'Power Felt' uses body heat to generate electricity

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The flexible, lightweight CNT/polymer thermoelectric fabric contains hundreds of alternating layers of conducting and insulating material. Image credit: Hewitt, et al. ©2012 American Chemical Society

(PhysOrg.com) -- Among the many applications of flexible thermoelectric materials is a wristwatch powered by the temperature difference between the human body and the surrounding environment. But if you wanted this watch made of low-cost carbon nanotube (CNT)/polymer materials, you would currently need a piece of fabric with an area of about 500 cm^2, which is about 50 times greater than the area of a typical wristwatch.

In order to make such applications more practical, a team of researchers has developed a new multi-layer CNT/polymer design and demonstrated that it has a greatly increased power output compared to previous designs. The new CNT/polymer, which the researchers call "Power Felt," also has the potential to be much less expensive than other thermoelectric materials.

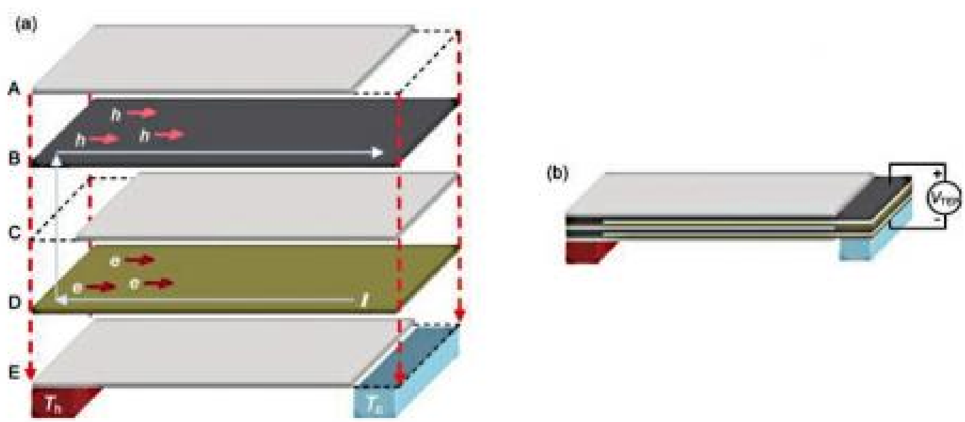
The research team, which includes Ph.D. student Corey Hewitt and Professor David Carroll from Wake Forest University, along with collaborators from other institutions, has published a paper on the new thermoelectric fabric design in a recent issue of *Nano Letters*.

Although thermoelectrics have been studied and used commercially for several decades, they're traditionally made of inorganic materials, such as bismuth telluride (Bi_2Te_3). But recent research has shown that organic materials could provide a promising alternative, with advantages such as low cost, ease of production, and flexibility. Yet for now, organic materials still lag behind inorganic ones in terms of performance.

One of the keys for designing a high-performance thermoelectric fabric is creating a large temperature difference on opposite sides of the material. Since CNT/polymer thermoelectric materials are very thin, the temperature difference perpendicular to the film's surface is limited.

To address this problem, the researchers here designed a multi-layer CNT/polymer film that allows for the arrangement of the temperature gradient parallel to the film's surface. The film consists of up to hundreds of alternating layers of conducting material (a polymer containing CNTs) and insulating material (pure polymer) bonded together. Each layer has a thickness of just 25-40 μm. When the fabric is subject to a temperature difference parallel to the surface, electrons or holes travel from the hot side to the cold side due to the Seebeck effect, which converts temperature difference into voltage.

As the researchers explain, the amount of generated voltage (and total power output) is equal to the sum of contributions from each layer. So adding layers to the fabric is equivalent to adding voltage sources in series, and the number of layers is limited only by the heat source's ability to produce a sufficient change in temperature throughout all the layers. Here, the heat source's temperature is limited to 390 K (117 °C, 242 °F), the point at which the polymer begins deforming.



