Scientists move closer to new kind of thermoelectric 'heat engine'

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Researchers who are studying a new magnetic effect that converts heat to electricity have discovered how to amplify it a thousand times over - a first step in making the technology more practical.

In the so-called spin Seebeck effect, the spin of electrons creates a current in magnetic materials, which is detected as a voltage in an adjacent metal. Ohio State University researchers have figured out how to create a similar effect in a non-magnetic semiconductor while producing more electrical power.

They've named the amplified effect the "giant spin-Seebeck" effect, and the university will license patent-pending variations of the technology.

The resulting voltages are admittedly tiny, but in this week's issue of the journal *Nature*, the researchers report boosting the amount of voltage produced per degree of temperature change inside the semiconductor from a few microvolts to a few millivolts - a 1,000-fold increase in voltage, producing a 1-million-fold increase in power.

Joseph Heremans, Ohio Eminent Scholar in Nanotechnology, said that his team's ultimate goal is a low-cost and efficient solid-state engine that coverts heat to electricity. These engines would have no moving parts, would not wear out, and would be infinitely reliable, he added.

"It's really a new generation of heat engine," said Heremans, professor of mechanical engineering and professor of physics at Ohio State. "In the

1700s we had steam engines, in the 1800s we had gas engines, in the 1900s we had the first thermoelectric materials, and now we're doing the same thing with magnetics."

This research could enable electronic devices that recycle some of their own waste heat into electricity. In a computer, it could enable heat-powered computation, or, inversely, it could provide cooling.

Researchers around the world are working to develop electronics that utilize the spin of electrons to read and write data. So-called "spintronics" are desirable because in principle they could store more data in less space, process data faster, and consume less power. And the spin-Seebeck effect takes the notion of spintronics a step further, by using heat to induce a flow of spin "information," called a "spin current."

Great progress has been made in understanding how the spin-Seebeck effect works, but many details are still a mystery. Though researchers around the world have been able to reproduce the spin-Seebeck effect with some success since it was discovered at Tohoku University in 2008, a unified theory is lacking. And the same holds true for the giant spin-Seebeck effect, though the Ohio State researchers have several suggestions as to what's going on.

People may be familiar with the concept of light being made of particles called photons, Heremans said. Heat, too, can be thought of the same way, and scientists have a similar-sounding name for heat particles: phonons.

The researchers think that they were able to induce a powerful stream of phonons inside the semiconductor. The phonons then smashed into the electrons and knocked them forward, while the atoms in the semiconductor made the electrons spin as they streamed through the material - like a bullet spinning in a rifle barrel.

Roberto Myers, assistant professor of materials science and engineering, said that the key to making the experiment work was the choice of materials.

The spin-Seebeck effect had previously only been seen in magnetic semiconductors and metals, but they looked to non-magnetic semiconductors instead, where there were more materials to choose from. They settled on indium antimonide, doped it with other elements, and then created a sample of the material about the size of stick of Trident gum.

Since the material was non-magnetic, they needed to create a magnetic field around it and lower the temperature to polarize the electrons.

"Those are the drawbacks - we had to do it at a low temperature, and with a high magnetic field," Myers said. "Right now, it works between 2 and 20 Kelvin, which is about the temperature of liquid helium, and with an external magnetic field of 3 Tesla, which is about the same strength as a medical MRI."

The temperature range corresponds to -456 to -423 degrees Fahrenheit.

Still, when they heated one side of the material one degree, they detected a voltage of 8 millivolts (thousandths of a volt) on the other side. That's three orders of magnitude bigger than the 5 microvolts (millionths of a volt) ever produced by researchers using the standard spin-Seebeck effect.

Heremans and his team are exploring other materials - magnetic and otherwise - to push the effect further.

Provided by Ohio State University

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