Study shows the potential of carbon nanotubes to cool electronic circuits

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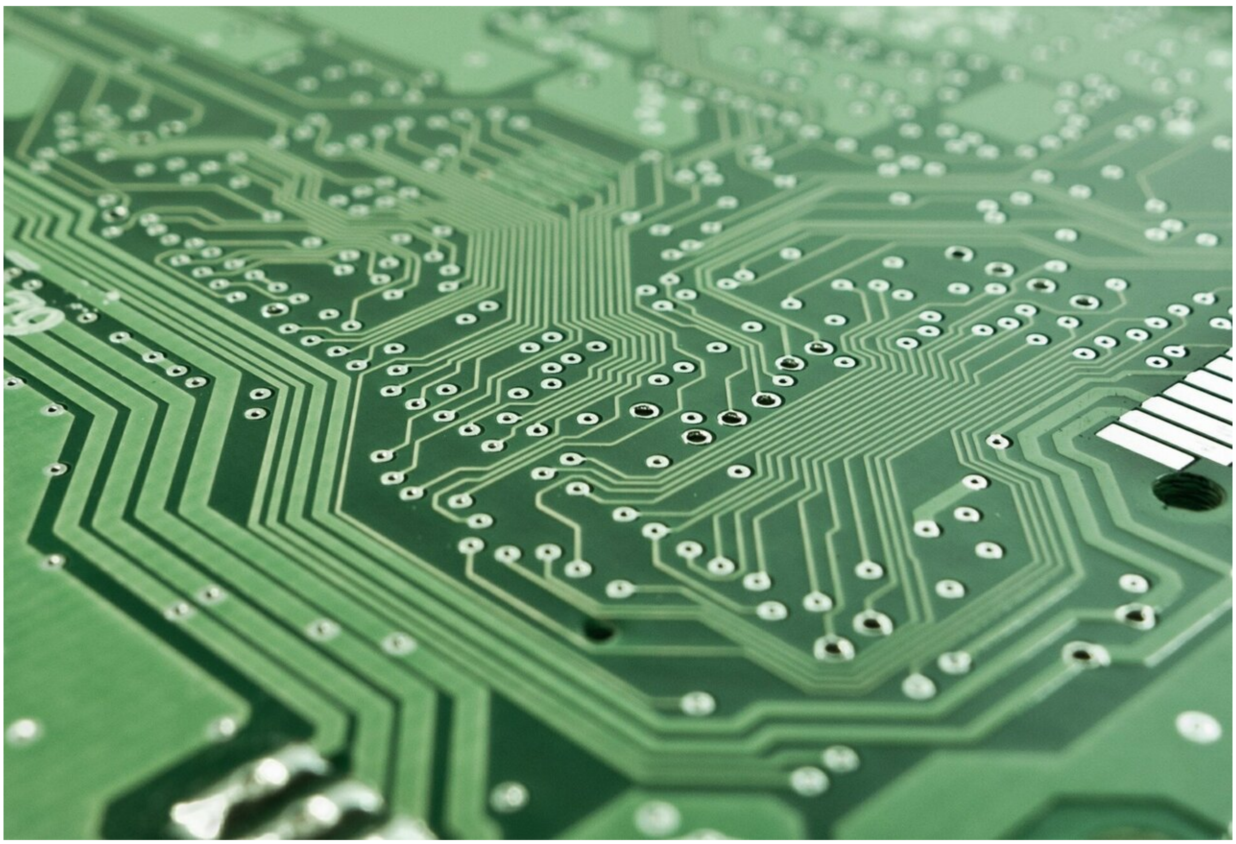

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The use of solid-state refrigerators to cool appliances and electronic devices is a possible technological application for a theoretical study conducted at the University of Campinas (UNICAMP) in São Paulo

State, Brazil.

Although this application is not considered in the study, which was based on computer simulations, such applications are on the horizon and could be an efficient and environmentally friendly alternative to vapor-compression refrigerators, which currently dominate the market and contribute to ozone depletion and global warming.

The study, led by Alexandre Fonseca with participation by his former student Tiago Cantuário, was part of the project "Carbon nanostructures: modeling and simulations," supported by São Paulo Research Foundation—FAPESP. The results are published in an article in the journal *Annalen der Physik*.

"Solid-state cooling is a young field of research with promising results. The method we investigated is based on the so-called elastocaloric effect (ECE), which makes use of temperature variations in a system in response to mechanical stress. We performed computer simulations of this effect in carbon nanotubes," Fonseca said.

In the macroscopic world, an analogous effect is observed when a rubber band warms up as it is rapidly stretched and cools down again as it is released. The effect occurs if the deformation is applied to the material so that there is no heat transfer into or out of the system, i.e., when the process is adiabatic.

"We began our research on the basis of an article entitled 'Elastocaloric effect in carbon nanotubes and graphene', published in 2016 by Sergey Lisenkov and collaborators. It described a computer simulation study showing that when a small deformation was applied to carbon nanotubes, corresponding to up to 3% of their initial length, they responded with a temperature variation of up to 30 °C," Fonseca said.

"In contrast with Lisenkov's research, which simulated only simple strain and compressive force applied to the nanotubes, we reproduced the process computationally for a complete thermodynamic cycle. In our simulation, we considered two phases—nanotube strain and release—and two heat exchanges with two external reservoirs. We estimated the heat that would be extracted by the nanotube if it was in ideal contact with a certain medium. We obtained a good result for the performance coefficient compared with those of other experimentally tested materials."

The performance coefficient is defined as the heat extracted by a system from a given region divided by the energy expended to do so. In the case of a household refrigerator, for example, it shows the amount of heat extracted by the appliance from the internal environment in proportion to the electricity consumed. The best household refrigerators have performance coefficients on the order of 8, meaning they transfer eight times more thermal energy from inside to outside than the amount of electricity extracted from the supply grid to perform the exchange.

"Simulating the process for two different nanotubes, we obtained performance coefficients of 4.1 and 6.5. These are relatively good numbers compared with those for other heat exchange phenomena," Fonseca explained.

Another advantage relates to atomic and molecular structure. "In the case of certain materials, the application of tensile strength makes the sample change phase by modifying its crystal structure. In the case of nanotubes, the thermal effect is due solely to expansion and relaxation of the structure, which is not modified. This is an advantage because phase changes make the material gradually lose its capacity to effect the function of interest. In the case of nanotubes, however, the process doesn't produce any structural transformations capable of causing defects. The atoms are separated during expansion and return to their original positions with relaxation," he said.

Nanoscale

According to Fonseca, rupture tests have shown carbon nanotubes to be capable of stretching as much as 20%. This deformation resistance combined with high performance in elastocaloric effects makes carbon nanotubes interesting materials for the development of nanoscale electronics.

"The core problem in electronics is cooling. Our motivation was imagining a device that could use a simple cycle to extract heat from an appliance. Carbon nanotubes proved highly promising," he said. "They also have another virtue, which is that they're small enough to be embedded in a polymer matrix, a desirable property at a time when manufacturers are investing in research and development to obtain flexible electronic devices such as foldable smartphones." All this is part of a larger picture in which vapor-compression refrigerators are replaced by solid-state refrigerators in the context of global climate change.

More information: Tiago E. Cantuario et al, High Performance of Carbon Nanotube Refrigerators, *Annalen der Physik* (2019). DOI: 10.1002/andp.201800502

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