When the multi-layer fabric is exposed to a temperature gradient, charge carriers (electrons or holes) travel from the hot side to the cold side due to the Seebeck effect. The resulting voltage can be read across the ends of the first and last conduction layers. Image credit: Hewitt, et al. ©2012 American Chemical Society

Experiments on a 72-layer fabric demonstrated a maximum power generation of 137 nW at a temperature difference of 50 K. But the researchers predict that the power output can be increased; for example, they calculate that a 300-layer fabric exposed to a 100 K temperature difference has a theoretical power output of up to 5 μW.

From another perspective, the wristwatch mentioned above would require much less fabric than the current requirement of 500 cm^2.

"As presented, the areal requirement of our fabric is on the order of approximately 10 cm^2," Carroll told *PhysOrg.com*. "However, the point of the paper is to show that the fabric's layers add somewhat linearly. This means that, as more layers are woven into the fabric (and these can be extraordinarily thin layers), the more power can be packed into a smaller area. So the fabric we show simply demonstrates this fact but doesn't optimize it. Thus, it may take 10 cm^2 of the fabric we show, but we have also made fabrics for which only a few cm^2 could power the watch. And we could go further."

In terms of cost, if CNT/polymer thermoelectrics are produced on a large scale, the electricity they generate could cost as little as $1 per watt due to the low material cost and ease of production. In contrast, Bi_2Te_3 thermoelectrics currently generate electricity at a cost of about $7 per watt. As Carroll explained, the true test of the materials will be cost.

"What is different in what we have done is to produce something in a form factor that allows for the application of large areas of the materials," he said. "Thus, large amounts of power can be generated and, as long as the cost is low, then the $/W is competitive with other forms of energy capture. Of course this would not be possible without two major innovations in the paper. The first, as I have already pointed out, is the origami-like folding of the fabric that allows for the interlayers to add their power together. The second pertains to that 'cost' thing. Notice that we do not use pure carbon nanotube mats. Rather, our mats are primarily commodity polymers with nanotubes added. Thus the cost of the expensive element is kept to a minimum without sacrificing the overall performance."

The researchers predict that low-cost organic thermoelectric fabrics could have a multitude of applications. Besides the wristwatch, another wearable application could be winter jackets with thermoelectric inside liners that use the temperature difference between body heat and the outdoor temperature to power electronic devices, such as an iPod.

Other potential applications include recapturing a car's wasted heat energy in order to improve fuel mileage, and lining a vehicle's seats with the fabric to provide electricity for the vehicle's battery. If installed under roof shingles, the fabric could generate electricity on hot days to help lower a building's electricity bills. And in emergencies, the fabric could potentially be used to power a cell phone or flashlight.

"There are a very wide variety of applications for which these materials will now be perfectly adequate [with their current power output]," Carroll said. "Furthermore, if more power is required, there is the option of simply making larger sheets of fabric. Because of the cost advantages, this is still cheaper than going to more expensive Bi_2Te_3. Imagine, for instance, putting this material throughout the bodies of automobiles, supplying both sound dampening (which they must already do) and adding the functionality of power scavenging for only a nominal cost above the materials used currently. As with all organic electronics, the real transformative power of this innovation lies in its economic vs. technical advantages."

In the future, the researchers plan to further improve the power output of each film, using methods such as chemical treatment of the CNTs and increasing the electrical conductivity of the polymers.

"Will we improve the performance? YES!" Carroll said. "We have already begun making significant advances in improving the overall power output and there is much more ground to cover. For you physics readers out there, the basic principle of suppressed phonon modes through scattering processes, coupled with fractal networks made of sections of phase coherent transport, is still young and we are confident we have not yet tapped into the real potential yet."

More information: Corey A. Hewitt, et al. "Multilayered Carbon Nanotube/Polymer Composite Based Thermoelectric Fabrics." *Nano Letters*, Article ASAP. DOI: 10.1021/nl203806q