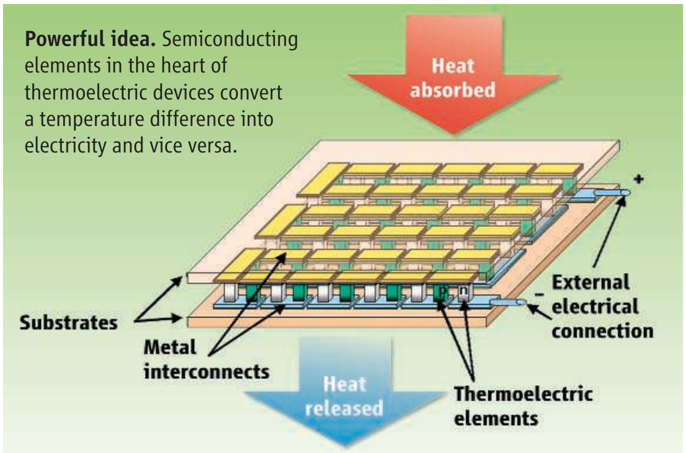
Silicon Adds to Its Roster of Skills

Is there anything silicon can't do? The silvery semiconductor is already the behemoth of the electronics world. Researchers have engineered it to manipulate light as well. Now, a California-based team has found that collections of whiskerlike silicon nanowires make an impressive thermoelectric material, capable of converting heat flow into electricity and vice versa.

At the meeting last month, James Heath, a chemist at the California Institute of Technology (Caltech) in Pasadena, reported that by simply growing silicon into wires about 10 nanometers across, he and his colleagues improved silicon's ZT—a measure of how well a material converts heat flow to electricity—to 1, roughly 100 times that of bulk silicon. "It's a really important finding," says chemical engineer Gyeong Hwang of the University of Texas, Austin. Although a ZT of 1 lags behind the record of 2.4, silicon is a far simpler material than the current record holder—a complex, multilayered material. That advantage, together with the computer industry's decades of experience working with silicon, means that silicon-based thermoelectric devices could one day be incorporated into computer chips to help cool them down and may eventually help turn waste heat from boilers and car engines into valuable electrical power.



Powerful idea. Semiconducting elements in the heart of thermoelectric devices convert a temperature difference into electricity and vice versa.

The thermoelectric effect, discovered nearly 200 years ago, works when a semiconductor is hotter on one side than the other. Heat and electrical charges flow from the warm side to the cool one. The movement of charges creates a voltage difference between the two sides that can be harnessed to do work. The effect also works in reverse: Apply a voltage, and the semiconductor pushes heat from one side to the other. So far, thermoelectric devices have been too inefficient to compete with other power-generating or heat-pumping technologies. But experts think large-scale markets could open up if a thermoelectric device achieved a ZT of about 3, or perhaps less if the starting material were cheap.

The key to making efficient thermoelectric devices is finding materials that are good electrical conductors but prevent heat-carrying vibrations, known as phonons, from traveling across the material's crystal lattice. Phonons equalize the temperature on both sides and so eliminate the material's ability to generate power. Thermoelectric devices made from alloys of bismuth and tellurium with a ZT of about 1 have been around for decades. But in the mid-1990s, physicists in Massachusetts and Pennsylvania calculated that the effect would spike if the semiconductor were just a few nanometers thick in at least one dimension. Such a shape would allow electrons to continue to whiz through the materials but would block phonons from carrying heat from one side of the device to the other. In 2001, researchers in North Carolina hit the jackpot with devices showing a ZT of 2.4, made from a complex sandwich of semiconductor layers, each as little as 1 nanometer thick.

Heath and colleagues decided to see what would happen if bismuth had two nanometer-scale dimensions instead of one—nanowires instead of sheets. Heath's team had previously developed a technique for making perfect nanowires from many different kinds of materials (*Science*, 4 April 2003, p. 112) and applied it to forge bismuth nanowires. But chemical reactions on the surface of the wires interfered with thermoelectric measurements. The Caltech team decided to try nanowires made from silicon instead. Silicon has dismal thermoelectric properties in bulk, but because its surface can be carefully controlled it seemed an ideal test bed. The tests showed a pleasant surprise: The electrical conductivity of the nanowires dipped slightly compared to the bulk, but the thermal conductivity went through the floor, dropping 1000-fold.

Heath suspects the drop is due to "phonon drag," in which phonons slow their movements because of interactions with electrons. If so, he adds, it suggests that the material's small dimensions, rather than its surface chemistry, is responsible. In any case, Heath says he suspects that spiking silicon with other elements to improve its electrical conductivity and slow phonons even further may give silicon nanowire thermoelectric devices yet another boost—possibly enough to hand silicon yet another job in the electronics world.

Antisense Particles Send Up a Flare

It takes skill and a bit of luck to succeed in science. So far, antisense technology, which tries to shut off the output of particular genes, has shown plenty of the former but little of the latter. The technique has long excelled in lab studies, but antisense-based drugs have struggled to reach the market. In many cases, researchers have been left wishing they could see what went wrong. Now they may be able to.

At the ACS meeting, chemist Chad Mirkin of Northwestern University in Evanston, Illinois, reported that his team has managed to create tiny particles that not only turn off the activity of genes inside cells but also send off cellular signal flares when they do, allowing researchers to instantly see whether their gene blockers are working or not. "It was a nice talk," says Zeev Rosenzweig, a chemist at the University of New Orleans in Louisiana. Although the technique isn't the only one that can be used to gauge patterns of gene expression, early indications suggest it well outperforms the competition.

Antisense technology works by interfering with the cellular assembly line that first converts DNA into RNA, and then RNA to proteins. The process can be inter-

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