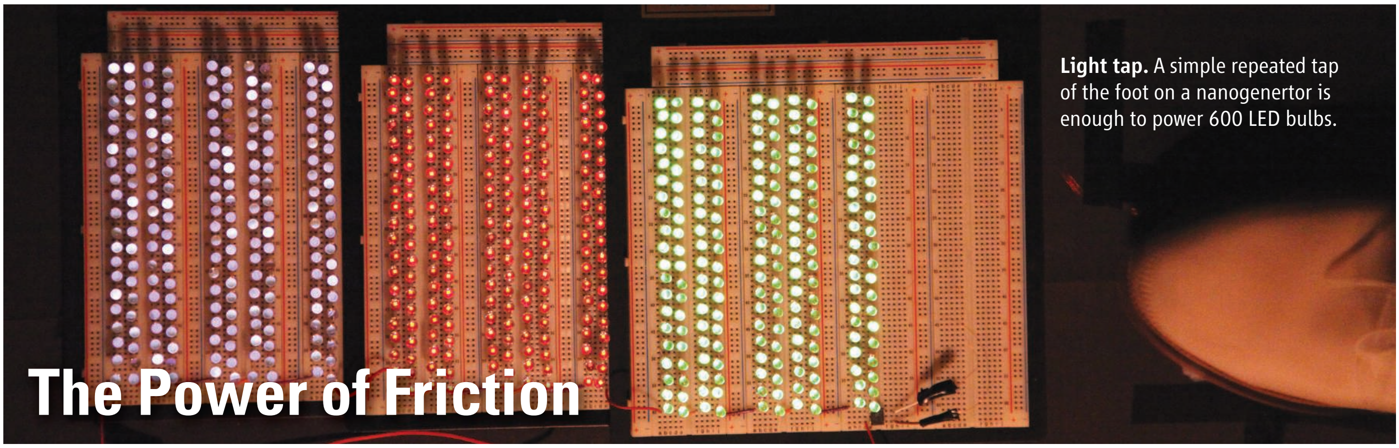

Light tap. A simple repeated tap of the foot on a nanogenertor is enough to power 600 LED bulbs.

The Power of Friction

When you're on the move and unable to plug in your portable devices to recharge them, you could use a tiny generator to harvest some of the energy of movement and turn it into electric charge. Engineers have created such devices, but so far they haven't produced enough power to drive most small portable electronics. At the meeting, however, researchers led by Zhong Lin Wang at the Georgia Institute of Technology (Georgia Tech) in Atlanta reported a new type of generator that uses everyday static electricity to juice things up considerably.

Since 2005, Wang and his colleagues have been working on tiny generators, or nanogenerators, most of which rely on the piezoelectric effect, which converts mechanical strain into an electric voltage across certain materials. Connect the material to a circuit and the voltage will drive a current. Despite improvements by Wang's team and others, such piezoelectric devices have generated mere microwatts of power. Until, that is, they wrapped one in plastic.

While investigating one piezo generator, Feng-Ru Fan, one of Wang's graduate students, put a layer of plastic known as PMMA on top of it for protection. The generator in turn was sitting on a different plastic called Kapton. When Fan measured the device's performance, he consistently found it was generating a higher voltage than expected. Fan and Wang spent months investigating what was happening, before concluding that the added power was coming from static electricity. When the PMMA and Kapton come into contact and rub against one another, friction generates electrical charges. The two plastics have a different affinity for electrons, with the Kapton eager to grab electrons and the PMMA able to give them up.

Wang and Fan realized that if these two plastics were incorpo-

A Boost for Lithium-Sulfur Batteries

They weren't ready in time for this holiday season's gadgets, but better lithium-ion batteries could be in the offing. Today's lithium-ion cells are already slightly better than those produced a few years ago. But new innovations unveiled at the meeting could see five-fold improvements in battery performance.

