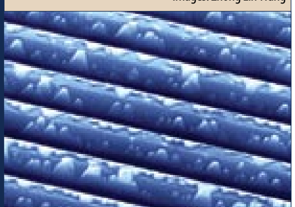
Taking advantage of the unique piezoelectric and semiconducting properties of zinc oxide nanostructures, researchers have demonstrated a prototype nanometer-scale generator that produces continuous direct-current electricity by harvesting mechanical energy from the environment.

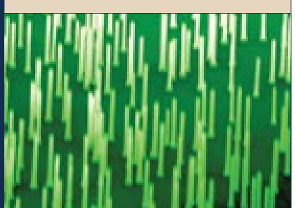
Powering Nanodevices

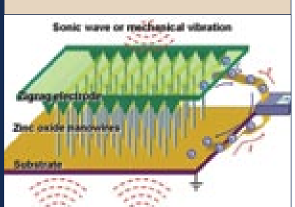
Nanogenerator provides continuous power by harvesting energy from the environment.

By John Toon

Images: Zhong Lin Wang







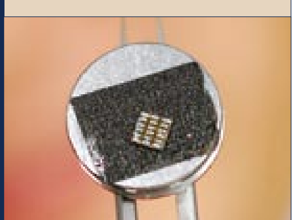


Photo: Gary Meek

Microscope images show components of the nanogenerator (top two images). A schematic of the nanogenerator shows how it extracts energy from the environment; while several prototype nanogenerators are shown (bottom image).

Researchers have demonstrated a prototype nanometer-scale generator that produces continuous direct-current electricity by harvesting mechanical energy from such environmental sources as ultrasonic waves, mechanical vibration or blood flow.

Based on arrays of vertically aligned zinc oxide nanowires that move inside a novel "zigzag" plate electrode, the nanogenerators could provide a new way to power nanoscale devices without batteries or other external power sources.

"This is a major step toward a portable, adaptable and cost-effective technology for powering nanoscale devices," says Zhong Lin Wang, Regents' Professor in the Georgia Tech School of Materials Science and Engineering. "There has been a lot of interest in making nanodevices, but we have tended not to think about how to power them. Our nanogenerator allows us to harvest or recycle energy from many sources to power these devices."

Details of the nanogenerator were reported in the journal *Science* in April 2007. The research was sponsored by the Defense Advanced Research Projects Agency (DARPA), the National Science Foundation (NSF), and the Emory-Georgia Tech Center of Cancer Nanotechnology Excellence.

The nanogenerators take advantage of the unique coupled piezoelectric and semiconducting properties of zinc oxide nanostructures, which produce small electrical charges when they are flexed.

Fabrication begins with growing an array of vertically aligned nanowires approximately a half-micron apart on gallium arsenide, sapphire or a flexible polymer substrate. A layer of zinc oxide is grown on top of the substrate to collect the current. The researchers also fabricate silicon zigzag electrodes, which contain thousands of nanometer-scale tips made conductive by a platinum coating.

The electrode is then lowered on top of the nanowire array, leaving just enough space so that a significant number of the nanowires are free to flex within the gaps created by the tips. Moved by mechanical energy such as waves or vibration, the nanowires periodically contact the electrode, transferring their electrical charges. By capturing the tiny amounts of current produced by hundreds of nanowires kept in motion, the generators produce a direct current output in the nano-Ampere range.

Wang and his group members – Xudong Wang, Jinhui Song and Jin Liu – expect that with optimization, their nanogenerator could produce as much as four watts per cubic centimeter – based on a calculation for a single nanowire. That would be enough to power a broad range of nanometer-scale defense, environmental and biomedical applications – including biosensors implanted in the body, environmental monitors – and even nanoscale robots.

With its multiple conducting tips similar to those of an atomic force microscope, the new zigzag electrode serves as a Schottky barrier that accumulates and preserves electrical charge from hundreds or thousands of wires simultaneously.

"We can now see the steps

involved in moving forward to a device that can power real nanometer-scale applications," Wang says.

Before that happens, additional development will be needed to optimize current production. For instance, though nanowires in the arrays can be grown to approximately the same length – about 1 micron – there is some variation. Wires that are too short cannot touch the electrode to produce current, while wires that are too long cannot flex to produce electrical charge.

"We need to be able to better control the growth, density and uniformity of the wires," Wang adds. "We believe we can make as many as millions or even billions of nanowires produce current simultaneously."

In their lab, the researchers aimed an ultrasound source at their nanogenerator to measure current output for as long as five days. Though there was some fluctuation in output, the current flow was continuous as long as the ultrasonic generator was operating, Wang says.

Providing power for nanometer-scale devices has long been a challenge. Batteries and other traditional sources are too large, and tend to negate the size advantages of nanodevices. And since batteries contain toxic materials such as lithium and cadmium, they cannot be implanted into the body as part of biomedical applications.

Because zinc oxide is non-toxic and compatible with the body, the new nanogenerators could be integrated into implantable biomedical devices to wirelessly measure blood flow and blood pressure within the body. And they could also find more ordinary applications.

"If you had a device like this in your shoes when you walked, you would be able to generate your own small current to power small electronics," Wang notes. "Anything that makes the nanowires move within the generator can be used for generating power. Very little force is required to move them." rh

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Photo: Gary Meek

Regents' Professor Zhong Lin Wang displays an array of nanogenerators that are able to extract electrical power from the environment.