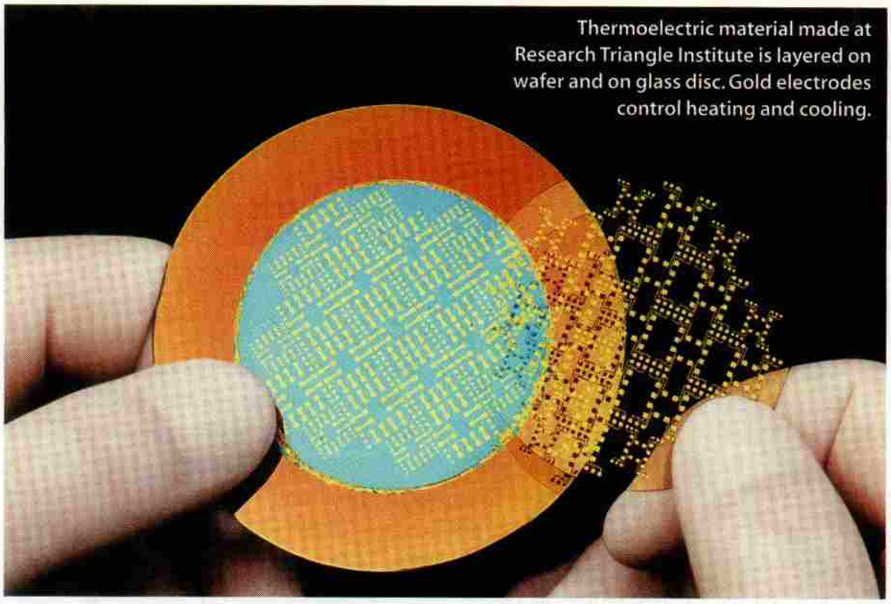
UPSTREAM

SPOTLIGHT ON A HOT TECHNOLOGY TO WATCH



Thermoelectric material made at Research Triangle Institute is layered on wafer and on glass disc. Gold electrodes control heating and cooling.

JOHN THEILGARD, RTI INTERNATIONAL

THERMOELECTRIC MATERIALS

Electricity from waste heat is just one of the potential uses

The promise of thermoelectric materials has, it seems, run hot and cold over the decades. These materials, which can directly convert heat into electricity (and vice versa), could be a boon for everything from power generation to microprocessor cooling. But except in a few niche applications, these solid-state heat pumps have proven too inefficient to be practical. As much as engineers would like to grab waste heat from, say, a car's engine and turn it into electricity, thermoelectric materials just haven't been up to the job.

Now, engineers and scientists at several leading labs have used nanotechnology to create novel semiconducting materials that could finally make thermoelectricity a widely used technology. "After six to 10 years of pretty intensive basic research, some of these materials are coming to fruition," says Terry Tritt, a professor of physics at Clemson University. "Within the last 18 months there have been substantial improvements." Indeed, at least one research group predicts it will soon have prototypes of a practical heat-conversion device that carmakers can begin testing.

In its simplest form, thermoelectricity is produced when you heat one end of a wire; electrons will move to the colder end, carrying electrical charge with them and producing a current. Alternatively, you can apply a current to the wire to carry heat away from a hot section to cooler areas. Since the 1960s, NASA has used this effect to generate electricity for spacecraft too far away from the sun for solar cells to operate. And one Japanese company is even selling thermoelectric wristwatches powered by the wearer's body heat. But the materials have so far been used only in novelty items because of a catch-22: to make the process efficient, you need materials that will conduct electricity, but that do not excel at conducting heat, so the temperature difference remains. In other words, the trick is to somehow block the heat flow while enhancing the electrical flow.

That's where nanotechnology comes in. "Nature is working against us with these materials," explains MIT physicist Mildred Dresselhaus. So, she says, starting in the mid-1990s, her group and several others turned to nanoscale structures to improve on nature at the molecular level.

Last October, Rama Venkatasubramanian at the Research Triangle Institute in North Carolina reported a major advance: tiny "superlattice" structures that appear to be more than twice as efficient as previous thermoelectric materials. The nano films consist of several alternating layers, each less than five nanometers thick. These layers block the travel of atomic vibrations that produce heat flow but still let the electrons flow as current.

The material's first application could be a device for siphoning off electrical power from the heat in automobile exhaust. Eventually such a device could be used to supplement power from electric and fuel cell engines or provide a conventional vehicle with most of its electricity needs, running everything from its radio to its air conditioner. Venkatasubramanian also envisions the material's use in microelectronics. The heat buildup in today's ultrafast microchips is, in particular, a problem in making smaller and faster devices. Tiny patches of the films precisely positioned on microelectronic chips could be used to spot-cool only the components that need it.

Other research groups are making nanowires and nanodots for thermoelectric applications. At the University of California, Berkeley, for example, chemist Peidong Yang has found a way to grow 20-nanometer-wide wires made of a combination of silicon and germanium for use in nano heating and cooling. And at MIT's Lincoln Laboratory, a group led by Ted Harmon has synthesized arrays of tiny nano particles. The arrays contain thousands of so-called quantum dots—each only a few nanometers in diameter—and are capable of acting as microcoolers or power generators.

Indeed, many researchers feel they are finally within striking distance of an efficient way to directly extract electricity from heat sources. Thermoelectric materials will first appear in specialty applications, but if efficiencies can be cranked up further, then whole other areas of technology will be fair game, from refrigerators to turbine power generators. *—David Voss*