Discovery Captures, Converts Heat

April 6 2005

Your car's engine loses 70 percent of its energy as waste heat-but Australian and Oregon scientists may have figured out an efficient way not only to recover that lost energy, but to at long last capture the power-producing potential of geothermal heat.
The trick is to convert it to electricity-and a promising way to accomplish this, the researchers have discovered, involves using extremely thin nanowires to potentially more than double the efficiency of thermoelectric materials.

"If all goes well, nanostructured thermoelectric devices may be practical for applications such as recycling of waste heat in car engines, on-chip cooling of computer microprocessors and silent, more compact domestic refrigerators," says Heiner Linke, a University of Oregon assistant professor of physics associated with ONAMI, the Oregon Nanoscience and Microtechnologies Institute.

Linke and Tammy Humphrey, an Australian Research Council fellow currently visiting the University of California at Santa Cruz, presented their findings on Tuesday, April 5, at the Nanoscale Devices and System Integration Conference in Houston. A review of their study in the online version of the journal Nature Materials described their results as "dramatic" and "a phenomenal enhancement relative to current bulk thermoelectrics."

The pair discovered that two objects can have different temperatures yet still be in equilibrium with each other at the nanoscale-a fact that may blow right past a non-physicist but which is crucial in order to attain the kind of performance needed for widespread application of thermoelectric technology in power generation and refrigeration.

Imagine a hot cup of coffee sitting on a bench. The coffee will quickly cool because molecules in the cup spontaneously ferry heat from hot to cold in a rush to reach equilibrium with the temperature of the bench. The same effect happens with electrons in the materials studied by Humphrey and Linke. In physics, this is the law of thermodynamics: that heat will always flow from hot to cold. Of course, the energy expended by those electrons is normally lost.

Thermoelectric materials try to recover this energy by converting it to electricity, but they don't work very well if the flow of heat is uncontrolled. The breakthrough presented by Humphrey and Linke involves controlling the motion of electrons using materials that are structured on the nanoscale.

"The idea is to play one type of non-equilibrium (the temperature difference) against another one," Linke explains.

Humphrey and Linke have shown that if an electrical voltage is applied to an electrical system in addition to a temperature difference, it is possible to harness electrons having a specific energy. This means that if a nanostructured material is designed to only allow electrons with this particular energy to flow, a novel type of equilibrium is achieved in which electrons do not spontaneously ferry heat from hot to cold.

"This delicate balance may have huge practical importance because it means that thermoelectric devices, which use electrical contact between hot and cold regions in a semiconductor to transform heat into useful electrical energy, can be operated near equilibrium," says Humphrey. "This is a key requirement for cranking up their efficiency toward the Carnot limit, the maximum efficiency possible for any heat engine."

Because the system is in a state of equilibrium, the flow of electrons is reversible, Humphrey explains, noting that reversibility allows the device to reach maximum possible efficiency.

Until now, the efficiency of such devices, which have no moving parts and can be small enough to fit on a microchip, has been too low (less than 15 percent of the Carnot limit for power generation) for use in all but a few specialized applications.

However, Linke and Humphrey say implementation of their design principle is possible by tailoring the electronic bandstructure in state-of-the-art thermoelectric materials made up of a huge number of nanowires. If all goes well, nanostructured thermoelectric devices with efficiencies close to 50 percent of the Carnot limit may be realized, Linke says.

Such materials could make possible the generation of electricity from geothermal sources-or from the waste heat of engines in hybrid cars, he explains.

Source: University of Oregon