

# Scientists use molecular layers to study nanoscale heat transfer

October 26 2012

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Scientific research has provided us with a fundamental understanding of how light (via photons) and electricity (via electrons) move within and between materials at the micrometer or nanometer levels, making possible a wide variety of miniature devices such as transistors, optical sensors and microelectromechanical systems (MEMS). However, man's knowledge of micro- and nanoscale heat flow is rudimentary at best.

Now, a research team at the University of Illinois at Urbana-Champaign (UIUC) has developed a novel system for examining and measuring nanoscale [thermal conductance](#) at the interface between two materials. With further refinement, the scientists believe their advance may one day provide data for applications such as harvesting electricity from waste heat, better cooling of [microelectronic devices](#) and "heat-seeking" targeting of [disease cells](#) by hyperthermal (above normal body temperature) therapeutics.

The team's findings will be presented by Mark Losego, formerly a post-doctoral fellow at UIUC and now a research assistant professor in chemical and biomolecular engineering at North Carolina State University, during the AVS 59th International Symposium and Exhibition, held Oct. 28-Nov. 2, 2012, in Tampa, Fla.

At the nanoscale, thermal properties are the result of vibrations between neighboring atoms. Bonds between atoms carry these vibrations similar to an oscillating spring. The UIUC team developed a technique for studying the effects of these bonds on [heat transport](#) across an interface

between two different materials. "We wanted a system where we could observe, analyze and quantify thermal flow across an interface with atomic-level precision," Losego says.

The system starts with a substrate base of [quartz crystal](#), upon which the researchers place [molecular chains](#) that are 12 [carbon atoms](#) long. At the base of each chain is a chemical "cap" that covalently bonds to quartz. The attraction of these caps to the substrate spontaneously aligns all of the carbon chains into an ordered array of molecules known as a self-assembled monolayer (SAM). At the opposite end of each carbon chain is a different kind of cap, either a thiol (sulfur and hydrogen) group that bonds strongly to metals or a methyl group (carbon and hydrogen) that bonds weakly.

"We then make use of a viscoelastic silicone stamp to 'transfer print' gold layers onto the SAM surface," Losego explains. "This process is similar to transferring a decal onto a T-shirt where the gold film is the 'decal' attached to the silicone stamp 'backing'. When we slowly peel away the silicone, we leave the gold layer on top of the SAM."

It is at the interface between the gold film and the SAM, Losego says, where nanoscale [heat flow](#) is characterized. "Changing the chemical groups that are in contact with the gold layer allows us to see how different bonds affect heat transfer," he adds.

Combined with an ultrafast laser technique capable of monitoring temperature decay (or heat loss) with picosecond (trillionth of a second) resolution, the UIUC researchers are able to use their experimental system to evaluate heat flow at the atomic scale. "We heat the gold layer attached to the monolayer and can monitor temperature decay with time," Losego explains. "Concurrently, we observe oscillations in the gold film that indicate the strength of the bonds at the gold-SAM junction. Using these measurements we are able to independently verify

that strong bonds [fast-decaying oscillations] have rapid heat transfer while weak bonds [slowly decaying oscillations] have slower heat transfer."

The researchers plan to refine their nanoscale thermal measurement system and develop theoretical calculations to better interpret the data it produces.

Provided by American Institute of Physics

Citation: Scientists use molecular layers to study nanoscale heat transfer (2012, October 26)  
retrieved 9 April 2024 from  
<https://phys.org/news/2012-10-scientists-molecular-layers-nanoscale.html>

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