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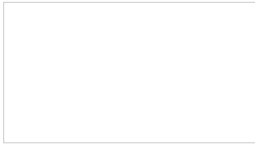
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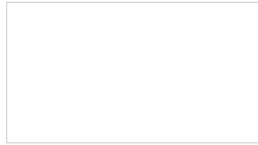
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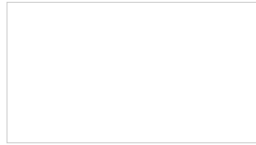
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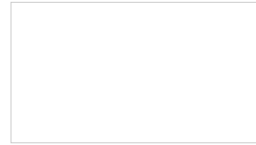
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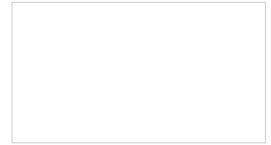
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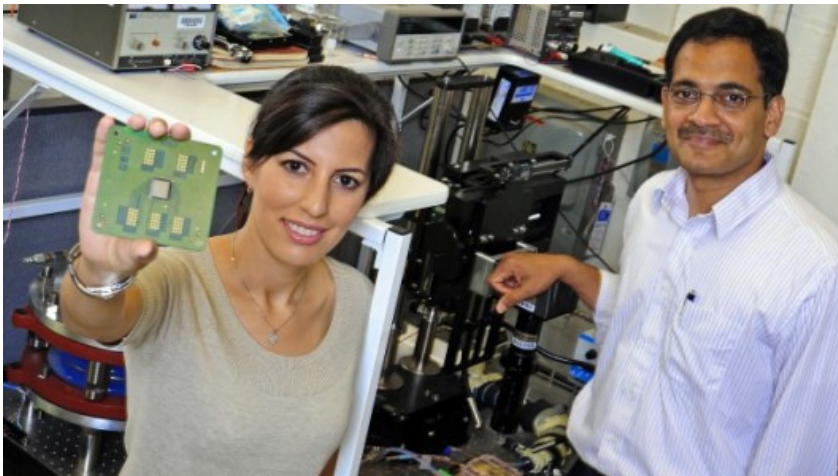
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## Keeping hybrids cool under the bonnet reaches boiling point

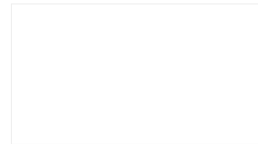
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23:50 September 23, 2009

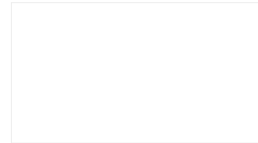


Purdue University's Tannaz Harirchian and Professor Suresh Garimella have developed a new means of cooling chips in electric and hybrid applications (Photo: Andrew Hancock)

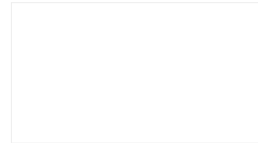
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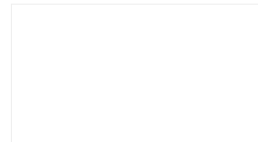
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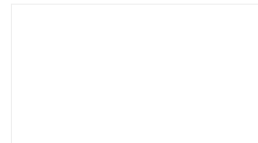
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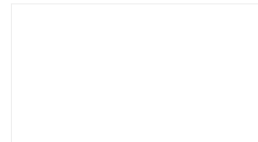
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As an increasing number of hybrid-powered vehicles move from concept to completion, technology is battling to keep pace with some of the less-publicized technical challenges found among the complex electronics aboard these land- and air-based vehicles, computers and other devices. For instance, how do you effectively cool the electronics in a high-power electric motor that propels a passenger car from 0-60mph in under 10 seconds and uses regenerative braking to

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stop? Researchers in the U.S. believe the secret may lie in understanding precisely how fluid boils in tiny 'microchannels', which has led them to develop formulas and models that will help engineers design unique systems to cool high-power electronics found in today's and tomorrow's devices.

The need to redesign cooling systems is caused by the level of heat generated by the computer chips that operate hybrids engine components (about four times more heat than conventional computer chips). The new type of cooling system will be used to help prevent overheating in high-power switching transistors used in hybrid and electric vehicles, called insulated gate bipolar transistors.

The chips heat up because they switch large amounts of power from the battery pack to electrical coils when vehicles accelerate quickly. They also are needed for 'regenerative braking', when the electric motors serve as generators to brake the vehicle which, in turn, generates power to recharge the battery pack. Some of this power is converted into electrical current used to run accessories in the vehicle; and some is converted from alternating current to direct current to charge the battery from a plug-in line.

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, Prof Suresh Garimella said.

Hence, microchannels used in liquid cooling 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.

Once the method of cooling the chips was determined, finding an appropriate liquid was the next challenge.

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.

## Heat transfer optimization - a boiling conundrum

"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 Garimella, the R. Eugene and Susie E. Goodson Professor of Mechanical Engineering at [Purdue University](#).

However, Garimella said boiling occurs differently in tiny channels than it does in ordinary size tubing that is 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."

"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.

The research is funded by the Purdue-based National Science Foundation Cooling Technologies Research Center, a consortium of corporations, university and government laboratories. Indiana's 21st Century Research and Technology Fund has provided \$1.9 million to help commercialize the advanced cooling system.

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.

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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.

Unlike boiling liquid in larger cooling systems, spherical bubbles sometimes don't form in the smallest channels. They may, rather, form 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 x 100 microns and as large as 100 microns deep by about 6mm 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 Website 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.

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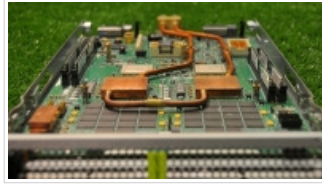
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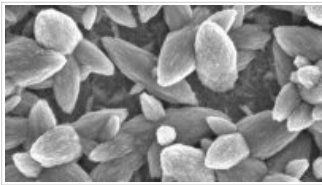
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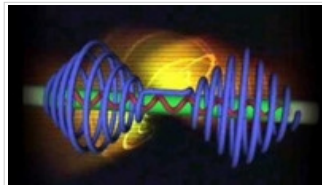
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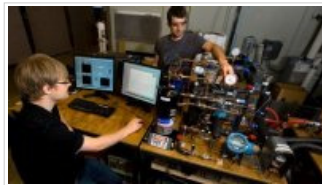
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