Nanogenerators Tap Waste Energy To Power Ultrasmall Electronics

Tiny devices that convert movements into electricity won’t power cities. But they may soon be efficient enough to power arrays of invisible sensors and hand-held electronics.

In the corner of a conference center on the main campus of Microsoft in Redmond, Washington, engineers have built a small four-room apartment. Called MS Home, it serves as both a testing ground and a showcase for how the future home may look and, well, behave. In Microsoft’s vision, that home will be run by a computer system that turns on lights, controls the heat, and manages the appliances. An array of invisible sensors would do everything from tracking your movements (in order to know when to turn the lights on in the next room) to monitoring whether your plants need water.

Uses of sensor networks have been talked about for years. One stumbling block has been figuring out how to power the devices. Sure, each one could be plied with batteries or wired to the grid. But that is expensive and requires periodic maintenance, which often upends such proposals. Now, however, the rise of a new technology to scavenge power from vibrations and other ambient sources may finally usher in this vision of the future into the present.

Power scavengers have actually been around for some time. Companies, for example, already make larger scale devices that harness vibrations to monitor the structural health of buildings and bridges. But over the past few years, researchers have been progressively shrinking these scavengers to nanoscale dimensions in an effort to power everything from minuscule sensors inside the body to arrays of self-powered environmental sensors to monitor things such as air quality and stream flows. This miniaturization push has been aided by the steady progress of microelectronics technology, which now turns out sensors and computing devices small enough and frugal enough with their energy needs that many can be powered with just nanowatts to microwatts of power.

Today, the field “has now reached a critical mass and momentum,” says Zhong Lin Wang, a physicist at the Georgia Institute of Technology (Georgia Tech) in Atlanta. “I am confident that with the way things are progressing, this will one day soon impact our daily lives.”

Although several technologies are competing to power such devices, most nanogenerators are made from piezoelectric materials that convert mechanical motion into electricity. Piezoelectric materials, such as crystals of the ceramic lead zirconate titanate (PZT), are made of subunits such as crystals of the ceramic lead zirconate titanate (PZT), are made of subunits, are essentially revealed, are grown between chromium (Cr) and gold (Au) electrodes (top) to make a nanogenerator that produces a high voltage when flexed. 

Good vibrations. Zinc oxide (ZnO) nanowires are grown between chromium (Cr) and gold (Au) electrodes (top) to make a nanogenerator that produces a high voltage when flexed. 

Still, flexible PZT nanoribbons have a way to go before they are ready to power real devices, McAlpine says. Among the steps still needed is to refine the PZT nanoribbons to the plastic (see bottom figure, p. 305). Several characterization studies showed that the transferred PZT nanoribbons retained their same piezoelectric properties, and they were roughly four times as efficient at transferring mechanical strain to electricity as were competing nanogenerators. 

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make the voltage output of individual nanowire devices add up. To do so they needed to orient the crystallographic axis of each ZnO nanowire in the same direction so that when force was applied to them all collectively, the polarity of charges on each wire would be aligned, producing a higher output voltage. Wang’s team patterned an array of parallel chromium wires atop a substrate. They then grew thousands of ZnO nanowires laterally between these wires, like rungs in a ladder, under conditions that ensured they all grew with the same crystallographic orientation. Finally, they soldered the ZnO nanowires to the chromium by depositing gold at the connection points (see figure, p. 304). The scheme worked. When they flexed their array, it generated 1.26 volts. That’s not quite the 1.5 volts of a AA battery, but in the months since their paper was submitted, Wang says his team has upped that output to 2.4 volts. “This enables us to operate true technology,” Wang says.

The Georgia Tech group isn’t the only one closing in on that goal. At the University of California, Berkeley, another nanogenerator group, headed by mechanical engineer Liwei Lin, is making nanogenerators out of long polymer fibers that one day may be woven into cloth. “This technology could eventually lead to wearable ‘smart clothes’ that can power hand-held electronics through ordinary body movements,” Lin says.

For their nanogenerators, Lin and his colleagues start with a polymer called polyvinylidene fluoride (PVDF) that can be processed to separate electrical charges. Other groups have previously made PVDF generators from thin films of the polymer. But PVDF films are typically inefficient, converting only 1% to 2% of kinetic energy to electricity. Lin and his colleagues also reported in the 10 February issue of Nano Letters that when they used a technique called electrospinning to spin PVDF into threadlike fibers as little as 500 nanometers across, the resulting fibers converted 10 times as much kinetic energy to electricity as the thin-film PVDF devices did.

Although Lin and his colleagues are still trying to understand exactly why that is, Lin says part of the explanation probably has to do with the electrospinning technique. The method draws out the polymer fibers in the presence of a large electric field, which seems to orient individual polymer molecules better than the filmmaking techniques do (see figure, left). And once the fibers are formed and solidify, this arrangement is locked in place. The output is high enough, Lin says, that calculations suggest that 1000 or so fiber generators incorporated into the cloth of a shirt would capture enough energy from a person’s movements to charge a cell phone or an iPod. Although Lin says he hasn’t yet formed a company to commercialize his power-suit material, he’s already taking visits from venture capitalists looking to do just that.

If nanogenerators of any sort succeed, could they possibly be scaled up to generate large amounts of power? After all, most of the handwringing about energy these days is about how to generate terawatts, rather than microwatts, of carbon-free power. Lin, Wang, and McAlpine agree that for now that doesn’t seem likely. Nanogenerators simply produce too little power to change our civilization. For now, they’ll be working on the small scale, which might still be enough to change our lives.

—ROBERT F. SERVICE