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Suresh Garimella: Creating Cool Devices For Hot Chips

by: **Francis C. Assisi**

West Lafayette, March 25: Meeting some of the challenges faced by 21st century electronics is a way of life for Purdue University's Suresh Garimella.

"Industry comes to us with a technical problem, and we conduct research to help solve those problems," explains Dr Garimella, a Professor in the School of Mechanical Engineering, and Director of the Cooling Technologies Research Center.

Refrigerator on-a-chip

Garimella has been focusing his attention on thermal challenges arising from next generation electronics.

That's because one of the technical problems faced by the electronic industry is how to keep components cool. Keeping chips cool is important because heat decreases their performance and reliability. But to satisfy consumer demand for smaller gadgets that do more stuff, manufacturers have had to cram more circuitry into smaller spaces - which only adds to the heat problem.

This trend toward smaller gadgets and the demand for more and more functions means electronic gadgets may look really cool, but they may also be too hot to handle.

In a report released this week, Garimella announced that a chip refrigerator no bigger than a dust particle could lead to important progress in solving the growing thermal problem for the high-tech industry. Garimella and his team have developed a new type of cooling technology for computers that uses a sort of nano-lightning to create tiny wind currents.

The report said that the researchers have shown that the underlying concept for a "micro-scale ion-driven airflow" device is sound and have recently filed for a patent.

"This is a groundbreaking idea," said Garimella, who is working on the device with Timothy Fisher, an associate professor of mechanical engineering, Daniel J. Schlitz , who recently earned a doctoral degree from Purdue, and doctoral student Vishal Singhal. Schlitz and Singhal have created Thorrn Micro Technologies Inc. to commercialize the cooling system.

"The key attribute of this work is that it sticks with air cooling while possibly providing the same rate of cooling as a liquid," he said.

The new technique works by generating ions - or electrically charged atoms - using electrodes placed close to one another on a computer chip. Negatively charged electrodes, or cathodes, are made of "nanotubes" of carbon with tips only as wide as five nanometers, or billionths of a meter.

Voltage is passed into the electrodes, causing the negatively charged nanotubes to discharge electrons toward the positively charged electrodes. The electrons react with surrounding air, causing the air molecules to be ionized just as electrons in the atmosphere ionize air in clouds. This ionization of air leads to an imbalance of charges that eventually results in lightning bolts.

The ionized air molecules cause currents like those created by the "corona wind" phenomenon, which happens between electrodes at voltages higher than 10 kilovolts, or 10,000 volts. "To create lightning you need tens of kilovolts, but we do it with 100 volts or less," Garimella said. "In simple terms, we are generating a kind of lightning on a nano-scale here." The researchers are able to create the ionizing effect with low voltage because the tips of the nanotubes are extremely narrow and the oppositely charged electrodes are spaced apart only about 10 microns, or one-tenth the width of a human hair.

Future cooling devices based on the design will have an "ion-generation region," where electrons are released, and a "pumping region," made up of another set of electrodes needed to create the cooling effect. Clouds of ions, created when electrons react with air, can then be attracted by the second region of electrodes and "pumped" forward by changing the voltages in those electrodes. The voltages are rapidly switched from one electrode to the next in such a way that the clouds of ions move forward and produce a cooling breeze.

"They are switching at the right frequency so that the ion cloud is constantly moving forward," Schlitz said. "As the ions move forward, they make repeated collisions with neutral molecules, producing the breeze."

The Purdue researchers have demonstrated that the pumping concept works with a region of electrodes made of many series, each series containing three electrodes. The first in the series is the most positively charged, followed by an electrode that has a less-positive charge and then a third electrode that is negative.

Switching the voltages from one electrode to the next causes the charges to move forward, which in turn moves the ion clouds. "The switching itself is a well-known concept from physics, but we are the first to bring about ion pumping on a micro-scale like this," said Garimella, who is director of Purdue´s Cooling Technologies Research Center, a consortium of corporations, university and government laboratories working to overcome obstacles in developing new, compact cooling technologies. "This is a very novel idea," he said. "It is certainly one of the most inventive things I´ve ever been involved with." More work must be done to perfect the technique and develop a prototype, the researchers said.

Another version of the design might replace the carbon nanotubes with a thin film of diamond, which would be sturdier and easier to fabricate than the nanotubes. "The grain boundaries in the diamond film provide the same kind of opportunity for electron emission and ion generation as a carbon nanotube," Garimella said.

