Harvesting the sun's energy with antennas

Update: Read a news release about the research team's recent conference presentation here.

Researchers at Idaho National Laboratory, along with partners at Microcontinuum Inc. (Cambridge, MA) and Patrick Pinhero of the University of Missouri, are developing a novel way to collect energy from the sun with a technology that could potentially cost pennies a yard, be imprinted on flexible materials and still draw energy after the sun has set.

The new approach, which garnered two 2007 Nano50 awards, uses a special manufacturing process to stamp tiny loops of conducting metal onto a sheet of plastic. Each "nanoantenna" is as wide as 1/25 the diameter of a human hair.

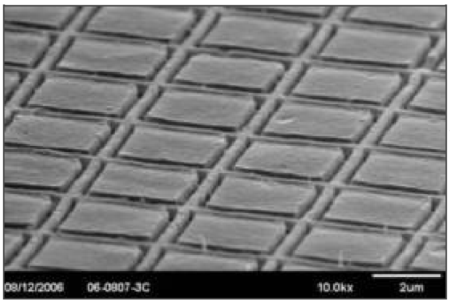
Because of their size, the nanoantennas absorb energy in the infrared part of the spectrum, just outside the range of what is visible to the eye. The sun radiates a lot of infrared energy, some of which is soaked up by the earth and later released as radiation for hours after sunset. Nanoantennas can take in energy from both sunlight and the earth's heat, with higher efficiency than conventional solar cells.

"I think these antennas really have the potential to replace traditional solar panels," says physicist Steven Novack, who spoke about the technology in November at the National Nano Engineering Conference in Boston.

INL researcher Steven Novack holds a plastic sheet of nanoantenna arrays, created by embossing the antenna structure and depositing a conductive metal in the pattern. Each square contains roughly 260 million antennas. Nanotechnology R&D usually occurs on the centimeter scale, but this INL-patented manufacturing process demonstrates nano-scale features can be produced on a larger scale.

Taking antennas to the atomic level

The miniscule circuits absorb energy just like the antenna on your television or in your cell phone. All antennas work by resonance, the same self-reinforcing physical phenomenon that allows a high note to shatter glass. Radio and television antennas must be large because of the wavelength of energy they need to pick up. In theory, making antennas that can absorb electromagnetic radiation closer to what we can see is simple: just engineer a smaller antenna.



An array of loop nanoantennas, imprinted on plastic and imaged with a scanning electron microscope. The deposited wire is roughly 200 nanometers thick.

But finding an efficient way to stamp out arrays of atom-scale loops took a number of years. "It's not that this concept is new," Novack says, "but the boom in nanotechnology is what has really made this possible." The INL team envisions the antennas might one day be produced like foil or plastic wrap on roll-to-roll machinery. So far, they have demonstrated the imprinting process with six-inch circular stamps, each holding more than 10 million antennas.

It wasn't immediately obvious the structures might be used for solar power. At first, the researchers considered pairing the antennas with conventional solar cells to make them more efficient. "Then we thought to start from scratch," Novack says. "We realized we could make the antennas into their own energy harvesters."

An economical alternative

Commercial solar panels usually transform less that 20 percent of the usable energy that strikes them into electricity. Each cell is made of silicon and doped with exotic elements to boost its efficiency. "The supply of processed silicon is lagging, and they only get more expensive," Novack says. He hopes solar nanoantennas will be a more efficient and sustainable alternative.

The team estimates individual nanoantennas can absorb close to 80 percent of the available energy. The circuits themselves can be made of a number of different conducting metals, and the nanoantennas can be printed on thin, flexible materials like polyethylene, a plastic that's commonly used in bags and plastic wrap. In fact, the team first printed antennas on plastic bags used to deliver the Wall Street Journal, because they had just the right thickness.

By focusing on readily available materials and rapid manufacturing from inception, Novack says, the aim is to make nanoantenna arrays as cheap as inexpensive carpet.

Fine-tuning fine structures

The real trick to making the solar nanoantenna panels is to be able to predict their properties and perfect their design before printing them in the factory. While it is relatively easy to work out the physics of one resonating antenna, complex interactions start to happen when multiple antennas are combined. When hit with the right frequency of infrared light, the antennas also produce high-energy electromagnetic fields that can have unexpected effects on the materials.

So the researchers are developing a computer model of resonance in the tiny structures, looking for ways to fine-tune the efficiency of an entire array by changing factors like materials and antenna shape. "The ability to model these antennas is what's going to make us successful, because we can't see these things," Novack says. "They're hard to manipulate, and small tweaks are going to make big differences."

A charged future

One day, Novack says, these nanoantenna collectors might charge portable battery packs, coat the roofs of homes and, perhaps, even be integrated into polyester fabric. Double-sided panels could absorb a broad spectrum of energy from the sun during the day, while the other side might be designed to take in the narrow frequency of energy produced from the earth's radiated heat.

INL researchers Dale Kotter (left), Steven Novack, and Judy Partin are developing flexible plastic sheets of nanoantennas to collect solar energy.

While the nanoantennas are easily manufactured, a crucial part of the process has yet to be fully developed: creating a way to store or transmit the electricity. Although infrared rays create an alternating current in the nanoantenna, the frequency of the current switches back and forth ten thousand billion times a second. That's much too fast for electrical appliances, which operate on currents that oscillate only 60 times a second. So the team is exploring ways to slow that cycling down, possibly by embedding energy conversion devices like tiny capacitors directly into the antenna structure as part of the nanoantenna imprinting process.

"At this point, these antennas are good at capturing energy, but they're not very good at converting it," says INL engineer Dale Kotter, "but we have very promising exploratory research under way." Kotter and Novack are also exploring ways to transform the high-frequency alternating current (AC) to direct current (DC) that can be stored in batteries. One possibility is to create antennas with a spiral shape and place high-speed rectifiers, or special diodes, at the center to convert the electricity from AC to DC. The team has a patent pending on a variety of potential energy conversion methods. They anticipate they are only a few years away from creating the next generation of solar energy collectors.

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