Turning heat to electricity... efficiently

18 November 2009, by David L. Chandler

(PhysOrg.com) -- In everything from computer processor chips to car engines to electric powerplants, the need to get rid of excess heat creates a major source of inefficiency. But new research points the way to a technology that might make it possible to harvest much of that wasted heat and turn it into usable electricity.

That kind of waste-energy harvesting might, for example, lead to cellphones with double the talk time, laptop computers that can operate twice as long before needing to be plugged in, or power plants that put out more electricity for a given amount of fuel, says Peter Hagelstein, co-author of a paper on the new concept appearing this month in the Journal of Applied Physics.

Hagelstein, an associate professor of electrical engineering at MIT, says existing solid-state devices to convert heat into electricity are not very efficient. The new research, carried out with graduate student Dennis Wu as part of his doctoral thesis, aimed to find how close realistic technology could come to achieving the theoretical limits for the efficiency of such conversion.

Theory says that such energy conversion can never exceed a specific value called the Carnot Limit, based on a 19th-century formula for determining the maximum efficiency that any device can achieve in converting heat into work. But current commercial thermoelectric devices only achieve about one-tenth of that limit, Hagelstein says. In experiments involving a different new technology, thermal diodes, Hagelstein worked with Yan Kucherov, now a consultant for the Naval Research Laboratory, and coworkers to demonstrate efficiency as high as 40 percent of the Carnot Limit. Moreover, the calculations show that this new kind of system could ultimately reach as much as 90 percent of that ceiling.

Hagelstein, Wu and others started from scratch rather than trying to improve the performance of existing devices. They carried out their analysis using a very simple system in which power was generated by a single quantum-dot device — a type of semiconductor in which the electrons and holes, which carry the electrical charges in the device, are very tightly confined in all three dimensions. By controlling all aspects of the device, they hoped to better understand how to design the ideal thermal-to-electric converter.

Hagelstein says that with present systems it’s possible to efficiently convert heat into electricity, but with very little power. It’s also possible to get plenty of electrical power — what is known as high-throughput power — from a less efficient, and therefore larger and more expensive system. “It’s a tradeoff. You either get high efficiency or high throughput,” says Hagelstein. But the team found that using their new system, it would be possible to get both at once, he says.

A key to the improved throughput was reducing the separation between the hot surface and the conversion device. A recent paper by MIT professor Gang Chen reported on an analysis showing that heat transfer could take place between very closely spaced surfaces at a rate that is orders of magnitude higher than predicted by theory. The new report takes that finding a step further, showing how the heat can not only be transferred, but converted into electricity so that it can be harnessed.

A company called MTPV Corp. (for Micron-gap Thermal Photo-Voltaics), founded by Robert DiMatteo SM ’96, MBA ‘06, is already working on the development of “a new technology closely related to the work described in this paper,” Hagelstein says.

DiMatteo says he hopes eventually to commercialize Hagelstein’s new idea. In the meantime, he says the technology now being developed by his company, which he expects to have on the market next year, could produce a tenfold improvement in throughput power over existing photovoltaic devices, while the further advance described in this new paper could make an additional tenfold or greater improvement possible. The work described in this paper “is potentially a major finding,” he says.

DiMatteo says that worldwide, about 60 percent of all the energy produced by burning fuels or generated in powerplants is wasted, mostly as excess heat, and that this technology could “make it possible to reclaim a significant fraction of that wasted energy.”

When this work began around 2002, Hagelstein says, such devices “clearly could not be built. We started this as purely a theoretical exercise.” But developments since then have brought it much closer to reality.

While it may take a few years for the necessary technology for building affordable quantum-dot devices to reach commercialization, Hagelstein says, “there’s no reason, in principle, you couldn’t get another order of magnitude or more” improvement in throughput power, as well as an improvement in efficiency.

“There’s a gold mine in waste heat, if you could convert it,” he says. The first applications are likely to be in high-value systems such as computer chips, he says, but ultimately it could be useful in a wide variety of applications, including cars, planes and boats. “A lot of heat is generated to go places, and a lot is lost. If you could recover that, your transportation technology is going to work better.”

More information: "Quantum-coupled single-electron thermal to electric conversion scheme" by D. M. Wu, P. L. Hagelstein, P. Chen, K. P. Sinha,3 and A. Meulenberg, in *Journal of Applied Physics*, published online Nov. 13, 2009, link.aip.org/link/?JAPIAU/106/094315/1

Provided by Massachusetts Institute of Technology (news : web)