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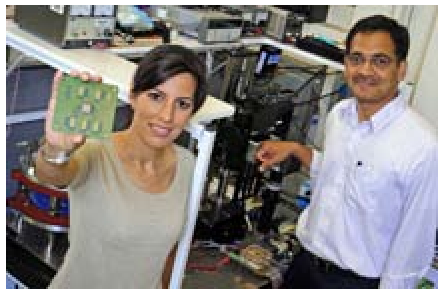
New findings could help hybrid, electric cars keep their cool

WEST LAFAYETTE, Ind. - Understanding precisely how fluid boils in tiny "microchannels" has led to formulas and models that will help engineers design systems to cool high-power electronics in electric and hybrid cars, aircraft, computers and other devices.



Tannaz Harirchian (L), Suresh Garimella
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Allowing a liquid to boil in cooling systems dramatically increases how much heat can be removed, compared to simply heating a liquid to below its boiling point, said Suresh Garimella, the R. Eugene and Susie E. Goodson Professor of Mechanical Engineering at Purdue University.

However, boiling occurs differently in tiny channels than it does in ordinary size tubing used in conventional cooling systems.

"One big question has always been, where is the transition from macroscale boiling to microscale boiling?" said doctoral student Tannaz Harirchian. "How do you define a microchannel versus a macrochannel, and at what point do we need to apply different models to design systems? Now we have an answer."

Findings will be detailed in a research paper by Garimella and Harirchian and a keynote address to be presented by Garimella on Oct. 8 during the conference Thermal Investigations of ICs and Systems, or Therminic, from Oct. 7-9 in Leuven, Belgium. The researchers also have published several related papers in peer-reviewed journals.

Indiana's 21st Century Research and Technology Fund has provided $1.9 million to Purdue and Delphi Corp. in Kokomo, Ind., to help commercialize the advanced cooling system using microchannels for electronic components in hybrid and electric cars. The research also is funded by the Purdue-based National Science Foundation Cooling Technologies Research Center, a consortium of corporations, university and government laboratories working to overcome heat-transfer obstacles in developing new compact cooling technologies.

The new type of cooling system will be used to prevent overheating of devices called insulated gate bipolar transistors, high-power switching transistors used in hybrid and electric vehicles. The chips are required to drive electric motors, switching large amounts of power from the battery pack to electrical coils needed to accelerate a vehicle from zero to 60 mph in 10 seconds or less. The devices also are needed for "regenerative braking," in which the electric motors serve as generators to brake the vehicle, generating power to recharge the battery pack; to convert electrical current to run accessories in the vehicle; and to convert alternating current to direct current to charge the battery from a plug-in line.

The high-power devices produce about four times as much heat as a conventional computer chip.

The researchers studied a "dielectric liquid," a fluid that doesn't conduct electricity, which allows it to be used directly in circuits without causing electrical shorts.

"We have finally made sense of boiling in small-scale channels and now have a nice understanding of the physics," said Garimella, director of the NSF Cooling Technologies Research Center.

Researchers used special test chips fabricated by Delphi that are about a half-inch on each side and contain 25 temperature sensors.

"Right under each of these sensors is a little heater, so we can adjust the amount of heat we apply to specific locations on the chip and simulate what happens in a real chip," he said.

Too much heat hinders the performance of electronic chips or damages the tiny circuitry, especially in small "hot spots."

"In order to design these systems properly you need to be able to predict the heat-transfer rate and how much cooling you will get," he said.

Conventional chip-cooling methods use a small fan and finned metal plates called heat sinks, which are attached to computer chips to dissipate heat. Such air-cooled methods, however, do not remove enough heat for the advanced automotive electronics, especially because of hot air under a car's hood, Garimella said.

The microchannels are etched directly on top of the silicon chips. Because both the channels and the chip are made of silicon, there is no dramatic difference in expansion from heating, which allows chips to be stacked on top of each other with the cooling channels between each chip.

This stacking makes it possible to create more compact systems, since the chips do not have to be laid out horizontally on a circuit board as they ordinarily would.

"We can fit a lot more chips in much less real estate using this approach," Garimella said.

