Material may help autos turn heat into electricity

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Researchers have invented a new material that will make cars even more efficient, by converting heat wasted through engine exhaust into electricity. In the current issue of the journal *Science,* they describe a material with twice the efficiency of anything currently on the market.

The same technology could work in power generators and heat pumps, said project leader Joseph Heremans, Ohio Eminent Scholar in Nanotechnology at Ohio State University.

Scientists call such materials thermoelectric materials, and they rate the materials' efficiency based on how much heat they can convert into electricity at a given temperature.

Previously, the most efficient material used commercially in thermoelectric power generators was an alloy called sodium-doped lead telluride, which had a rating of 0.71. The new material, thallium-doped lead telluride, has a rating of 1.5 -- more than twice that of the previous leader.

What's more important to Heremans is that the new material is most effective between 450 and 950 degrees Fahrenheit -- a typical temperature range for power systems such as automobile engines.

Some experts argue that only about 25 percent of the energy produced by a typical gasoline engine is used to move a car or power its accessories, and nearly 60 percent is lost through waste heat -- much of which escapes in engine exhaust.

A thermoelectric (TE) device can capture some of that waste heat, Heremans said. It would also make a practical addition to an automobile, because it has no moving parts to wear out or break down.

"The material does all the work. It produces electrical power just like conventional heat engines -- steam engines, gas or diesel engines -- that are coupled to electrical generators, but it uses electrons as the working fluids instead of water or gases, and makes electricity directly."

"Thermoelectrics are also very small," he added. "I like to say that TE converters compare to other heat engines like the transistor compares to the vacuum tube."

The engineers took a unique strategy to design this new material.

To maximize the amount of electricity produced by a TE material, engineers would normally try to limit the amount of heat that can pass through it without being captured and converted to electricity. So the typical strategy for making a good thermoelectric material is to lower its thermal conductivity.

In Heremans' lab, he used to work to lower the thermal conductivity by building nanometer-sized structures such as nanowires into materials. A nanometer is one billionth of a meter.

Those nanostructured materials are not very stable, are very difficult to make in large quantities, and are difficult to connect with conventional electronic circuits and external heat sources.

For this new material, he and his colleagues took a different strategy: they left out the fancy nanostructures, and instead focused on how to convert the maximum amount of heat that was trapped in the material naturally.

To do this, they took advantage of some new ideas in quantum mechanics.

Heremans pointed to a 2006 paper published by other researchers in the journal *Physical Review Letters*, which suggested that elements such as thallium and tellurium could interact on a quantum-mechanical level to create a resonance between the thallium electrons and those in the host lead telluride thermoelectric material, depending on the bonds between the atoms.

"It comes down to a peculiar behavior of an electron in a thallium atom when it has tellurium neighbors," he said. "We'd been working for 10 years to engineer this kind of behavior using different kinds of nanostructured materials, but with limited success. Then I saw this paper, and I knew we could do the same thing we'd been trying to do with nanostructures, but with this bulk semiconductor instead."

Heremans designed the new material with Vladimir Jovovic, who did this work for his doctoral thesis in the Department of Mechanical Engineering at Ohio State. Researchers at Osaka University -- Ken Kurosaki, Anek Charoenphakdee, and Shinsuke Yamanaka -- created samples of the material for testing. Then researchers at the California Institute of Technology -- G. Jeffrey Snyder, Eric S. Toberer, and Ali Saramat -- tested the material at high temperatures. Heremans and Jovovic tested it at low temperatures and provided experimental proof that the physical mechanism they postulated was indeed at work.

The team found that near 450 degrees Fahrenheit, the material converted heat to electricity with an efficiency rating of about 0.75 -- close to that of sodium doped telluride. But as the temperature rose, so did the efficiency of the new material. It peaked at 950 degrees Fahrenheit, with a rating of 1.5.

Heremans' team is continuing to work on this patent-pending technology.

"We hope to go much further. I think it should be quite possible to apply other lessons learned from thermoelectric nanotechnology to boost the rating by another factor of two -- that's what we're shooting for now," he said.

Source: Ohio State University

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