Engineer creates a new tool for keeping computers cool

July 11 2005

Anyone who has listened to the constant whir of a computer's fan or held a laptop for too long knows how blazing hot computers can get.
In fact, today's ultra-powerful computers generate so much heat that air cooling technology can't keep pace anymore, says University of Wisconsin-Madison mechanical engineering professor Tim Shedd.

Shedd and graduate student Adam Pautsch have now created a spray cooling method that early tests show can remove heat at rates up to three times faster than other spray techniques. Rather than wetting computer chips with a cone-shaped shower of coolant as do existing devices, the new system drenches chips with high velocity lines of liquid, much like sheets of wind-driven rain.

"As far as the density of heat goes, this technology can remove up to four times what the space shuttle experiences upon re-entry," says Shedd, "which is performance we haven't seen before."

The key, he says, is that when it contacts the chip, the coolant mimics a boiling liquid - one of the most efficient and widely used means to remove heat - while avoiding the problems true boiling can cause.

"Ever since we began boiling liquids inside heat exchangers, we haven't really seen any dramatic shifts in the basic mechanisms of heat exchange," says Shedd. "With this technology we're taking advantage of new ways to think about heat transfer."

The project began at the request of Cray, Inc., a manufacturer of supercomputers in Chippewa Falls, Wis., and was funded through the UW-Madison Graduate School Industrial and Economic Development Research (I&EDR) program.

When electricity is harnessed, a portion always ends up as thermal energy, or what people commonly think of as heat. A 100-watt light bulb grows blistering hot, for example, because most of its electricity becomes heat rather than light. Computer chips can produce the same 100 watts of thermal energy as the bulb, but that energy is concentrated in a much tinier area.

"When you have a large amount of thermal energy in a very small spot, the temperature becomes very, very high, to the point where materials begin to deform or the chip shuts down completely," says Shedd.

One of the most promising ways to combat this is spray cooling. In current designs, arrays of miniature nozzles with pinhole-sized openings shower the chip with droplets of a special liquid that won't damage electronic circuits. Cooling occurs in two ways. Heat is thought to disperse most efficiently when bubbles of vapor form as the coolant evaporates from the surface - the process known as boiling. The coolant also removes heat by simply warming as it flows over the chip toward a drain.

The liquid and vapor are then collected, recycled, and the heat they carry is dissipated by a heat exchanger, such as a radiator with a slow-moving fan.

The current technique has limitations, however, and at Cray 's request, Shedd and Pautsch set out to investigate them. By replacing a computer chip with a plate of transparent Plexiglas and visualizing the flow with microscopic techniques, they observed deep ridges of liquid forming in areas where sprays from adjacent nozzles streamed into one another. As it collected, the liquid flowed more slowly and began to boil.

But rather than being favorable, the runaway boiling created dry spots on the Plexiglas surface that resisted re-wetting by fresh coolant. When this happens, chip temperatures can spike by hundreds of degrees in a matter of seconds.

"We discovered that we actually wanted to avoid boiling," says Shedd, "which was kind of a new discovery."

The UW-Madison engineers' new approach uses a linear nozzle array to shoot droplets of coolant in lines at a 45-degree angle to the chip surface. Because they all move in the same direction, the lines of liquid have no chance to interact, slow down and boil. Instead, they rush off the surface in a torrent, carrying with them the chip's heat.

The system performs so well, says Shedd, because "the mixing of liquid caused by the droplets at the chip surface achieves very high heat transfer, and the high rate of liquid delivery and removal keeps the temperature fairly constant. In other words, the two attributes most often associated with boiling are found in a system with little or no actual boiling."

Cray is excited by the possibility of using the technology in the cooling system for one of its new supercomputers, says Cray's senior engineering manager Greg Pautsch, whose son Adam is Shedd's doctoral student.

"This research has given us a fundamental understanding of how the technology works at the microscopic level," he says. "Based on this, we can enhance the heat transfer performance of spray cooling."

In addition to computer and other electronics applications, bulky liquid-

liquid heat exchangers - found in everything from automotive oil coolers to ice cream makers - could be made 30 to 50 times smaller if the new approach is adopted, says Shedd.

"I think we may be looking at a paradigm shift in how heat exchangers are designed," he adds.