Like all batteries, today's lithium-ion rechargeables work by shuttling electrical charges back and forth between two electrodes—a positively charged cathode and a negatively charged anode. When the battery is fully charged, positively charged lithium ions are nestled in a matrix of negatively charged graphitic carbon at the anode. When the switch on a toy or tool is turned on, electrons are pulled out of the graphite and sent through an external circuit to perform work before being injected back into the material in the cathode, typically an alloy such as lithium cobalt oxide ($LiCoO_2$). Shifting electrons from the anode to the cathode causes the lithium ions to migrate through an ion-conducting electrolyte to the positively charged electrode. When the rechargeable is plugged into a socket, the applied voltage drives electrons back out of the cathode into the anode; the lithium ions then detach from the cathode and migrate back to the anode to team up with the electrons in the graphite again.

One problem is that $LiCoO_2$ cathodes can't hold on to very many lithium ions, which keeps the battery's overall electrical storage capacity low. Researchers have long wanted to replace the $LiCoO_2$ with sulfur, each atom of which can grab nearly 10 times the number of lithium ions. When other considerations are taken into account, this should give lithium-sulfur batteries about five times the capacity of current lithium-ion cells.

But sulfur has its problems. The first task of any electrode is to be a good conductor, allowing electrons to shuttle in and out easily. Sulfur is a mediocre conductor. Also, because so many lithium ions can bind to the sulfur, this causes the cathode material to swell and shrink repeatedly during charging and discharging. Ultimately, this causes it to crack and break apart. Unwanted side reactions involving lithium and sulfur can also create a family of byproducts called polysulfides that can poison lithium batteries.

At the meeting, Yi Cui, a materials scientist at Stanford University in Palo Alto, California, reported a possible way around sulfur's problems. Cui and his team encapsulated tiny nanoparticles of sulfur inside a shell of titanium dioxide (TiO_2), leaving extra space inside each shell. They then packed their coated nanoparticles together to form a cathode. When they ran their battery, they found that TiO_2's high conductivity made it easy to shuttle electrons in and out. During discharge, the lithium ions readily penetrated the TiO_2 shells and bound to sulfur atoms in the nanoparticles. And even though the sulfide nanoparticles repeatedly swelled and shrank inside their shells as the batteries were charged and discharged,

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rated into flexible materials in a shoe or a piece of clothing, for example, the mechanical forces of walking or tapping a foot would cause the negatively and positively charged surfaces to separate and create an electrical potential. Hook up a wire between the two surfaces and electrons will flow through the wire from the electron-rich Kapton to the electron-poor PMMA.

Initially they created a maximum potential of 5 volts. But at the meeting, Wang reported that by patterning the surface of the two materials to increase the amount of friction they could create a potential of up to 1000 volts and a current density of 128 milliwatts per cubic centimeter. A 6-centimeter-by-6-centimeter device powered by foot tapping was able to recharge a cell phone battery or power some 600 LED lights. "I was very impressed with the power output," says Seung-Wuk Lee, a bioengineer and nanogenerator expert at the University of California, Berkeley. The Georgia Tech results are also reported in the 12 December 2012 issue of *Nano Letters*.

Wang says he is already considering making square meter–sized devices with up to 200 layers of nanogenerators stacked atop one another for use in harvesting ocean power. Such a device may be able to produce as much as 40 kilowatts of power per cubic meter, which could make nanogenerators a large-scale power source.

the small size of the particles allowed these changes without cracking.

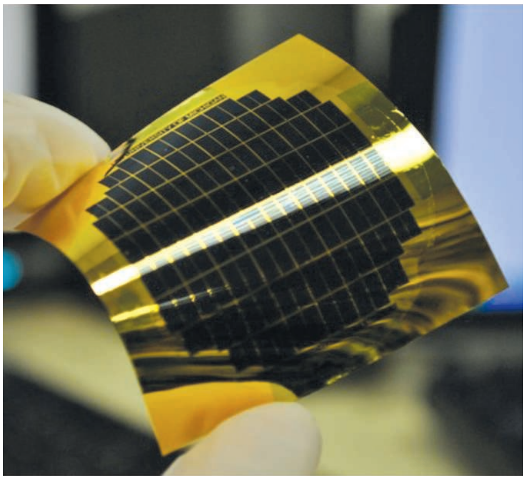
Finally, the TiO_2 also constrained the polysulfides, so these byproducts were unable to escape and poison the rest of the cell. At the meeting, Cui reported that the new batteries have a capacity of about 800 to 1000 milliamp-hours per gram, roughly six times that of the current devices on the market. And Cui said his team charged and discharged the battery more than 1000 times with negligible drop off in performance.

