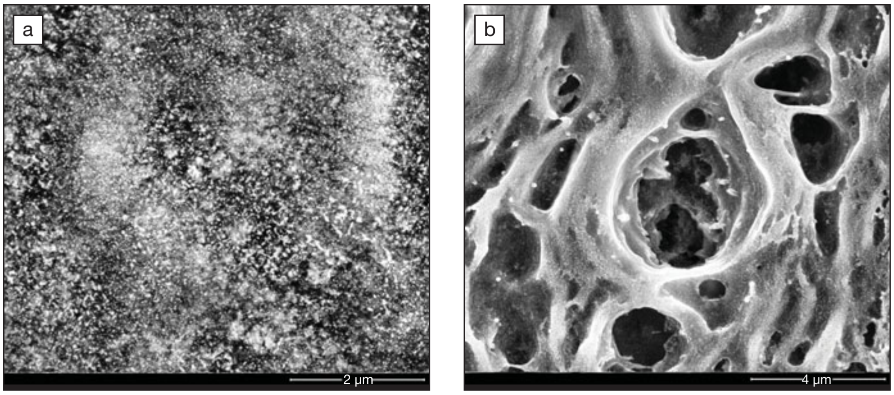
To overcome this problem, the researchers investigated a high-vacuum evaporation and annealing technique. Starting with three different types of substrates (glass, 50-µm-thick Mo foil, and 30-µm-thick steel foil with a 60/230-nm-thick Ti/TiN impurity diffusion barrier), they first deposited a 600-nm-thick Mo electrical back contact by dc sputtering and layers of MoO_3 (150 nm) and Te (50 nm) by vacuum evaporation. Next, they used high-vacuum evaporation to deposit 4–6 µm of CdTe, followed by a standard recrystallization step. They then deposited a carefully controlled layer of Cu through high-vacuum evaporation followed by annealing at 400°C to promote diffusion into the CdTe. The cells were completed with a CdS layer and an i-ZnO/ZnO:Al bilayer front contact. Using secondary ion mass spectroscopy, the researchers found that the CdTe layer was successfully doped with Cu. For the optimal Cu concentration (equivalent to a submonolayer of approximately 1 Å thickness), the glass-substrate cells displayed efficiencies of up to 13.6%, while the Mo-foil-substrate and steel-foil-substrate cells achieved 11.5% and 10.9%, respectively.

These results suggest that roll-to-roll manufacturing of CdTe solar cells with efficiencies approaching those of conventional CdTe cell configurations may be possible, offering significant manufacturing cost reductions and potentially positioning CdTe as an even more notable competitor to silicon-based solar cells.

Colin McCormick

Nano Focus

Stretchable gold conductor grows its own wires



(a) An electron microscope image of the gold nanoparticles in a relaxed sample of the layer-by-layer material. The nanoparticles are dispersed. (b) A similar sample stretched to a little over twice its original length, at the same magnification. The nanoparticles form a distinct network. Reproduced with permission from *Nature* **500** (2013), DOI: 10.1038/nature12401. © 2013 Macmillan Publishers Ltd.

Networks of spherical nanoparticles embedded in elastic materials may make the best stretchy conductors yet, engineering researchers at the University of Michigan and Korea Basic Science Institute have discovered.

Flexible electronics have a wide variety of possibilities, from bendable displays and batteries to medical implants that move with the body.

"Essentially the new nanoparticle materials behave as elastic metals," said lead researcher Nicholas Kotov, the Joseph B. and Florence V. Cejka Professor of Engineering.

Finding good conductors that still work when pulled to twice their length is a tall order—researchers have tried wires in zigzag or spring-like patterns, liquid metals, and nanowire networks. The team was surprised that spherical gold nanoparticles embedded in polyurethane could outcompete the best of these in their stretchability and concentration of electrons.

"We found that nanoparticles aligned into chain form when stretching. That can make excellent conducting pathways," said U-Mich. graduate student Yoonseob Kim, first author of the study published in the July 17 online edition of *Nature* (DOI: 10.1038/nature12401).

To find out what happened as the material was stretched, the team took state-of-the-art electron microscope images of the materials at various tensions. The nanoparticles started out dispersed, but under strain they could filter through the minuscule gaps in the polyurethane, connecting in chains as they would in a solution.

"As we stretch, they rearrange themselves to maintain the conductivity, and this is the reason why we got the amazing combination of stretchability and electrical conductivity," Kotov said.

The team made two versions of their material—by building it in alternating layers or filtering a liquid containing polyurethane and nanoparticle clumps to leave behind a mixed layer. Overall, the layer-by-layer material design is more conductive while the filtered method leads to extremely supple materials. Without stretching, the layer-by-layer material with five gold layers has a conductance of 11,000 Siemens per centimeter (S/cm), on par with mercury, while five layers of the filtered material came in at 1800 S/cm, which is more akin to good plastic conductors.