The researchers envision cooling devices that are small enough to fit on individual chips, actually making up a layer of the chip. "The entire thing would sit on, and be integrated into, a chip that is 10 millimeters by 10 millimeters," Garimella said.

Chips in desktop computers currently are cooled with "heat sinks" that contain fins to dissipate heat. The heat sinks are connected to bulky fan assemblies to carry away the heated air. "You need an external means of creating air," Garimella said. "That´s important. You need the fan."

"Here, the creation of air as well as the cooling is all happening on one chip. That´s the key value of this idea."

Most features of the device could be manufactured with conventional silicon fabrication techniques used in the semiconductor industry to make computer chips, Garimella said.

Confronting Thermal Challenges

For Garimella, research in this area has moved one step at a time. And his Indian American students and colleagues have been a supportive force.

For example, two years ago, using the electrical behavior of various materials to siphon heat away from chips, Garimella and his team developed miniature devices that mimic the motion of a Chinese fan to prevent computer chips from overheating. Another Indian American colleague, Arvind Raman, was part of that team.

The new fans consisted of polyester or metal blades attached to tiny patches of "piezoelectric" ceramic. An alternating current applied to the ceramic causes it to expand and contract, making the blades wave back and forth like an old-fashioned Chinese folding fan.

When Garimella put a piezoelectric fan inside a laptop computer with a rotational fan, it brought the temperature down by 8 degrees centigrade. The piezoelectric fans are far less power hungry, he says, using about one per cent of the power needed by rotational fans.

In addition to their small size, the small fans use only 2 mW of electricity, compared to 300 mW used by conventional rotary fans in some laptop computers. Without motors that contain magnets, the new fans do not generate electromagnetic noise. The small fans also have no gears or bearings that produce friction and heat. Instead, the piezoelectric ceramic attached to the fan blades moves them back and forth with alternating current.

Mathematical models developed by the Purdue team provide design guidelines for specific applications such as computers, telephones, PDAs, and pharmaceutical mixing equipment.

"It´s a neat technology because of the low noise performance it offers," said Girish Upadhya, senior thermal scientist at Apple. "One fan for all the cooling needs is now no longer working in a laptop, so we need several fans. But we also need to cut down on the noise, and so the piezoelectric fan would be the answer," Upadhya said.

D.H.R. Sarma, engineering group manager at Delphi Delco Electronic Systems, part of Delphi Automotive Systems, agrees about the fan´s usefulness. "Thermal management separates the men from the boys," Sarma said. "People who can figure out the right way to manage heat will be more successful in this business."

"We saw a match between our needs and this technology. Cars have a limited space and this offers compact cooling," Sarma added

However efficiency is critical because the energy used to move the fan blades, eventually gets dissipated as heat - meaning an inefficient fan could add heat, not lose it.

Garimella concedes the piezoelectric fans probably cannot move as much air as a rotational fan, but he says they are designed to work with rotational fans in laptops, not replace them.

The next step for Garimella was to build fans with 100 micrometre blades that could be attached directly to computer chips.

Garimella is confronting the problem of cooling electronic circuits head-on because he knows that heat reduces performance and will eventually destroy the delicate circuitry. "Even if it´s just a bit overheated, its performance and reliability goes down," Garimella said. "Another reason for cooling is to improve performance as you go to smaller and smaller devices."

Garimella found that a major obstacle to making smaller electronic devices is the need to remove heat. The concentrated circuits in a semiconductor computer chip can generate more heat per square centimeter of chip area than the surface of the sun.

"That is kind of mind-boggling," Garimella said. "The fact that it´s in such a tiny area is the nature of the problem. If that same amount of heat were distributed over a larger area, cooling would not be so difficult."

Besides computer technology, Garimella's research has many other promising applications, including the use of phase change materials to keep a car´s engine warm overnight and technologies that improve food processing.

"Thermal management is really what it is," Garimella said. "We are dealing with the management of heat, either in heating or cooling applications."

After receiving his B.Tech (1985) from IIT Madras, Garimella went on to earn an M.S. (1986) from Ohio State University and a Ph.D (1989) from the University of California at Berkeley.

Besides high-performance compact cooling technologies using innovative types of tiny fans, Garimella's research interest includes "phase change" materials that turn from solid to liquid as they absorb heat, minuscule "heat pipes" that cool electronics with internally circulating fluid and chips that cool electronic components by using "microchannels" as small as the width of a human hair.

Science researchers interested in profiling their work in this column are encouraged to submit their biodata and relevant publications to INDOlink at: editor@indolink.com