Imec introduces framework to model GaN HEMT and InP HBT RF devices for 5G & 6G

Monte Carlo simulation uses microscopic heat carrier distributions to predict 3D thermal transport.

At the 68th annual IEEE International Electron Devices Meeting (IEDM 2022) in San Francisco (3–7 December), nanoelectronics research center imec of Leuven, Belgium presented a Monte Carlo Boltzmann modeling framework that, for the first time, uses microscopic heat carrier distributions to predict 3D thermal transport in advanced RF devices intended for 5G and 6G wireless communication.

The results were presented in two invited papers, by Bjorn Vermeersch on thermal modeling and by Nadine Collaert on gallium nitride (GaN) and indium phosphide (InP) technologies for next-generation high-capacity wireless communication, respectively [papers 11.5 and 15.3].

Case studies with GaN high-electron-mobility transistors (HEMTs) and InP heterojunction bipolar transistors (HBTs) revealed peak temperature rises up to three times larger than conventional predictions with bulk material properties. Imec reckons that the new tool will be useful in guiding optimizations of next-generation RF devices toward thermally improved designs.

GaN- and InP-based devices have emerged as interesting candidates for 5G millimeter-wave (mm-wave) and 6G sub-THz mobile front-end applications, respectively, due to their high output power and efficiency. To optimize these devices for RF applications and make them cost-effective, much attention is paid to upscaling the III/V technologies to a silicon platform and making them CMOS compatible. However, with shrinking feature sizes and rising power levels, self-heating has become a major reliability concern, potentially limiting further RF device scaling.

"Tuning the design of GaN- and InP-based devices for optimal electrical performance often worsens thermal performance at high operating frequencies," notes Nadine Collaert, program director of advanced RF at imec. "For GaN-on-Si devices, for example, we recently achieved tremendous progress in electrical performance, bringing the power-added efficiencies and output power for the first time on par with that of GaN-on-silicon carbide (SiC). But further enlarging device operating frequency will require downsizing the

