NREL reveals potential for capturing waste heat via nanotubes

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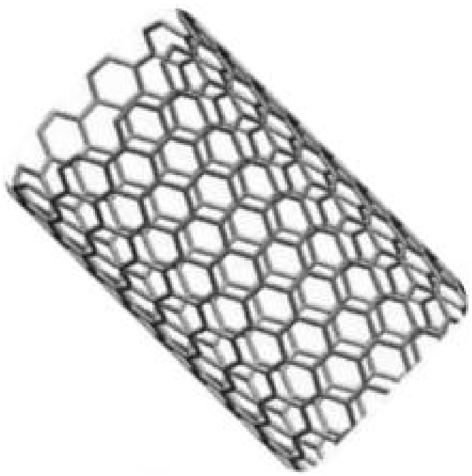

A finely tuned carbon nanotube thin film has the potential to act as a thermoelectric power generator that captures and uses waste heat, according to researchers at the Energy Department's National Renewable Energy Laboratory (NREL).

The research could help guide the manufacture of thermoelectric devices based on either single-walled carbon nanotube (SWCNT) films or composites containing these nanotubes. Because more than half of the energy consumed worldwide is rejected primarily as waste heat, the idea of thermoelectric power generation is emerging as an important part of renewable energy and energy-efficiency portfolios.

"There have not been many examples where people have really looked at the intrinsic thermoelectric properties of carbon nanotubes and that's what we feel this paper does," said Andrew Ferguson, a research scientist in NREL's Chemical and Materials Science Center and co-lead author of the paper with Jeffrey Blackburn.

The research, "Tailored Semiconducting Carbon Nanotube Networks with Enhanced Thermoelectric Properties," appears in the journal *Nature Energy*, and is a collaboration between NREL, Professor Yong-Hyun Kim's group at the Korea Advanced Institute of Science and Technology, and Professor Barry Zink's group at the University of Denver. The other authors from NREL are Azure Avery (now an assistant professor at Metropolitan State University of Denver), Ben Zhou, Elisa Miller, Rachelle Ihly, Kevin Mistry, and Sarah Guillot.

Nanostructured inorganic semiconductors have demonstrated promise for improving the performance of thermoelectric devices. Inorganic materials can run into problems when the semiconductor needs to be lightweight, flexible, or irregularly shaped because they are often heavy and lack the required flexibility. Carbon nanotubes, which are organic, are lighter and more flexible.

How useful a particular SWCNT is for thermoelectrics, however, depends on whether the nanotube is metallic or a semiconductor, both of which are produced simultaneously in SWCNT syntheses. A metallic nanotube would harm devices such as a thermoelectric generator, whereas a semiconductor nanotube actually enhances performance. Furthermore, as with most optical and electrical devices, the electrical band gap of the semiconducting SWCNT should affect the thermoelectric performance as well.

Fortunately, Blackburn, a senior scientist and manager of NREL's Spectroscopy and Photoscience group, has developed an expertise at separating semiconducting nanotubes from metallic ones and his methods were critical to the research, Ferguson said.

"We are at a distinct advantage here that we can actually use that to probe the fundamental properties of the nanotubes," he said.

To generate highly enriched semiconducting samples, the researchers extracted nanotubes from polydisperse soot using polyfluorene-based polymers. The semiconducting SWCNTs were prepared on a glass substrate to create a film, which was then soaked in a solution of oxidant, triethyloxonium hexachloroantimonate (OA), a process known as "doping." Doping increases the density of charge carriers, which flow through the film to conduct electricity. The researchers found the samples that performed the best were exposed to a higher concentration of OA, but not at the highest doping levels. They also discovered an optimum diameter for a carbon nanotube to achieve the best thermoelectric performance.

When it comes to thermoelectric materials, a trade-off exists between thermopower (the voltage obtained when subjecting a material to a temperature gradient) and electrical conductivity because thermopower decreases with increasing conductivity. The researchers discovered, however, that with carbon nanotubes you can retain large thermopowers even at very high electrical conductivities. Furthermore, the researchers found that their doping strategy, while dramatically increasing the electrical conductivity, actually decreased the thermal conductivity. This unexpected result is another benefit of carbon nanotubes for thermoelectric power generation, since the best thermoelectric materials must have high electrical conductivity and thermopower, while maintaining low thermal conductivity.

More information: Azure D. Avery et al. Tailored semiconducting carbon nanotube networks with enhanced thermoelectric properties,

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