Findings Could Help Hybrid, Electric Cars Keep Their Cool

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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.

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

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