New radiation therapy promises relief for overheating laptops

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(PhysOrg.com) -- Our modern age has become accustomed to regular improvements in information technology, says Slava Rotkin, but these advances do not come without a cost.

Take the laptop, for example. Its components, especially its billions of semiconductor electronic circuits, are growing ever tinier while the instrument's power and capacity increase. But heat generated by electric current can cause the circuits to melt and the laptop hardware to fail.

Indeed, says Rotkin, an assistant professor of physics, a laptop in use can generate heat faster than an everyday hotplate and almost as fast as a small nuclear reactor.

Developing better methods to dissipate this heat has been listed as a "grand challenge" for modern electronics by the International Technology Roadmap for Semiconductors (ITRS) , a consortium of semiconductor manufacturers.

Rotkin and his colleagues at IBM's T.J. Watson Research Center and at the Ioffe Institute in St. Petersburg, Russia, have developed a heat-dissipation method that cools carbon nanotube electronics by utilizing nonconventional radiation in a "near-field zone" just above the substrate, or surface, on which the nanotubes rest.

The new cooling method requires that the nanotubes' substrate be composed of a polar material such as silicon-dioxide (SiO_2), says

Rotkin. The method channels excess heat from the nanotubes into the substrate which, being much larger, can be more effectively cooled by the vents that push cool air through laptops.

"Other methods of heat dissipation do not succeed at discharging heat from within the channel of the nanotube or nanowire," says Rotkin. "Our method enables the heat to leave the channel and move to the substrate, while also scattering the hot electrons. This constitutes a novel cooling mechanism without any moving parts or cooling agents."

Rotkin and his colleagues described the results of their research in an article published in March in Nano Letters, one of the premier international journals in the field of nanotechnology.

The article, titled "An Essential Mechanism of Heat Dissipation in Carbon Nanotube Electronics," was coauthored by Rotkin, who is a primary faculty member with Lehigh's Center for Advanced Materials and Nanotechnology; Vasilii Perebeinos and Phaedon Avouris of IBM's T.J. Watson Research Center; and Alexey G. Petrov of the Ioffe Institute.

Rotkin and his colleagues have been studying the heat-dissipation problems associated with carbon nanotube electronics for three years. Their current article is the fifth coauthored by Rotkin that *Nano Letters* has published in the past year.

Because the nanotubes and substrate are made of heterogeneous materials, says Rotkin, their rate of thermal coupling, or heat release, is relatively low, similar to that of dry wood. This makes it difficult to dissipate heat from the nanotubes to the substrate through classical thermal conduction.

Rotkin and his colleagues instead utilize what they call surface phononpolariton (SPP) thermal coupling by exploiting the high level of electron scattering that occurs in non-suspended carbon nanotube transistors.

A wave called a surface polariton is caused by this electron scattering, says Rotkin. This polariton is particularly strong in the near field zone just above the substrate on which the carbon nanotubes rest.

"If you put a graphene monolayer, or layer of carbon nanotubes, in a near field zone," says Rotkin, "this enables the hot electrons to be scattered by the surface polariton and to give out energy to the substrate. Heat is dissipated into the substrate as radiation tunnels from the nanotube through the near field zone to the substrate.

"If you move the nanotube away from the substrate, the near field tunneling ceases and the mechanism is absent.

"We achieve all of our coupling through surface polariton scattering because of a large enhancement of the electrical field of the polariton in the near field zone.

"Most semiconductor devices fabricated now have the nanotube or nanowire placed directly on a silica substrate, which is polar. With this mechanism, if the substrate is polar and if there's a small van der Waals gap, our new near-field channel totally dominates thermal coupling."

A change advocated by ITRS - from a silica substrate to one made of dielectric materials with a higher dielectric constant - would give the substrate material an even stronger surface polariton, says Rotkin.

Rotkin's group used microscopic quantum models to calculate heat dissipation as a function of electric field, doping and temperature.

"Most of the energy losses are dissipated directly into the polar substrate and do not contribute to the field-effect transistor temperature rise," the group wrote in the most recent *Nano Letters* article.

"We have shown that SPP thermal coupling increases the effective thermal conductance over the interface between nanotube and [polar substrate] by an order of magnitude."

Rotkin will summarize his research in an invited talk titled "Thermal Moore's law and near-field thermal conductance in carbon-based electronics" to be presented in August at SPIE's Optics + Photonics conference in San Diego, Calif. SPIE is an international organization devoted to light-based research.

More information: *Nano Letters:* pubs.acs.org/doi/abs/10.1021/nl803835z

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