Decoupling electronic and thermal transport

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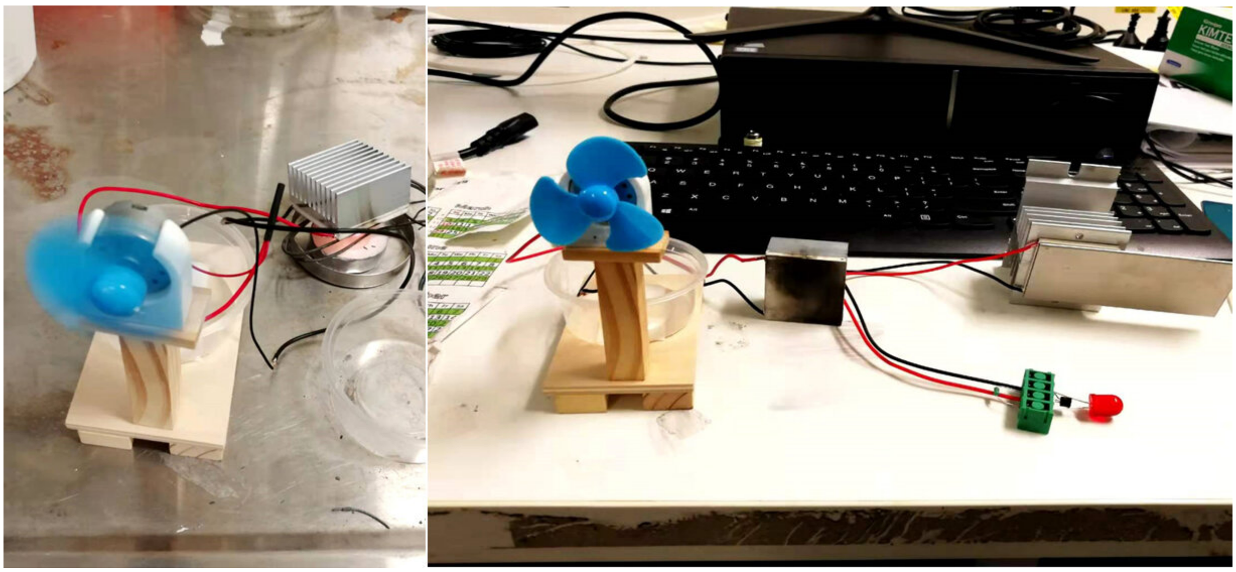

Thermoelectric material demonstration: powering a small fan, LED. Credit: FLEET

A new University of Wollongong study overcomes a major challenge of thermoelectric materials, which can convert heat into electricity and vice versa, improving conversion efficiency by more than 60%.

Current and potential future applications range from low-maintenance, solid-state refrigeration to compact, zero-carbon power generation, which could include small, personal devices powered by the body's own heat.

"The decoupling of electronic (electron-based) and thermal (phonon-based) transport will be a game-changer in this industry," says the UOW's Prof Xiaolin Wang.

Thermoelectric applications and challenges

Bismuth telluride-based materials (Bi_2Te_3, Sb_2Te_3 and their alloys) are the most successful commercially-available thermoelectric materials, with current and future applications falling into two categories: converting electricity into heat, and vice versa:

- Converting electricity into heat: reliable, low-maintenance solid-state refrigeration (heat pump) with no moving parts, no noise, and no vibration.
- Converting heat into electricity including fossil-free power generation from a wide range of heat sources or powering micro-devices for free, using ambient or body temperature.

Heat harvesting takes advantage of the free, plentiful heat sources provided by body heat, automobiles, everyday living, and industrial process. Without the need for batteries or a power supply, thermoelectric materials could be used to power intelligent sensors in remote, inaccessible locations.

An ongoing challenge of thermoelectric materials is the balance of electrical and thermal properties: In most cases, an improvement in a material's electrical properties (higher electrical conductivity) means a worsening of thermal properties (higher thermal conductivity), and vice versa.

"The key is to decouple thermal transport and electrical transport," says lead author, Ph.D. student Guangsai Yang.

Better efficiency through decoupling

The three-year project at UOW's Institute of Superconductivity and Electronic Materials (ISEM) found a way to decouple and simultaneously improve both thermal and electronic properties.

The team added a small amount of amorphous nano-boron particles to bismuth telluride-based thermoelectric materials, using nano-defect engineering and structural design.

Amorphous nano boron particles were introduced using the spark plasma sintering (SPS) method.

"This reduces the thermal conductivity of the material, and at the same time increases its electron transmission," explains corresponding author Prof Xiaolin Wang.

"The secret of thermoelectric materials engineering is manipulating the phonon and electron transport," explains Professor Wang.

Because electrons both carry heat and conduct electricity, material engineering based on electron transport alone is prone to the perennial tradeoff between thermal and electrical properties.

Phonons, on the other hand, only carry heat. Therefore, blocking phonon transport reduces thermal conductivity induced by lattice vibrations, without affecting electronic properties.

"The key to improving thermoelectric efficiency is to minimize the heat flow via phonon blocking, and maximize electron flow via (electron transmitting)," says Guangsai Yang. "This is the origin of the record-high thermoelectric efficiency in our materials."

The result is record-high conversion efficiency of 11.3%, which is 60% better than commercially-available materials prepared by the zone melting method.

As well as being the most successful commercially-available thermoelectric materials, bismuth telluride-based materials are also typical topological insulators.

Ultra-High Thermoelectric Performance in Bulk BiSbTe/Amorphous Boron Composites with Nano-Defect Architectures was published in *Advanced Energy Materials* in September 2020.

More information: Guangsai Yang et al. Ultra-High Thermoelectric Performance in Bulk BiSbTe/Amorphous Boron Composites with Nano-Defect Architectures, *Advanced Energy Materials* (2020). DOI: 10.1002/aenm.202000757

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