Thermal computing is heating up

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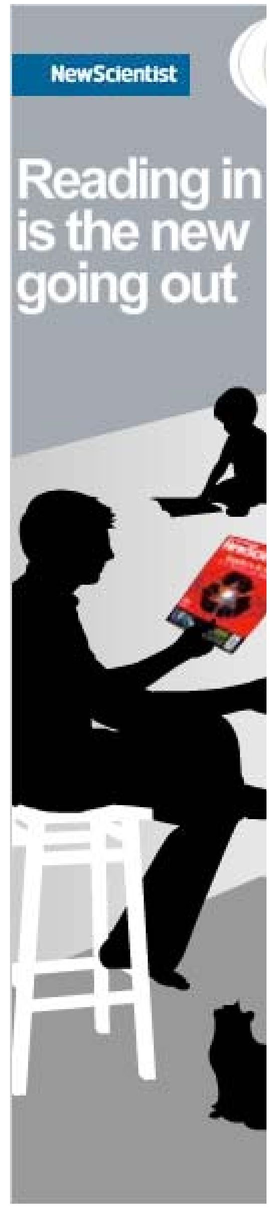

Waste heat from computers could be used to add to their processing power, say physicists working in an emerging field known as phononics. The latest advance is a design for a thermal memory device that stores data as heat, not magnetism or electricity like existing computing devices.

The search for ever-faster hardware has in recent years sent physicists and engineers exploring more complex ways to perform calculations.

Crunching data coded using photons - photonic computing - is one example, and in 2007 researchers built the first workable optical transistor. But now the idea of computing using heat flow is gaining popularity among applied physicists.

Heat travels through solid materials by means of phonons - ripples of vibration passing through a series of atoms. Those ripples can be used to send and store data in digital form: one temperature is read as 0 or "off" while a second, higher temperature is interpreted as 1 or "on". Provided that the thermal memory is well insulated, it can keep its temperature - and data - intact for a long time.

Memory trouble

However, accessing stored data by latching a thermometer onto a thermal memory is likely to either heat it up or cool it down, altering the memory being read.

So Lei Wang of the Renmin University of China in Beijing and Bao Wen Li at the National University of Singapore have come up with a design that doesn't suffer from this problem, and have tested it in simulations.

It exploits the fact that some materials can only exchange heat when they are at similar temperatures. The small memory store at the heart of their design is set to either a 1 or 0 temperature by an element that can rapidly shunt in or draw out heat. The store itself is sandwiched between two large chunks of other materials.

One of those materials is constantly hot, but can only donate heat to the memory store when that too is hot, in the 1 state. The material on the other side of the memory patch is always kept cold, but can draw heat away from the store whatever state it is in.

When the store is in its hotter state, it receives a strong flow of heat from the hot side of the sandwich, which then passes through to the cold side. The heat flow maintains the temperature of the memory patch, and reading its temperature cannot alter the flow enough to confuse the reading.

When heat is sucked out of the memory store to cool it to the 0 temperature, it can no longer receive heat from the hot material, despite the temperature difference. The cold side of the sandwich helps maintain the memory's 0 state, even when the temperature is read.

Wang and Li also have a design for a thermal logic gate - a key component of digital circuitry - which they developed in 2007 (*Physical Review Letters*, DOI: 10.1103/PhysRevLett.99.177208).

Hybrid systems

Thermal equivalents of most of the other basic components needed for computing have also been designed. Giulio Casati at the University of Insubria at Como, Italy, has created designs for a thermal rectifier, to convert digital into analogue signals (a pre-print of Casati's paper is available on the arXiv (pdf)), and more recently a design for a thermal transistor was published (*Applied Physics Letters*, DOI: 10.1063/1.2191730).

These components are only theoretical, though - the only working example is a thermal rectifier built at the University of California in Berkeley (*Science*, DOI: 10.1126/science.1132898), and no one is exactly sure how and why it works.

Casati remains cautious about the immediate future of phononics. "Thermal memory is possible in principle, but it would be a mistake to think that we will have such things actually working in the short term," he says. "The main problem is the gap between theory and experiments."

Casati says practical physicists must rise to the challenge set by the theorists. Yet even if they can, phononic computing is unlikely to threaten electronics because phonons travel a lot slower than electrons. Li imagines that the two technologies will work together, in hybrid devices that perform some computation using waste heat.

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