Improving materials that convert heat to electricity and vice-versa

EurekAlert!

ANN ARBOR---Thermoelectric materials can be used to turn waste heat into electricity or to provide refrigeration without any liquid coolants, and a research team from the University of Michigan has found a way to nearly double the efficiency of a particular class of them that's made with organic semiconductors.

Organic semiconductors are carbon-rich compounds that are relatively cheap, abundant, lightweight and tough. But they haven't traditionally been considered candidate thermoelectric materials because they have been inefficient in carrying out the essential heat-to-electricity conversion process.

Today's most efficient thermoelectric materials are made of relatively rare inorganic semiconductors such as bismuth, tellurium and selenium that are expensive, brittle and often toxic. Still, they manage to convert heat into electricity more than four times as efficiently as the organic semiconductors created to date.

This greater efficiency is reflected in a metric known by researchers as the thermoelectric "figure of merit." This metric is approximately 1 near room temperature for state-of-the-art inorganic thermoelectric materials, but only 0.25 for organic semiconductors.

U-M researchers improved upon the state-of-the-art in organic semiconductors by nearly 70 percent, achieving a figure-of-merit of 0.42 in a compound known as PEDOT:PSS.

"That's about half as efficient as current inorganic semiconductors," said project leader Kevin Pipe, an associate professor of mechanical engineering as well as electrical engineering and computer science. Pipe is a co-author of a paper on the research published in Nature Materials on May 5, 2013.

PEDOT:PSS is a mixture of two polymers: the conjugated polymer PEDOT and the polyelectrolyte PSS. It has previously been used as a transparent electrode for devices such as organic LEDs and solar cells, as well as an antistatic agent for materials such as photographic films.

One of the ways scientists and engineers increase a material's capacity for conducting electricity is to add impurities to it in a process known as doping. When these added ingredients, called dopants, bond to the host material, they give it an electrical carrier. Each of these additional carriers enhances the material's electrical conductivity.

In PEDOT doped by PSS, however, only small fraction of the PSS molecules actually bond to the host PEDOT; the rest of the PSS molecules do not become ionized and are inactive. The researchers found that these excess PSS molecules dramatically inhibit both the electrical conductivity and thermoelectric performance of the material.

"The trouble is that the inactive PSS molecules push the PEDOT molecules further apart, making it harder for electrons to jump between PEDOT molecules," Pipe said. "While ionized PSS molecules improve electrical conductivity, non-ionized PSS molecules reduce it."

To improve its thermoelectric efficiency, the researchers restructured the material at the nanoscale. Pipe and his team figured out how to use certain solvents to remove some of these non-ionized PSS dopant molecules from the mixture, leading to large increases in both the electrical conductivity and the thermoelectric energy conversion efficiency.

This particular organic thermoelectric material would be effective at temperatures up to about 250 degrees Fahrenheit.

"Eventually this technology could allow us to create a flexible sheet---think of Saran Wrap---that can be rolled out or wrapped around a hot object to generate electricity or provide cooling," Pipe said.

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