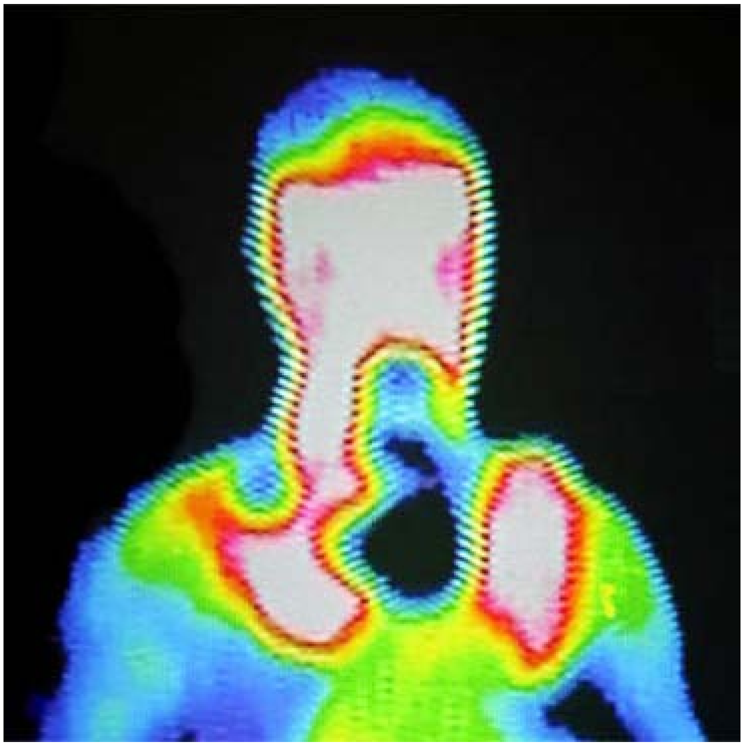
Self-powered sensors



Harvesting electricity from small temperature differences could enable a new generation of electronic devices that don't need batteries

David L. Chandler, MIT News Office

February 11, 2010

This is the first of a two-part series about MIT research on harnessing micro-sources of power.

It can be inconvenient to replace batteries in devices that need to work over long periods of time. Doctors might have to get beneath a patient's skin to replace batteries for implanted biomedical monitoring or treatment systems. Batteries used in devices that monitor machinery, infrastructure or industrial installations may be crammed into hard-to-reach nooks or distributed over wide areas that are often difficult to access.

But new technology being developed by MIT researchers could make such replacements unnecessary.

Soon, such devices could be powered just by differences in temperature between the body (or another warm object) and the surrounding air, eliminating or reducing the need for a battery. They would use new energy-scavenging systems being developed by Anantha Chandrakasan, MIT's Joseph F. and Nancy P. Keithley Professor of Electrical Engineering and director of the MIT Microsystems Technology Laboratories, and Yogesh Ramadass SM '06, PhD '09.

Such a system, for example, could enable 24-hour-a-day monitoring of heart rate, blood sugar or other biomedical data, through a simple device worn on a patient's arm or a leg and powered by the body's temperature (which, except on a 98.6-degree F summer day, would always be different from the surrounding air). A similarly powered system could monitor the warm exhaust gases in the flues of a chemical plant, or air quality in the ducts of a heating and ventilation system.

The concept of harvesting energy from differences in temperature is nothing new. Many technologies for doing so have been developed, including devices NASA has used to power probes sent into deep space (the probes harvest heat from radioactive plutonium). Certain semiconductor materials, by their nature, will produce a flow of electrical current when one side is hotter than the other — or, conversely, will produce a difference in temperature when a current is run through them. Such materials are already used for solid-state coolers and heaters for food or beverages.

The principle was discovered in the 19th century, but only in recent years has it been seriously explored as an energy source. In thermoelectric materials, as soon as there is a temperature difference, heat begins to flow from the hotter to the cooler side. In the process, at the atomic scale this heat flow propels charge carriers (known as electrons or electron holes) to migrate in the same direction, producing an electric current — and a voltage difference between the two sides.

The key to making this principle practical for low-powered devices is to harness as much as possible of the available energy. Chandrakasan and Ramadass have been working to get as close as possible to the theoretical limits of efficiency in tapping this heat energy.

The higher the temperature difference, the greater the potential for producing power, and most such power-generating devices are designed to exploit differences of tens to hundreds of degrees C. The unique aspect of the new MIT-developed devices is their ability to harness differences of just one or two degrees, producing tiny (about 100 microwatts) but nevertheless usable amounts of electric power. The key to the new technology is a control circuit that optimizes the match between the energy output from the thermoelectric material and the storage system connected to it, in this case a storage capacitor. The findings were presented this week at the International Solid State Circuits Conference in San Francisco.

Because thermoelectric systems rely on a difference in temperature between one side of the device and the other, they are not usable for implanted medical devices, where they would be in a uniform-temperature environment. The present experimental versions of the device require a metal heat-sink worn on an arm or leg, exposed to the ambient air. “There’s work to be done on miniaturizing the whole system,” Ramadass says. This might be accomplished by combining and simplifying the electronics and by improving airflow over the heat sink.

Ramadass says that as a result of research over the last decade, the power consumption of various electronic sensors, processors and communications devices has been greatly reduced, making it possible to power such devices from very low-power energy harvesting systems such as this wearable thermoelectric system.

David Lamb, chief operating officer of Camgian Microsystems, a company that produces a variety of low-power, lightweight semiconductor chips, says that “we believe the wireless sensor products we are developing will all migrate to energy harvesting, as we push their size, weight and power down.” He adds that the research of Chandrakasan and Ramadass “is in the critical path of technologies required by companies such as Camgian that are developing next-generation microsystems.”

Devices to use this power would in most cases still need some energy storage system, so that the constant slow trickle of energy could be accumulated and used in short bursts, for example to operate a transmitter to send data readings back to a receiver. Different ways of storing the energy are possible, such as the use of ultracapacitors, Ramadass says. “These will play a critical role, in order to build a complete energy harvesting system,” he says.

After years of work on these highly efficient energy-scavenging devices, currently funded by a seed grant from the MIT Energy Initiative, Chandrakasan says, “the time has come to find the real applications and realize the vision."