Pooi See Lee, a materials scientist at Nanyang Technological University in Singapore, says that Cui's work represents "big progress" for lithium-sulfur batteries. In previous work, Cui's team encapsulated silicon nanoparticles in either a carbon or polymer coating for use as a high capacity anode, which can potentially give lithium-ion batteries another 10-fold power boost. Now, Cui says, his group is working to put the two nanoparticle electrodes together to see if they can produce the battery Christmas presents have been waiting for.

Space Solar Cells With A Down-to-Earth Cost

The joke among electrical engineers is that gallium arsenide (GaAs) is the semiconductor of the future and always will be. Nowhere is that more true than with commercial solar cells that use semiconductors to convert sunlight to electricity—a market where profit margins are razor thin. GaAs has been used for decades to make ultrahigh-efficiency solar cells for spacecraft. But the out-of-this-world cost of GaAs itself makes these too expensive for mass-market uses. Now, researchers at the University of Michigan may have found a way not only to drop the cost of producing GaAs cells, but also to drop the cost of the power they produce to near that of grid power from fossil fuels.

Rao Tatavarti, a condensed matter physicist at MicroLink Devices in Niles, Illinois, says the new work is "a good approach." However, he cautions, the work remains an early proof-of-concept, and scaling up advances in GaAs solar cells has long proven challenging. "In principle it's a good idea. But it can be a costly process to do it on a large scale," Tatavarti cautions.



Recycled. A new strategy for reusing gallium arsenide wafers may allow solar cells made from this top performer to be cheap and flexible.

CREDIT: KYUSANG LEE/UNIVERSITY OF MICHIGAN

The idea for that process isn't dramatically different from what others have been trying to do for a long time. Crystals of GaAs are typically grown in 200-millimeter-diameter cylinders that are then sliced into thin wafers. Other materials are then layered on the wafers and patterned to make electronic devices or solar cells. But this tends to use too much of the expensive GaAs.

More recently, groups around the world have used GaAs as a substrate on which to grow other semiconductor alloys. These top layers are grown to perfectly match the atomic arrangement of atoms in the underlying GaAs, which gives them good electronic properties. Manufacturers then use a process known as epitaxial liftoff to remove the topping layers and recover the GaAs wafer so that it can be reused. Unfortunately, the epitaxial liftoff usually causes some minor damage to the GaAs wafer, so it can only be used a few times before engineers must replace it with a fresh wafer. As a result, costs for GaAs solar cells remain high.

Three years ago, Stephen Forrest, a materials scientist at the University of Michigan, Ann Arbor, came up with a way to solve this problem for a related semiconductor alloy called indium phosphide (InP). His team's strategy was to add two additional very chemically different layers to the sandwichlike stack of materials. The added layers allowed the materials grown above to continue to match the exact lattice spacing of InP, but because they were chemically distinct, they could be etched away selectively without damaging the underlying InP wafer at all, enabling it to be reused again and again.

Still, Forrest says that interest in the approach was muted because InP is not as good of a solar cell material as GaAs. At the meeting, Forrest presented his group's latest achievements in extending their epitaxial liftoff approach to GaAs. As before, the two extra chemically distinct sacrificial layers allowed Forrest's student Kyusang Lee and electrical engineer Jeramy Zimmerman to grow thin layers of high-quality GaAs on top of a GaAs wafer and then remove the top layer while not damaging the underlying wafer at all. Moreover, additional steps also allowed them to bond the final GaAs layer to a clear plastic substrate, giving them a flexible solar cell with more than 22% efficiency.

If cheap solar concentrators are added to focus more light onto the cell, Forrest says he believes that they should be able to convert more than 30% of the energy in sunlight into electricity. If that's the case, Forrest says his calculations show that they can reduce the cost of power from the cells to less than $1 per watt, roughly the current cost for silicon-based solar cells. If they can muster further improvements, that price could drop close to grid parity—the holy grail for solar power.

–ROBERT F. SERVICE

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