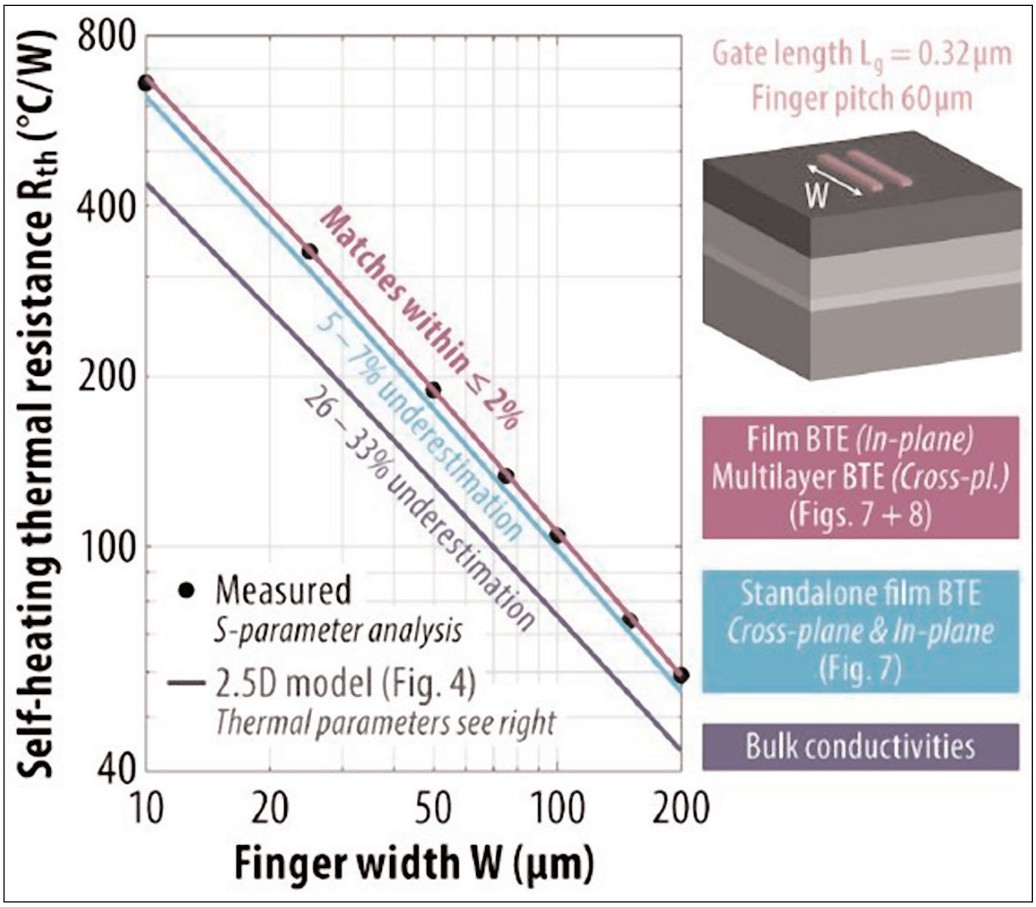

Figure 1. Measured and predicted thermal resistance versus finger width of two-finger GaN-on-Si HEMTs.

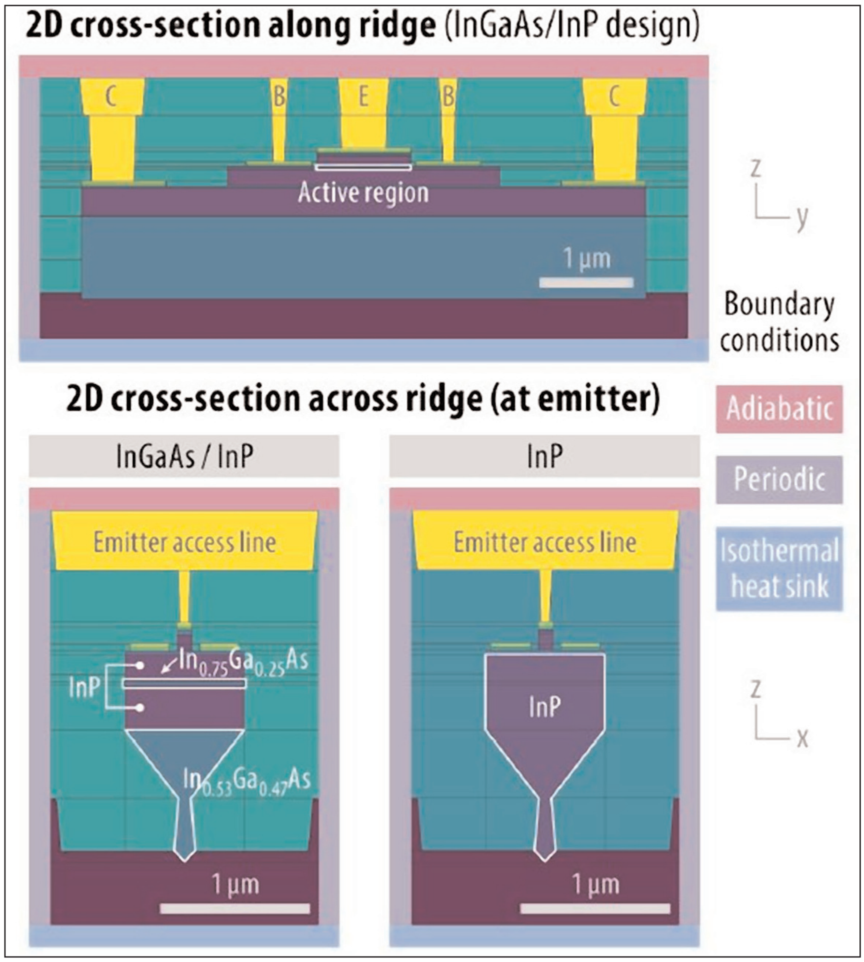

Figure 2. Geometry of InP nanoridge HBT used in the 3D simulation.

existing architectures. In these confined multi-layer structures, however, thermal transport is no longer diffusive, challenging accurate self-heating predictions," she adds. "Our novel simulation framework, yielding good matches with our GaN-on-Si thermal measurements, revealed peak temperature rises up to three times larger than previously predicted. It will provide guidance in optimizing these RF device layouts early in the development phase to ensure the right trade-off between electrical and thermal performance."