The blood-vessel-like web of nanoparticles emerged in both materials upon stretching and disappeared when the materials relaxed. Even when close to its breaking point, at a little more than twice its original length, the layer-by-layer material still conducted at 2400 S/cm. Pulled to an unprecedented 5.8 times its original length, the filtered material had an electrical conductance of 35 S/cm—enough for some devices.

Kotov and Kim chiefly see their stretchable conductors as implantable electrodes although other applications are also being developed. Rigid electrodes create scar tissue that prevents the electrode from working over time, but electrodes that move like brain tissue, for example, could avoid damaging cells, Kotov said. These electrodes could also be used in displays that can roll up or in the joints of lifelike "soft" robots.

Because the chain-forming tendency of nanoparticles is so universal many other materials could stretch, such as semiconductors. In addition to serving as flexible transistors for computing, elastic semiconductors may extend the lives of lithium-ion batteries. Kotov's team is exploring various nanoparticle fillers for stretchable electronics, including less expensive metals and semiconductors.

In Memoriam

James W. Mayer

James W. Mayer, a pioneer in the application of ion beams to materials science, passed away on June 14, 2013, in Kailua-Kona, Hawaii. Jim was one of the most innovative and out-of-the-box thinkers imaginable, and for six decades he literally defined the field of how energetic ions could be used to advance materials science. He earned his PhD degree from Purdue University in physics, and worked at Hughes Research Lab before going to the California Institute of Technology in 1967 as a professor of electrical engineering. In 1980, he joined Cornell University as the Francis Norwood Bard Professor of Materials Science and Engineering, becoming director of the Microscience and Technology Program in 1989. In 1992, Jim joined the faculty at Arizona State University (ASU) where he served as director of the Center for Solid State Science, subsequently becoming a Regents Professor (1994) and P.V. Galvin Professor of Science & Engineering (1997).

Mayer was a Fellow of the American Physical Society and the Institute of Electrical and Electronic Engineers. In 1981, he received the Von Hippel Award, the highest honor bestowed by the Materials Research Society, for having "carried out research on implantation that identified the damage and the epitaxial regrowth phenomena crucial to the semiconductor industry, and pioneered the use of ion beam techniques for materials analysis." Three years later Jim was elected to the National Academy of Engineering.

Among Jim Mayer's many accomplishments, three stand out as exceptional scientific and technological advances. In the 1950s, he played a critical role in the development of semiconductor detectors to measure the energy of energetic particles and ionizing radiation. Second, he was pivotal in the creation of the field of ion-beam analysis, often referred to as Rutherford backscattering spectrometry (RBS), as a major analytical tool for materials science. He used RBS to define many of the advances in thin-film science of the 1970s and 1980s, including thin-film reactions and kinetics, solid-phase regrowth of semiconductors, ion-beam mixing for the formation of metastable alloys, implantation disorder and impurity location in semiconductors, and the study of metal silicides and dielectric films. His third major contribution was the development of ion implantation to electrically dope silicon. Using RBS and ion channeling, Jim discovered the key annealing steps to remove implantation disorder and activate implanted dopant atoms, making ion implantation a practical tool. The importance is summed up by the story of the 1970 plenary speech at the first international conference on ion implantation by an electronics industry head who firmly predicted that implantation would never be used in the electronics industry. One year later implantation was on the production floor of every major semiconductor house, enabling low power complementary metal oxide semiconductor integrated circuits and the myriad of computer and communication applications that followed.

As equally amazing as his scientific accomplishments was Jim Mayer's mentoring and dedication to helping others. He guided more than 40 graduate students. He had a steady stream of visiting scientists from around the world in his laboratory, creating an "extended family" of lifelong friends. Jim had an encyclopedic memory for what was published in the field and would admonish those around him to "never forget your own data." It has been said that people did their very best work when they were with Jim. His enthusiasm, dedication, and quiet encouragement swept everyone in. He remained a longtime career mentor to many, quietly helping them behind the scenes.

Jim was a dedicated teacher and a Renaissance man. He was an aficionado of art, cinema, and good books. He had a rare sense of humor, and students and colleagues alike loved hanging out with him. At Caltech he became a scuba diving instructor for students. Noting the dearth of recognition available to colleagues working at the interface between energetic ions and materials science, he simply created his own Bõhmische Physical Society, which recognized achievements and hosted enormously popular beer and wine evenings at ion-beam meetings. At Cornell, Jim developed a course on the science of art, using ion beams to analyze paint pigments and inks. He published two books on the topic and was invited to lecture conservators at the Louvre museum in Paris. At ASU he created a popular "Patterns in Nature" course for

https://doi.org/10.1557/mrs.2013.240 Published online by Cambridge University Press