Unlike boiling liquid in larger cooling systems, spherical bubbles sometimes don't form in the smallest channels. Rather, one long continuous "liquid annulus," or oblong "slugs" of vapor in liquid form.

Harirchian developed formulas that allow engineers to tell when different kinds of flows occur and how to design the systems accordingly. The specific "flow regimes" -- whether the fluid is bubbly, annular or in slugs -- must be known before the proper formulas can be used to predict the performance of certain channel designs.

She also determined that it's not the width or the depth of the channels that most influence the boiling behavior but the cross sectional area of each channel, said Garimella, who began the microchannel research about 10 years ago.

"I am very proud of this work," Garimella said. "We have come a long way."

Researchers used a high-speed camera to capture the behavior of the circulating fluid, studying channels as small as 100 by 100 microns and as large as 100 microns deep by about 6 millimeters wide.

"We wanted to test a wide range of channel sizes," Harirchian said.

Delphi has taken the work further, creating prototypes and commercializing the cooling technology, said Delphi's Bruce Myers, principal technical fellow.

The researchers have created a database of movies accessible on the NSF center's Web site to demonstrate the boiling behavior in microchannels. They also have created a "complete test matrix" that enables engineers to determine how a particular system would perform given a range of channel dimensions, amount of heating and fluid flow.

"You can basically mix and match different design specifics and see the result," Garimella said.

The cooling systems also are being developed to cool the electronic controls in aircraft, military systems and for other applications.

"We hope to be able to use the new models to help us in designing vapor cycle system evaporators for aircraft thermal management," said Hal Strumpf, senior technology fellow and chief engineer for thermal systems at Honeywell International Inc. "These evaporators typically operate over the full range of flow regimes studied by Garimella's team, and each individual flow regime must be accurately modeled to predict evaporator performance."

Future research is concentrating on creating additional heat-transfer models for designing the cooling systems.

Some of the research was conducted at the Birck Nanotechnology Center in Purdue's Discovery Park.

Writer: Emil Venere, (765) 494-4709, venere@purdue.edu

Sources: Suresh Garimella, (765) 494-5621, sureshg@ecn.purdue.edu

Bruce Myers: Bruce.A.Myers@delphi.com

Hal Strumpf: hal.strumpf@honeywell.com

Purdue News Service: (765) 494-2096; purduenews@purdue.edu

Note to Journalists: An electronic copy of the research paper is available from Emil Venere, 765-494-4709, venere@purdue.edu.

PHOTO CAPTION:

Researchers have determined precisely how fluid boils in tiny "microchannels," creating formulas and models that will help engineers design systems to cool high-power electronics in electric and hybrid cars, aircraft, computers, and other applications. Here, Purdue University doctoral student Tannaz Harirchian holds up special chips provided by Delphi Electronics and Safety that she and Professor Suresh Garimella used to simulate what happens in a real chip. (Purdue News Service photo/Andrew Hancock)

A publication-quality photo is available at http://news.uns.purdue.edu/images/+2009/garimella-boiling.jpg

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ABSTRACT

Boiling Heat Transfer and Flow Regimes in Microchannels – a Comprehensive Understanding

Suresh V. Garimella and Tannaz Harirchian

Cooling Technologies Research Center

School of Mechanical Engineering and Birck Nanotechnology Center

Purdue University

Although flow boiling in microscale passages has received much attention over the last decade, the implementation of microchannel heat sinks operating in the two-phase regime in practical applications has lagged due to the complexity of boiling phenomena at the microscale. This has led to difficulties in predicting the heat transfer rates that can be achieved as a function of the governing parameters. From extensive experimental work and analysis conducted in recent years in the authors' group, a clear picture has emerged that promises to enable prediction of flow boiling heat transfer over a wide parameter space. Experiments have been conducted to determine the effects of important geometric parameters such as channel width, depth, and cross-sectional area, operating conditions such as mass flux, heat flux and vapor quality, as well as fluid properties, on flow regimes, pressure drops and heat transfer coefficients in microchannels. High-speed flow visualizations have led to a detailed mapping of flow regimes occurring under different conditions. In addition, quantitative criteria for the transition between macro- and micro-scale boiling behavior have been identified. These recent advances towards a comprehensive understanding of flow boiling in microchannels are summarized here.

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