New high-power thermoelectric device may provide cooling in next-gen electronics

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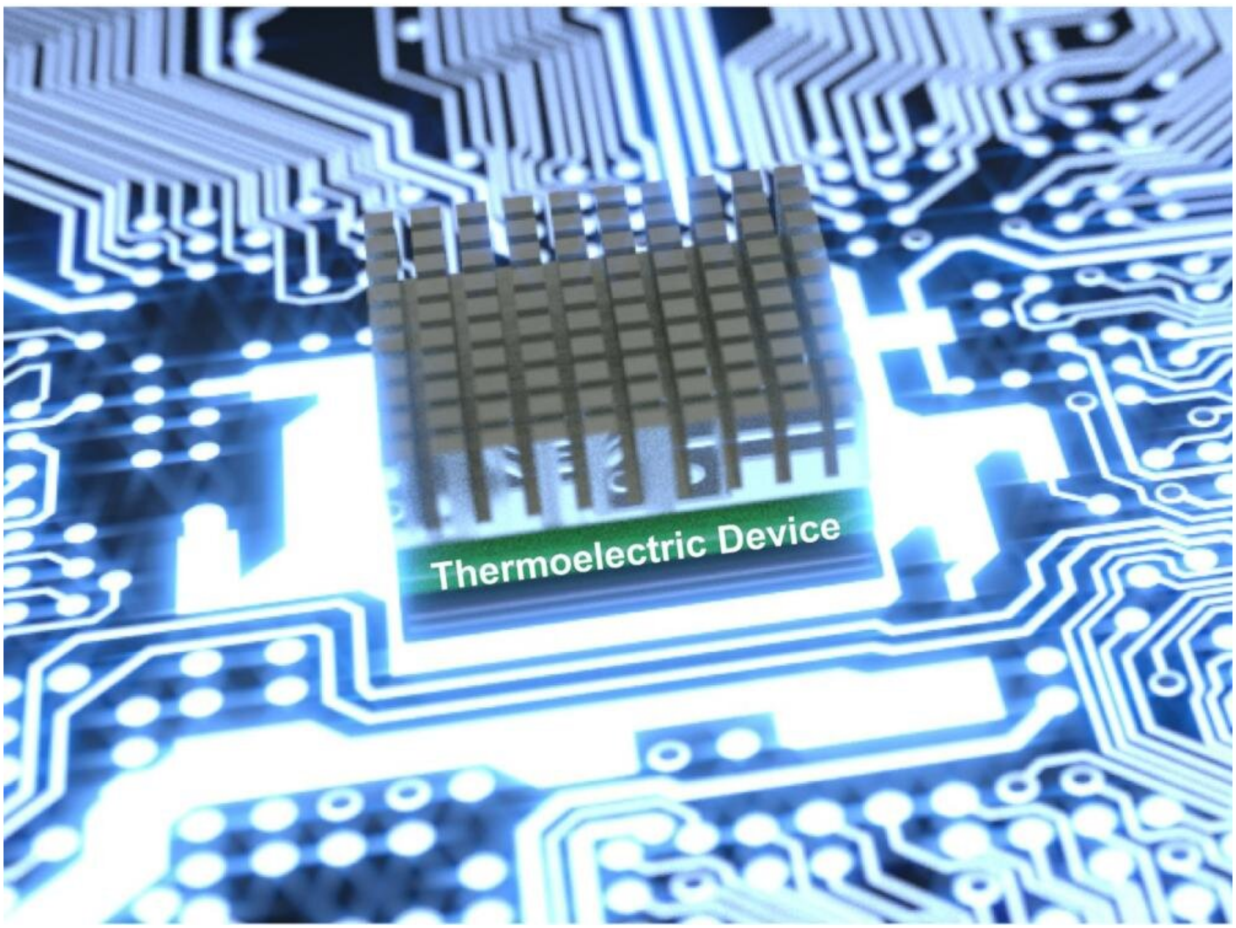

Half-Heusler materials may provide a boost in cooling power density of thermoelectric devices and provide a cooling solution for next generation of high-power electronics. Credit: Wenjie Li

Next-generation electronics will feature smaller and more powerful components that require new solutions for cooling. A new thermoelectric cooler developed by Penn State scientists greatly improves the cooling power and efficiency compared to current commercial thermoelectric units and may help control heat in future high-power electronics, the researchers said.

"Our new material can provide thermoelectric devices with very high cooling power density," said Bed Poudel, research professor in the Department of Materials Science and Engineering at Penn State. "We were able to demonstrate that this new device can not only be competitive in terms of technoeconomic measures but outperform the current leading thermoelectric cooling modules. The new generation of electronics will benefit from this development."

Thermoelectric coolers transfer heat from one side of the device to the other when electricity is applied, creating a module with cold and hot sides. Placing the cold side on electronic components that generate heat, like laser diodes or microprocessors, can pump the excess heat away and help control the temperature. But as those components become more powerful, thermoelectric coolers will also need to pump more heat, the scientists said.

The new thermoelectric device showed a 210% enhancement in cooling power density compared to the leading commercial device, made of bismuth telluride, while potentially maintaining a similar coefficient of performance (COP), or the ratio of useful cooling to energy required, the scientists reported in *Nature Communications*.

"This solves two out of the three big challenges in making thermoelectric cooling devices," said Shashank Priya, vice president for research at the University of Minnesota and a co-author on the paper. "First, it can provide a high cooling power density with a high COP. This means a small amount of electricity can pump a lot of heat. Second, for a high-powered laser or applications that require a lot of localized heat to be removed from a small area, this can provide the optimum solution."

The new device is made from a compound of half-Heusler alloys, a class of materials with special properties that show promise for energy applications like thermoelectric devices. These materials offer good strength, thermal stability and efficiency.

The researchers used a special annealing process—which deals with how materials are heated and cooled—that allowed them to modify and manipulate the microstructure of the material to remove defects. It had not been used previously to make half-Heusler thermoelectric materials, the scientists said.

The annealing process also dramatically grew the grain size of the material, leading to fewer grain boundaries—areas in a material where crystallite structures meet and that reduce electrical or thermal conductivity.

"In general, half-Heusler material has very small grain size—nano-sized grain," said Wenjie Li, assistant research professor in the Department of Materials Science and Engineering at Penn State. "Through this annealing process we can control the grain growth from the nanoscale to the microscale—a difference of three orders of magnitude."

Reducing the grain boundaries and other defects substantially enhanced carrier mobility of the material, or how electrons can move through it, yielding a higher power factor, the scientists said. The power factor determines the maximum cooling power density and is especially important in electronics-cooling applications.

"For instance, in laser diode cooling, a significant amount of heat is generated in a very small area, and it must be maintained at a specific temperature for the optimal performance of the device," Li said, "That's where our technology can be applied. This has a bright future for local high thermal management."

In addition to the high power factor, the materials produced the highest average figure of merit, or efficiency, of any half-Heusler material in the temperature range of 300° to 873° Kelvin (80 to 1,111° Fahrenheit.) The scientists said the results show a promising strategy for optimizing half-Heusler materials for near-room-temperature thermoelectric applications.

"As a country we are investing a lot in the CHIPS and Science Act, and one problem might be how the microelectronics can handle high-power density as they get smaller and operate at higher power," Poudel said. "This technology may be able to address some of these challenges."

More information: Hangtian Zhu et al, Half-Heusler alloys as emerging high power density thermoelectric cooling materials, *Nature Communications* (2023). DOI: 10.1038/s41467-023-38446-0

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