Fermi kinetics transport program models high-speed semiconductor devices better, says study

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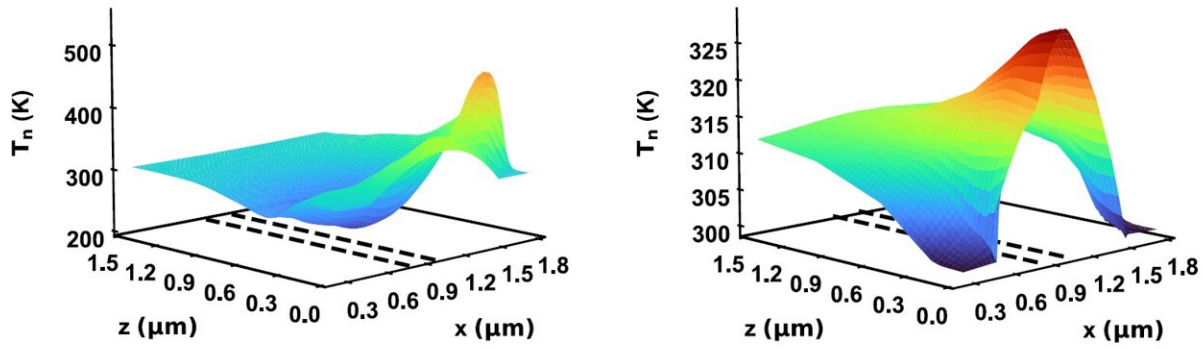

The commercial hydrodynamics package (left) predicts that electron temperatures can drop below the ambient temperature (300 kelvins, or 80 degrees Fahrenheit in this simulation) while the Fermi kinetics solver (right) gives more reasonable temperature predictions. Credit: The Grainger College of Engineering at the University of Illinois Urbana-Champaign

Electronic devices made from the semiconductor gallium nitride stand to revolutionize wireless communications. They can operate at higher speeds and temperatures than devices made from silicon, so they can be used to control the higher frequency radio waves needed for faster and higher bandwidth data transfer. In addition, their ability to withstand much lower temperatures makes them promising for use in quantum computing. To realize the material's full potential, though, accurate

modeling and simulation tools are needed to guide scientists and engineers designing new devices.

The research group of Shaloo Rakheja, a professor of electrical and computer engineering at the University of Illinois Urbana-Champaign, collaborated with Air Force Research Laboratory engineers Nicholas Miller and Matt Grupen to study two semiconductor simulation tools: a commercial hydrodynamics software package, and the Fermi kinetics transport solver developed by Grupen.

Their article, named an editor's pick in the *Journal of Applied Physics*, reports that the Fermi kinetics solver has mathematical properties that allow it to better handle the extreme conditions under which gallium nitride devices will operate.

"This is the first time a direct comparison has been made between the state-of-the-art commercial program and a custom-developed research code," Rakheja said. "It is important for the semiconductor community to understand the strengths and limitations of each."

According to Rakheja and Miller, the most important difference between the two programs is how they model the electronic heat flow. The commercial package uses Fourier's law, an empirical model that does not necessarily work well for semiconductors, while the Fermi kinetics transport solver uses more fundamental thermodynamic principles for this purpose. The researchers believe that this accounts for the different predictions each program makes.

"There is a strong connection between the underlying physics and the behavior of each program," Rakheja said, "and we wanted to explore that in the context of a device technology that's highly relevant today: gallium nitride."

To compare the two codes, the researchers simulated an elementary gallium nitride transistor with each. They found that the two programs gave similar results under modest operating conditions. However, when they introduced large, transient signals of the kind expected in high-speed applications, they obtained unexpected results for electron temperature from the commercial package. It predicted that at short time scales the electron temperature would dip below the ambient temperature, while the Fermi kinetics solver gave more consistent temperature profiles.

In addition, when they examined the rate of convergence, a mathematical indicator of simulation self-consistency, of each, the Fermi kinetics solver converged faster. The researchers concluded from this that the Fermi kinetics solver is more computationally robust.

Rakheja's group is now using the solver's robustness to simulate more gallium nitride devices. They aim to understand how the material heats up as it operates at high speeds and use this information to design devices that fully take advantage of the material's properties.

"Gallium nitride has really been a game changer," Miller said. "As the technology continues to evolve into more sophisticated forms, a critical component of the development cycle is modeling and simulation of the transistors."

More information: Ashwin Tunga et al, A comparison of a commercial hydrodynamics TCAD solver and Fermi kinetics transport convergence for GaN HEMTs, *Journal of Applied Physics* (2022). DOI: 10.1063/5.0118104

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