

Cellulose ion trap turns heat into electricity

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Researchers are harnessing the nanofibrous structure of cellulose to trap ions, creating a system that converts low-grade heat into useful electricity [Li et al., *Nature Materials* (2019), <https://doi.org/10.1038/s41563-019-0315-6>]. The team from the University of Maryland College Park, University of Colorado, and University of British Columbia believe that the naturally hierarchical alignment of nanofibers within wood could make interesting heat-harvesting materials.

To make such materials, chemical treatments are used to remove the lignin and hemicellulose components of wood, leaving an all-cellulose scaffold. Then a second chemical treatment stage transforms the cellulose structure from type I to type II, to make ion movement within the scaffold easier. Finally, the treated nanofibrous cellulose membrane is infused with a high concentration NaOH electrolyte solution (Fig. 1).

“The role of the cellulosic membrane is to provide confinement with negative surface charge,” explains Liangbing Hu of the University of Maryland College Park, who led the effort. “The scale of confinement is extremely important. When ions are transported within such a small confined region, their interactions with each other, water, and the channel walls become critical.”

The system simply comprises the electrolyte-infused cellulosic membrane sandwiched between two platinum (Pt) electrodes (Fig. 2). When the material is exposed to a temperature difference of 5.5 °C, the diffusion of the ions within the cellulose scaffold charges up the membrane in just over a minute. The difference in mobility of the Na⁺ and OH⁻ ions leads to a separation between the two ions, producing a voltage.

“We utilized, for the first time, the low dimensional confinement inside cellulose for enhanced ion selectivity,” says Hu. “This effect is exemplified in the increased voltage signal observed under a thermal gradient.”

The idea of using an electrolyte to generate a voltage under a temperature gradient is not new, points out Hu, but he and his team have found a way of enhancing ion selectivity and the resulting thermoelectric signal. Moreover, as the system is based on wood, it should be easy to scale up. The demonstration membrane fabricated by the researchers is 10 × 10 cm² and still retains its flexibility.

Currently, the material works rather like a capacitor – charging up and discharging. This limits the ability of the system to produce a continuous signal. However, Hu believes that if the electrodes were designed to facilitate a redox reaction, this would serve to extract continuous electrical power from the system.

“In the future, continuous operation is the next step,” he says. “We will continue optimizing the performance of this type of device and look into the new ion transport phenomenon.”

Eventually, the findings could lead to wood-based, flexible, lightweight, and biocompatible ionic conductors for a range of temperature sensing or low-grade thermal energy harvesting applications.

Andres Cantarero of the University of Valencia in Spain believes the work represents an advance in the field of thermoelectricity.

“Although we have to advance our knowledge of the fundamental parameters of the nanofibers fabricated in this work, the fact that

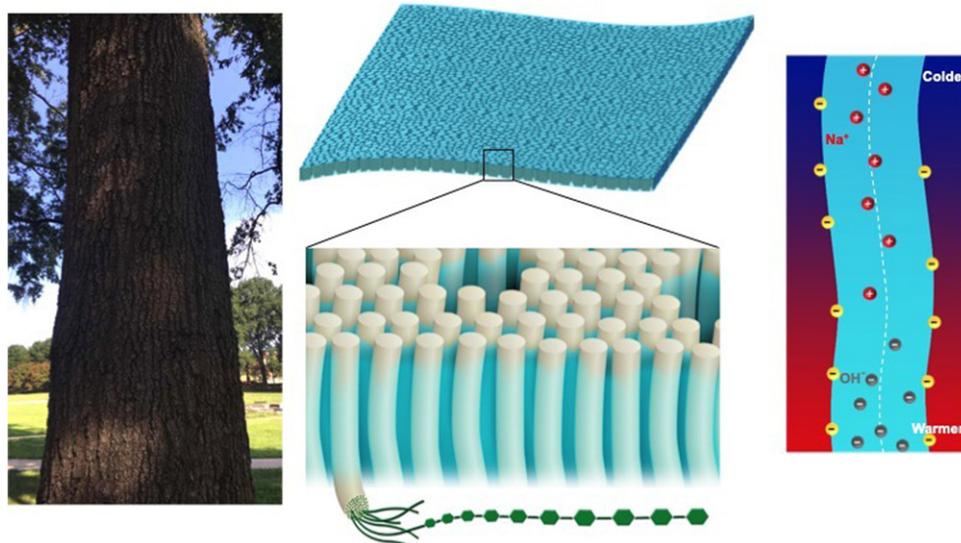


Fig. 1. Schematic of the aligned cellulose nanofiber ionic conductor: (left) cellulose fibers are naturally aligned in the tree growth direction; (middle) cellulose has a hierarchical alignment, with the fibers consisting of aligned molecular chains; (right) ionic device after infiltrating with electrolyte showing that under a thermal bias the surface charged nanofiber regulate ionic movement.

