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Carbon nanotubes are superior to metals for electronics

In the quest to pack ever-smaller electronic devices more densely with integrated circuits, nanotechnology researchers keep running up against some unpleasant truths: higher current density induces electromigration and thermomigration, phenomena that damage metal conductors and produce heat, which leads to premature failure of devices.

But University at Buffalo researchers who study electronics packaging recently made a pleasant discovery: that's not the case with Single-Walled Carbon Nanotubes (SWCNTs).

"Years ago, everyone thought that the problem of cooling for electronics could be solved," said Cemal Basaran, Ph.D., professor in the UB Department of Civil, Structural and Environmental Engineering and director of the Electronics Packaging Lab in UB's School of Engineering and Applied Sciences. "Now we know that's not true. Electronics based on metals have hit a wall. We are done with metals."

Single Walled Carbon Nanotubes are extremely thin, hollow cylinders, measuring no thicker than a single atom. Thousands of times stronger than metals, they are expected to one day replace metals in millions of electronic applications.

Basaran and his doctoral student Tarek Ragab have spent the past four years performing quantum mechanics calculations, which prove that in carbon nanotubes, higher current density does not lead to electromigration and thermomigration; it also produces just one percent of the heat produced by traditional metals, such as copper.

Basaran will present the findings in November when he delivers a keynote lecture at the American Society of Mechanical Engineers (ASME) International Mechanical Engineering Congress and Exposition in Orlando.

The findings demonstrate yet another tantalizing property of CNTs, he said.

"It has been assumed that for carbon nanotubes, the electrical heating process would be governed by Joules law, where resistance in a circuit converts electric energy into heat," said Basaran. "We are the first to show mathematically, from a quantum mechanics point of view, that carbon nanotubes do not follow Joules law."

According to Basaran, this essential difference between metals and carbon nanotubes lies in the way they conduct electricity.

"Even though carbon nanotubes are conductive, they do not have metallic bonds," he said. "As a result,

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they do not conduct electricity the way that traditional metals do."

In conventional metals, he explained, conduction causes a scattering of electrons within the lattice of the material so that, when electrons move during conduction, they bump into atoms. This creates friction and generates heat, the same way a household iron works.

"On the other hand, in carbon nanotubes, electric conduction happens in a very different, one-dimensional 'ballistic' way," he said. "The electrons are fired straight through the material, so that the electrons have very little interference with the atoms."

He drew an analogy, using the difference between a conventional railroad train and a magnetically levitated train.

"In the conventional train, you have friction between the wheels and the track," said Basaran. "Through the generation of heat, that friction causes a loss of energy. But with a magnetically levitated train, the wheels and track are not in direct contact. Without that friction, they can travel much faster."

The minimal amount of friction gives carbon nanotubes a tremendous advantage over conventional metals, said Basaran. The unique properties of carbon nanotubes will allow engineers to realize a host of smaller, faster and more powerful new devices that right now cannot exist because of the limitations of conventional metals.

"When an electric car finally is manufactured, its batteries probably will be based on carbon nanotubes," said Basaran. "You can't use traditional metals in the engines because they run so hot."

Much of Basaran's $1 million-plus funding at UB comes from sources like the U.S. Navy, which is interested in sophisticated electronics systems that could operate under very demanding conditions, such as the electric ship the Navy is building.

Basaran's unique perspective comes from decades of research, which has fundamentally changed what is known about the high current density performance properties of metals and their limitations.

He also sounded a cautionary note, pointing out that current research and development expenditures on carbon nanotubes in the U.S. electronics industry are very small when compared to those of our Asian competitors.

"If the industry continues this way, when carbon nanotube-based electronics become a reality, U.S. electronics manufacturers may be in a position similar to U.S. car manufacturers today, because they have failed to keep up with advances in engineering," he said.

Basaran and his colleagues in the Electronics Packaging Lab actively participate in the UB 2020 strategic strength in Integrated Nanostructured Systems, which brings together physicists and engineers to further enhance and understand nanotechnologies like carbon nanotubes.

By University at Buffalo

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