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PRESS RELEASE (2019/09/17)

Thermoelectric performance of graphene gets a boost

By carefully manipulating material size and quality, researchers have dramatically enhanced the thermoelectric performance of graphene. This collaborative work by Kyushu University, Tohoku University, and Purdue University not only demonstrates the ability to separately tune electrical and thermal conductivity at an unprecedented level but also indicates that graphene is a very promising non-toxic, low-cost, light-weight, and flexible thermoelectric material for powering small-scale smart devices with heat.

Able to directly convert heat into electricity without any moving parts, thermoelectric materials have attracted intense attention as great candidates to harvest energy from waste heat or renewable sources. Such materials are particularly important for the coming Internet of Things society, which requires reliable and clean energy conversion technologies to power trillions of small wireless devices.

However, the large-scale deployment of thermoelectric technology is severely restricted by the relatively low conversion efficiency of current materials. Efficient thermoelectric materials should possess a high electrical conductivity—so electricity can easily flow—but they also require a low thermal conductivity to maintain a hot and cold side. It is this temperature difference between these two sides that drives power generation.

“These requirements are very challenging because a good electrical conductor, like graphene, is usually also a good thermal conductor, which leads to energy losses as heat transfers to the cold side,” says Qin-Yi Li, an assistant professor at Kyushu University and lead author of the paper detailing the new results in *ACS Nano*.

To oppositely influence these two seemingly intertwined properties, the researchers exploited subtle differences in their behaviors in graphene, a material primarily based on carbon. Recognizing that structures with short and narrow geometries suppress thermal conductivity much more than electrical conductivity (Fig. 1), the researchers designed a one-process approach for fabricating nanoscale, high-quality graphene along with an 8-terminal test device (Fig. 2), allowing for precise measurement of the materials.

“The suspended graphene nanoribbons were synthesized by a method called plasma chemical vapor deposition. This synthesis method can ensure a low number of defects, which is important for maintaining high electrical conductivity”, says Toshiaki Kato, an associate professor at Tohoku University and co-author of this work.

The ribbons were approximately 250-nm long and 40-nm wide, greatly suppressing the thermal conductivity because of the short and narrow geometry while barely affecting the conductivity of electrical charges, which are too likely to interact with each other to be greatly affected by the ribbon boundaries.

"These mechanisms were clearly revealed by our physical simulations of quasi-particles," says Xiulin Ruan, a professor at Purdue University and another co-author on the study.

The samples exhibited record-high ratios of electrical conductivity to thermal conductivity—an important factor in determining efficiency—for graphene that were 10 to 100 times those previously reported. Furthermore, the voltage created by the thermal energy was several times larger than that for bulk graphene, an improvement the researchers attributed to changes in the characteristics of the materials because of their narrow width. As a result, the *ZT*—a figure of merit used to compare efficiency of thermoelectric devices—reached record-high values for graphene of about 0.1 (Fig. 2), which is 100 to 10,000 times previously reported values of *ZT* for graphene.

"In addition to optimizing the size and shape of graphene to achieve even higher *ZT* values, we are now searching for strategies to scale up the devices for practical applications," states Li.

For more information about this research, see "Enhanced thermoelectric performance of as-grown suspended graphene nanoribbons," Qin-Yi Li, Tianli Feng, Wakana Okita, Yohei Komori, Hiroo Suzuki, Toshiaki Kato, Toshiro Kaneko, Tatsuya Ikuta, Xiulin Ruan, and Koji Takahashi, *ACS Nano* **13**, 9182 (2019), https://doi.org/10.1021/acsnano.9b03521

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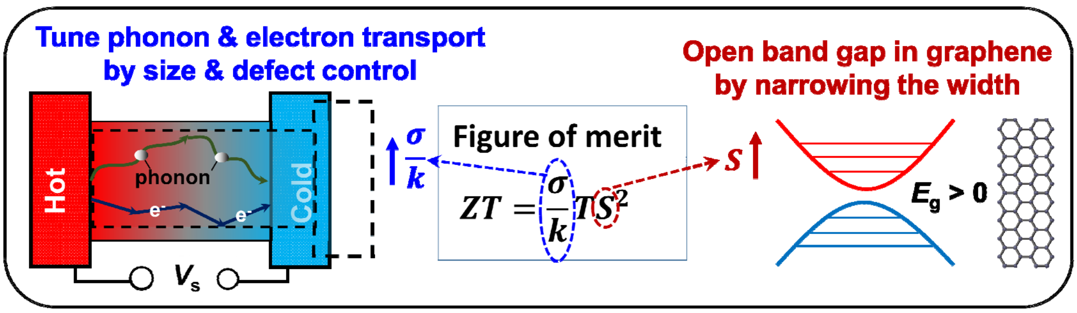

Fig. 1. Strategies to enhance the thermoelectric performance of graphene

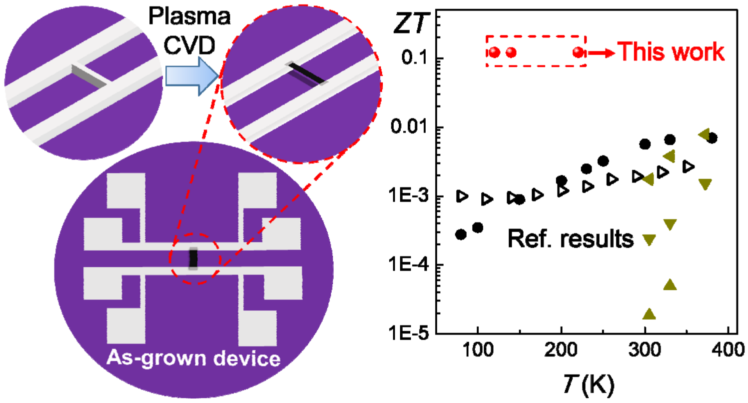

Fig. 2. Schematic of an as-grown test device and the record-high thermoelectric performance

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