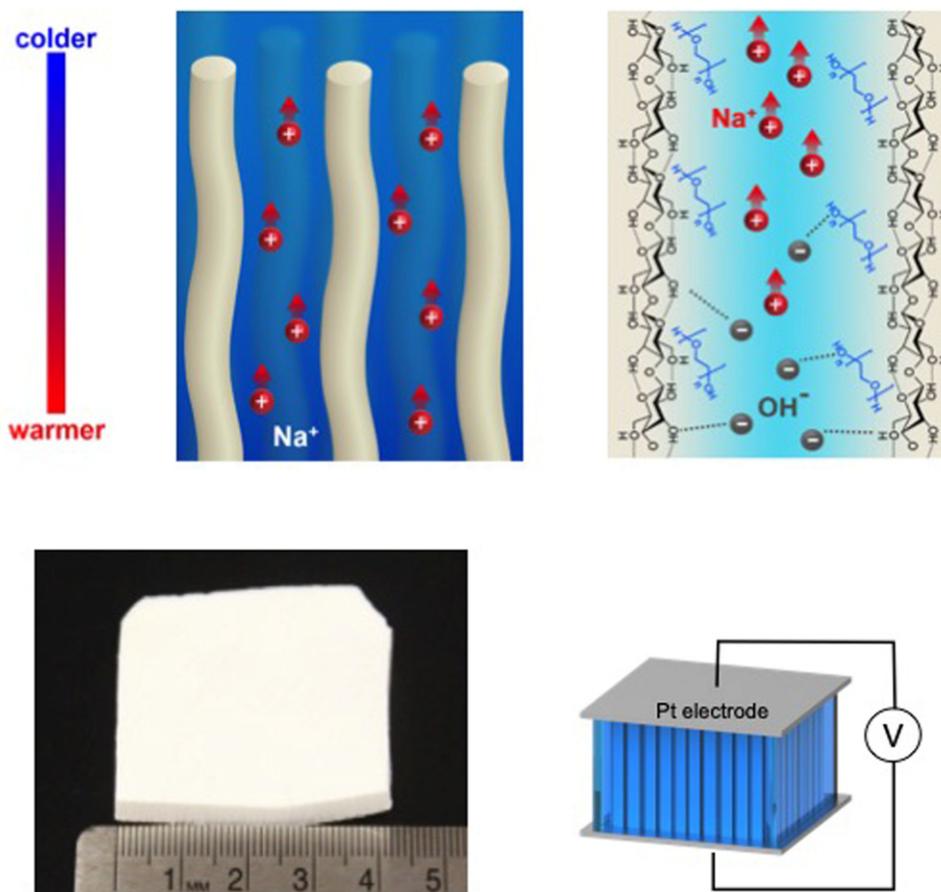


Fig. 2. (Bottom) Photo and schematic of cellulosic membrane in testing set up; (top) Schematic of the ion mobility and cellulosic membrane selectivity arising from the nanochannels formed in between the cellulose nanofibers.

the chemical process is scalable, easy to carry out, and that wood is readily available makes this work a pioneering work in the field of organic thermoelectrics,” he told *Nano Today*. “The main novelty is that there is bipolar transport in one direction inside the fibers and in the opposite direction outside.”

While thermoelectricity is only starting to emerge as an approach to energy harvesting, says Cantarero, if excess heat from cars, air conditioners, roads, or even solar cells could be collected, thermoelectric devices could have a promising future.

“Despite many unknown parameters, the nanomaterial fabricated in this work could have unbelievable thermoelectric applications,” he suggests. Mathias Dietzel of Technische Universität Darmstadt in Germany agrees that the study is highly promising and relevant. “It aims to develop waste heat recovery units that are not

only efficient but also based on (relatively) simple physics so that they are robust and can be fabricated at large scale as well as low cost. Using the natural structure of wood for this purpose is remarkable, as it also has a beneficially low thermal conductivity.” While he believes that the Seebeck coefficients reported in the work are outstanding – exceeding even conventional thermoelectric devices based on semiconductor materials – Dietzel cautions that the system might not yet be fully understood and mechanisms other than those described by the research could also be contributing significantly.

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