New device may make converting waste heat to electricity industrially competitive

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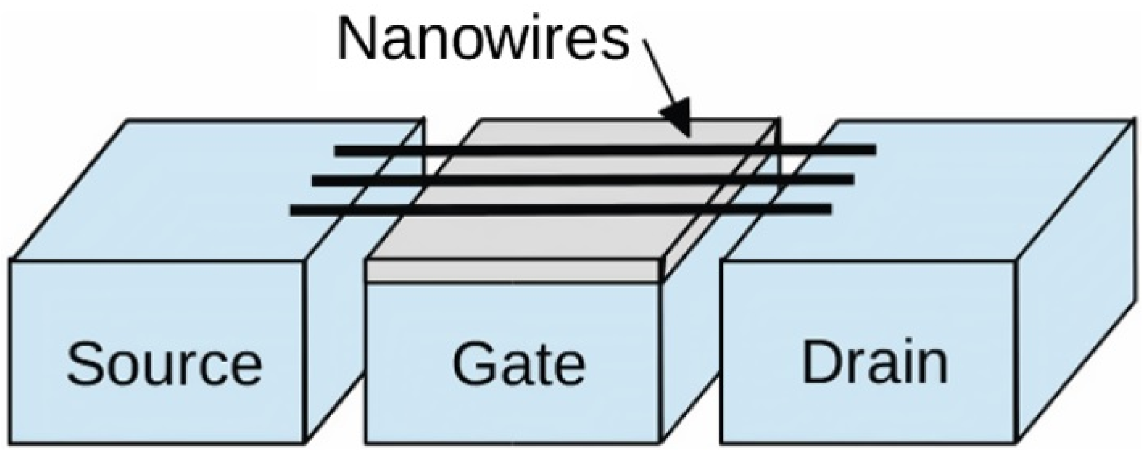

The proposed thermoelectric device consists of many parallel nanowires with an external gate voltage that can be tuned to optimize the efficiency and power output for different temperature differences between the leads and different loads. Credit: Muttalib and Hershfield. ©2015 American Physical Society

(Phys.org)—Currently, up to 75% of the energy generated by a car's engine is lost as waste heat. In theory, some of this waste heat can be converted into electricity using thermoelectric devices, although so far the efficiency of these devices has been too low to enable widespread commercialization.

Now in a new study, physicists have demonstrated that a thermoelectric device made of nanowires may achieve a high enough efficiency to be industrially competitive, potentially leading to improvements in fuel economy and other applications.

The scientists, Khandker A. Muttalib and Selman Hershfield, both physics professors at the University of Florida in Gainesville, have published a paper on the new thermoelectric device in a recent issue of *Physical Review Applied*.

In addition to recovering energy from the waste heat in combustion engines in vehicles, thermoelectric devices could also perform similar functions in the engines of ships, as well as in power plants, manufacturing refineries, and other places that produce large amounts of waste heat.

In their paper, the scientists explain that using bulk materials in thermoelectric devices has turned out to be inherently inefficient, but nanoengineered materials appear to be more promising. The new device consists simply of two large leads at different temperatures connected by several noninteracting, very thin nanowires. Each nanowire transmits current from the hotter lead to the colder lead, and many nanowires in parallel can scale the power up to high levels.

One of the biggest challenges facing thermoelectric devices is that the conditions that optimize a device's efficiency and power output are different for different temperature gradients between the two leads as well as for different electrical loads (how much power is being consumed at a given moment). Because of this complexity, the optimum device for a particular temperature gradient and load may not work nearly as well for a different temperature gradient or load.

The researchers here found a way around this issue by applying a voltage to the nanowires, which allows power to be transmitted along the nanowires only at energies above a certain value. This value depends on the temperature gradient and the load, which vary, but the applied voltage can also be varied in order to tune the power transmission and simultaneously optimize the device's power and efficiency.

Using nanowires to connect the leads also has a practical advantage compared to using other materials. While many other candidate materials are difficult to manufacture reliably, nanowires can be manufactured reliably and controllably, which is important for realizing the precise optimum dimensions.

Although the physicists' theoretical analysis suggests that the proposed device could have significant performance advantages over current devices, they caution that it's too early to make any definite estimates.

"Any estimate at this point is going to be unreliable because there are so many ways to lose heat in any practical device that our theoretical proposal does not take into account," Muttalib told *Phys.org*. "Even then, we gave a very crude estimate in our paper where both the efficiency and power output can be tuned (with a gate voltage) to be significantly larger than any commercial device currently available. Note that there are other theoretical proposals with large efficiency but without sufficient power, and therefore not practically usable."

Most importantly, the physicists hope that the new ideas presented here may inspire new ways of thinking about thermoelectric technology.

"Perhaps the greatest significance is a possible shift in paradigm in the design of thermoelectric devices," Muttalib said. "Currently, the focus of the community is overwhelmingly in the so-called 'linear response' regime (where the temperature and the voltage gradients across the material connecting the hot and the cold leads are small); the performance of such devices depends solely on the properties of the connecting material. This has kept the current efforts limited to finding or designing a 'good' thermoelectric material. Our work suggests that, in the 'non-linear' regime, the performance of the device also depends crucially on the parameters of the leads and the loads; the optimization of performance in such cases has many more interesting possibilities to be explored."

Although this work offers many new possible directions for future research, Muttalib and Hershfield hope that it will be other scientists who move the technology forward.

"We are both theoretical physicists doing research in basic sciences, and in particular we are not experts in device technology," Muttalib said. "We stumbled upon the current idea while trying to understand the effects of non-linear response on electron transport in nano systems. We hope that experimentalists and device engineers will find our work interesting and will pursue it to build an actual device. Our next plan in this general area is to understand, again at a very fundamental theoretical level, the effects of phonons or lattice vibrations in nano systems in general; these effects are known to be important for thermoelectric devices as well."

The nanowire-based thermoelectric device isn't the only new thermoelectric design to appear recently. In the same issue of *Physical Review Applied*, Riccardo Bosisio, et al., at Service de Physique de l'Etat Condensé in France have developed a thermoelectric device in which the electrons travel through the nanowires by "phonon-assisted hopping," where the phonons are vibrations that carry heat.

More information: K. A. Muttalib and Selman Hershfield. "Nonlinear Thermoelectricity in Disordered Nanowires." *Physical Review Applied*. DOI: 10.1103/PhysRevApplied.3.054003