Such guidance also proves very valuable for the novel InP HBTs, where imec's modeling framework highlights the substantial impact that non-diffusive transport has on self-heating in complex scaled architectures. For these devices, nanoridge engineering (NRE) is an interesting heterogeneous integration approach from an electrical performance point of view. "While the tapered ridge bottoms enable low defect density within the III–V materials, they however induce a thermal bottleneck for heat removal towards the substrate," explains Bjorn Vermeersch, principal member of technical staff in the thermal modeling and characterization team at imec. "Our 3D Monte Carlo simulations of NRE InP HBTs indicate that the ridge topology raises the thermal resistance by over 20% compared to a hypothetical monolithic mesa of the same height," he adds. "Our analyses furthermore highlight the direct impact of the ridge material (e.g. InP versus InGaAs) on self-heating, providing an additional knob to improve the designs thermally." ■

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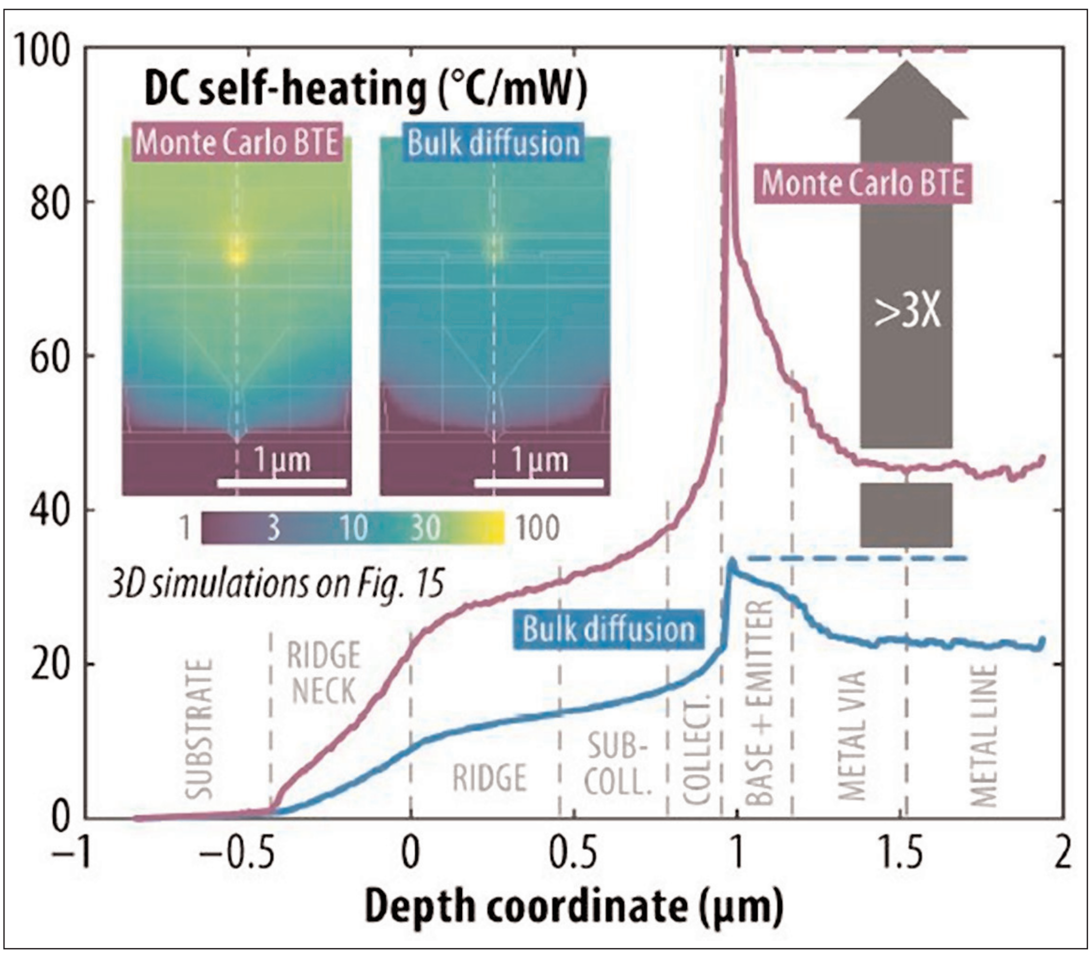

Figure 3. Impact of non-diffusive thermal transport effects (as captured by imec's Monte Carlo simulation) in InP nanoridge HBTs.