New method found for controlling conductivity

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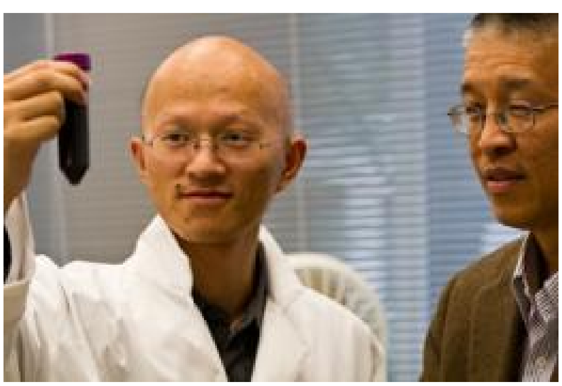
An artistic rendering of the suspension as it freezes shows graphite flakes clumping together to form a connected network (dark spiky shapes at center), as they are pushed into place by the crystals that form as the liquid hexadecane surrounding them begins to freeze. Image: Jonathan Tong

A team of researchers at MIT has found a way to manipulate both the thermal conductivity and the electrical conductivity of materials simply by changing the external conditions, such as the surrounding temperature. And the technique they found can change electrical conductivity by factors of well over 100, and heat conductivity by more than threefold.

"It's a new way of changing and controlling the properties" of materials — in this case a class called percolated composite materials — by controlling their temperature, says Gang Chen, MIT's Carl Richard Soderberg Professor of Power Engineering and director of the Pappalardo Micro and Nano Engineering Laboratories. Chen is the senior author of a paper describing the process that was published online on April 19 and will appear in a forthcoming issue of *Nature Communications*. The paper's lead authors are former MIT visiting scholars Ruiting Zheng of Beijing Normal University and Jinwei Gao of South China Normal University, along with current MIT graduate student Jianjian Wang. The research was partly supported by grants from the National Science Foundation.

The system Chen and his colleagues developed could be applied to many different materials for either thermal or electrical applications. The finding is so novel, Chen says, that the researchers hope some of their peers will respond with an immediate, "I have a use for that!"

One potential use of the new system, Chen explains, is for a fuse to protect electronic circuitry. In that application, the material would conduct electricity with little resistance under normal, room-temperature conditions. But if the circuit begins to heat up, that heat would increase the material's resistance, until at some threshold temperature it essentially blocks the flow, acting like a blown fuse. But then, instead of needing to be reset, as the circuit cools down the resistance decreases and the circuit automatically resumes its function.



Graduate student Jianjian Wang holds a flask containing the suspension of graphite flakes in hexadecane, as Gang Chen looks on. Photo: Melanie Gonick

Another possible application is for storing heat, such as from a solar thermal collector system, later using it to heat water or homes or to generate electricity. The system's much-improved thermal conductivity in the solid state helps it transfer heat.

Essentially, what the researchers did was suspend tiny flakes of one material in a liquid that, like water, forms crystals as it solidifies. For their initial experiments, they used flakes of graphite suspended in liquid hexadecane, but they showed the generality of their process by demonstrating the control of conductivity in other combinations of materials as well. The liquid used in this research has a melting point close to room temperature — advantageous for operations near ambient conditions — but the principle should be applicable for high-temperature use as well.

The process works because when the liquid freezes, the pressure of its forming crystal structure pushes the floating particles into closer contact, increasing their electrical and thermal conductance. When it melts, that pressure is relieved and the conductivity goes down. In their experiments, the researchers used a suspension that contained just 0.2 percent graphite flakes by volume. Such suspensions are remarkably stable: Particles remain suspended indefinitely in the liquid, as was shown by examining a container of the mixture three months after mixing.

By selecting different fluids and different materials suspended within that liquid, the critical temperature at which the change takes place can be adjusted at will, Chen says.

"Using phase change to control the conductivity of nanocomposites is a very clever idea," says Li Shi, a professor of mechanical engineering at the University of Texas at Austin. Shi adds that as far as he knows "this is the first report of this novel approach" to producing such a reversible system.

"I think this is a very crucial result," says Joseph Heremans, professor of physics and of mechanical and aerospace engineering at Ohio State University. "Heat switches exist," but involve separate parts made of different materials, whereas "here we have a system with no macroscopic moving parts," he says. "This is excellent work."

More information: Reversible temperature regulation of electrical and thermal conductivity using liquid–solid phase transitions, Nature Communications 2, Article number: 289 doi:10.1038/ncomms1288
www.nature.com/ncomms/journal/ … full/ncomms1288.html

Abstract

Reversible temperature tuning of electrical and thermal conductivities of materials is of interest for many applications, including seasonal regulation of building temperature, thermal storage and sensors. Here we introduce a general strategy to achieve large contrasts in electrical and thermal conductivities using first-order phase transitions in percolated composite materials. Internal stress generated during a phase transition modulates the electrical and thermal contact resistances, leading to large contrasts in the electrical and thermal conductivities at the phase transition temperature. With graphite/hexadecane suspensions, the electrical conductivity changes 2 orders of magnitude and the thermal conductivity varies up to 3.2 times near 18 °C. The generality of the approach is also demonstrated in other materials such as graphite/water and carbon nanotube/hexadecane suspensions.