NAIST® Research Highlights

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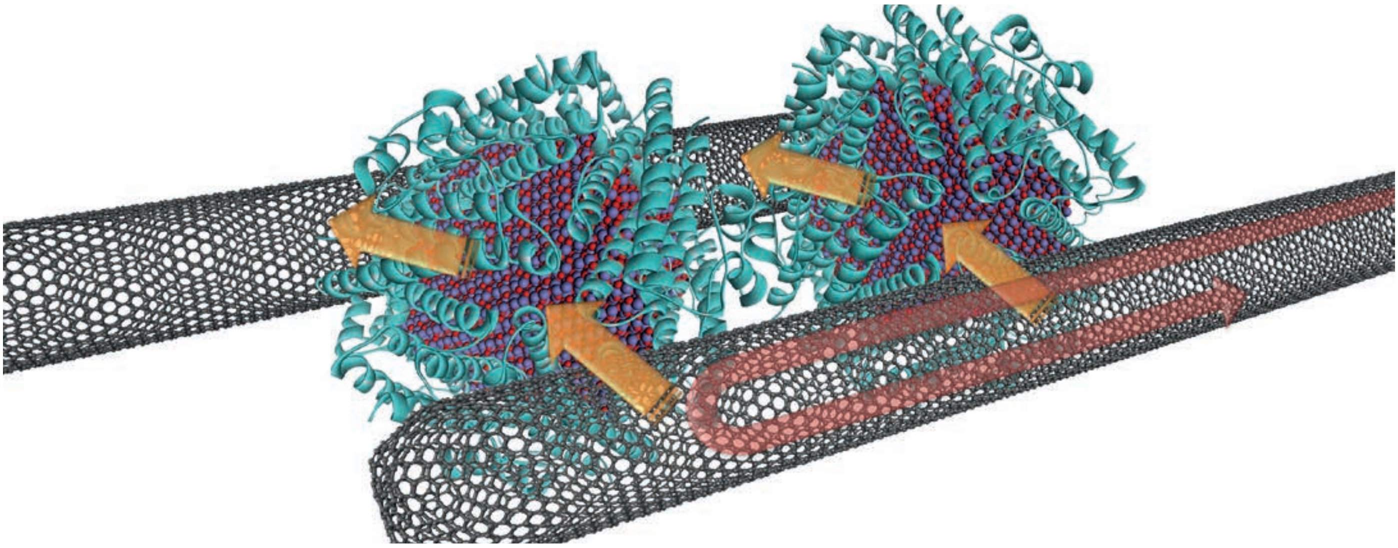

Carbon nanotubes (CNTs) linked by protein molecules (blue) with a semiconducting core (purple). Orange arrows show electric current flow from hot to cold CNTs. Red arrow indicates phonon scattering.

Semiconductors

Making waste heat into energy

Combining carbon nanotubes and protein molecules produces electricity from low-temperature heat sources

Thermoelectric devices convert heat into electrical energy without the need for moving parts, meaning they are long-lasting, reliable and environmentally-friendly. It is now even possible to harvest energy from low-temperature waste heat, thanks to advances in nanoscale components such as carbon nanotubes.

Carbon nanotubes (CNTs) are strong, light and excellent conductors of electricity, making them promising candidates as thermoelectric components. Their thermal conductivity when in pure form, however, is too high. For this reason, researchers at NAIST are working to improve the thermoelectric properties of CNTs for use in tiny power generators and even wearable electronics.

Effective thermoelectric devices require materials with high electrical conductivity, low thermal conductivity, and a high 'Seebeck coefficient'— the proportion of voltage generated by temperature differences across the material. The higher the coefficient, the better the device performs.

Masakazu Nakamura and co-workers at the NAIST Graduate School of Materials Science developed a composite CNT material by inserting biomolecules with semiconducting cores at the junctions between CNTs[1]. The CNTs retain high electrical conductivity, but the biomolecules help suppress thermal conductivity and enhance the Seebeck coefficient.

"Conventional modifications to improve thermoelectric properties in CNTs, such as impurity doping, usually improve one or two of these parameters," explains Nakamura. "Our proposed method controls the three parameters independently, quite different from any previous approach to thermoelectric materials design."

The team's main aim was to create a nanostructure which blocks heat transfer but enhances electron mobility. To do this, they used the unique functions of a cage-shaped protein molecule designed at another NAIST laboratory.

"Luckily, the ideal protein molecule for my work had already been developed by a colleague, so I neatly side-stepped one of the biggest challenges in this study," explains Nakamura. "Peptides sticking out of the molecule's surface help the structure to self-assemble with the CNTs. The soft shell of the molecule prevents the heat transfer from one CNT to another, while the semiconducting core helps the electric current flow through the CNT junctions effectively."

Heat scattered at the biomolecular junctions lowers the thermal conductivity of the CNTs, and the steep temperature gradient at the CNT/molecule interface increases the Seebeck coefficient. This combined effect enhances the thermoelectric conversion efficiency of the CNTs.

"We need various methods for energy harvesting in the future," says Nakamura. "I want to create thermoelectric stickers, thermoelectric clothes — even walls should be able to produce energy from waste heat."

Reference

1. Ito, M., Okamoto, N., Abe, R., Kojima, H., Matsubara, R. *et al*. Enhancement of thermoelectric properties of carbon nanotube composites by inserting biomolecules at nanotube junctions. *Applied Physics Express* **7**, 075102 (2014).

More information about the group's research can be found at the Organic Electronics Laboratory webpage: http://mswebs.naist.jp/LABs/greendevice/index_e.html