Comments

Reply to "Comparison of Thermal-Shunt and Flip-Chip HBT Thermal Impedances: Comment on Novel HBT with Reduced Thermal Impedance"

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We would like to take this opportunity to respond to the above comment[1] by Jenkins *et al.*, who raise some good points that we would like to address concerning out letter.[2] However, the primary point of their comment is to question whether flip-chip heterojunction bipolar transistors (HBT's) offer any advantage over the thermal-shunt technology developed by Bayraktaroglu *et al.* [1]. This question has been answered unambiguously in a recent report by Bayraktaroglu *et al.* that directly compared the thermal resistance of thermal-shunt and flip-chip devices [2]. In this report, flip-chip devices on the average had 37% lower thermal resistance compared to conventional thermally shunted devices of similar size.

We agree with the thermal resistance data reported in both the Comment[1] and Bayraktaroglu's recent report and do not see any inconsistency between them. Both sets of data are in line with our simulations and expectations. As we stated in our letter, the thermal resistance of the thermal-shunt approach is less favorable as the total emitter area placed under the airbridge increases. However, we failed to indicate any size scale over which the thermal-shunt approach becomes less attractive. We acknowledge that the thermal-shunt approach is the favored method for the device sizes reported by Jenkins *et al.*; however, even our 20-GHz unit cells have larger area than the largest device described in the Comment. At X-band, we employ unit cells that are more than four times larger; at S-band, the unit cell size is over 30 times larger than anything they described.

We have performed numerous thermal simulations of flip-chip and thermal-shunt devices in various configurations and with various substrate thicknesses, including advanced thermal-shunt devices employing multiple through-wafer vias next to the active device, which serve purely as heat conduction paths, similar to what was reported in [3]. If realistic X-band unit cell dimensions are used, with emitter pitch and distance between adjacent unit cells held fixed, the flip-chip approach appears to give about 30% lower thermal resistance, based on our simulations. This is in good agreement with Bayraktaroglu's measurements in [2].

The difference between large-area and small-area thermal-shunt devices is due to the essentially fixed thermal resistance of the thermal shunt in the lateral direction. As additional heat sources (emitter fingers) are added to a thermal shunt, the temperature drop across the shunt must necessarily increase because of the one-dimensional heat flow. Thus, while small-area devices have extremely low thermal resistance, larger-scale devices are not as attractive. The obvious solution is to add more thermal shunts so that the number of fingers per shunt is held constant at a low value, as demonstrated in [3]. This approach entails additional process complexity, just as our approach does; even so, the resulting structure still has somewhat higher thermal resistance than the flip-chip device, according to our simulations.

We do not claim or believe that our flip-chip approach is the best solution for all applications requiring low thermal resistance. However, we do think our approach will give the smallest chip size and lowest junction temperature for monolithic microwave integrated circuit (MMIC) power amplifiers beyond 10 W.

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[2] D. Hill, A. Khatibzadeh, W. Liu, T. Kim, and P. Ikalainen, "Novel HBT with reduced thermal impedance," *IEEE Microwave Guided Wave Lett.*, pp. 373–375, Nov. 1995.

References

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[3] G. Jackson, D. Teeter, D. Bradford, and M. Cobb, "A scalable MMIC-compatible power HBT," in *1995 IEEE MTT-S Dig.*, pp. 457–460.