Heat flow control for future nanoelectronics

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Electronic devices and their components are getting smaller and smaller. Through his doctoral research at the Department of Applied Physics in Aalto University, Tomi Ruokola has examined how the heat generated by electronic components could be controlled and utilised.

There is little research in the area of heat flows and their control. Ruokola's study tackles the basic questions of the field: how heat transfer occurs from one point to another and how this flow can be controlled in electronic circuits approaching nano-scale?

"Heat flows are considerably more difficult to control than electrical currents. Heat is pure energy, electricity on the other hand is charges that can be accurately measured. Heat flows are not directly accessible in the same way, which makes experimental research hard," explains Ruokola.

Ruokola has designed two mesoscopic—a size between macroscopic and microscopic—devices for heat transport. They are based on single-electron phenomena: the movement of single electrons through the constructed system. Electrons carry, in addition to their electrical charge, an arbitrary amount of heat.

"The smaller the scale of devices and components becomes, the more quantum level phenomena come to the fore. This requires new ideas and methods for heat transfer as well."

Together with researcher Teemu Ojanen of O.V. Lounasmaa Laboratory in Aalto University, Ruokola developed a single-electron diode, a rectifier, which allows heat to flow only in one direction and blocks the flow to the other. The idea comes from the well-known electronic component of a similar function.

"The flow between different temperatures is normally symmetric: the flow goes from a hotter point to a cooler one, as the temperatures seek to balance each other out. If we want to control the flows, we need to manipulate them to flow in the direction desired. The diodes we present are ideas for how to come up with a strongly asymmetrical heat flow."

"The diode we developed performed remarkably well compared to existing literature," says Ruokola.

Groundbreaking applications require experimental research

Ruokola tells that basic nano-level research of heat flows is severely held back by a lack of experimental setups.

"The motivation behind my research was above all the desire and need to understand the basic phenomena and control of heat transfer and flows."

If the problems in basic research and experimentation were to be solved, future applications in nanoelectronics would be outstanding.

Computers could work on heat currents instead of electricity, and the vast amount of waste heat in server farms could be captured and converted already on microchip level. Microchips smaller than a nanometre would also work in room temperature; making use of quantum level phenomena would not anymore require temperatures approaching absolute zero.

"These are of course out of reach, at least a decade, or decades, away."

Nonetheless Ruokola is intrigued by the utilisation of waste heat. As outlined in his dissertation, he built a thermoelectric heat engine, which puts waste heat energy back into work. In the engine the charge flows of electrons doing the work and the heat-transferring flows of photons can be separated from each other.

"In heat engines and waste energy, the main issue usually is the efficiency of energy use. However, when there is an abundance of waste heat, the most crucial thing is not efficiency, but rather the maximum power that can be extracted from the heat," Ruokola points out.

"As long as there is cold and a hot spot in microchip, the heat flow between them can be put back into the chip as useful work."

In the diodes the main problem is transferring large currents. In the single-electron systems built by Ruokola, the currents and power levels are of course low. Similar systems of high interaction—and with large currents—would be of great demand.

"These are the basic issues yet to be solved in heat flow control in nanoelectronics. There is still a lot do get our heads around in basic theory," believes Ruokola.

More information: Tomi Ruokola's doctoral dissertation Thermal Transport in Mesoscopic Devices: lib.tkk.fi/Diss/2012/isbn97895 … sbn9789526047157.pdf

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