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Effective Heat Spreading with Separate Ohmic in AlGaN/GaN HEMTs

Kang-il Lee[1], Jin-hong Park[1], Hyun-jun Cho[1], Jin-cherl Her[1], Chan-sei Yoo[1,3], Ho-young Cha[2] and Kwang-seok Seo[1]

[1]School of Electrical Engineering and Computer Science, Seoul National University, Republic of Korea
San 56-1 Shillim-dong Kwanak-gu Seoul 151-742, Republic of Korea
Phone: +82-2-877-0298, Fax: +82-2-887-6575, E-mail: traveler83@snu.ac.kr
[2]School of Electronic and Electrical Engineer, Hong-Ik University, Republic of Korea
[3]Electronic Materials & Packaging Research Center, Korea Electronic Technology Institute

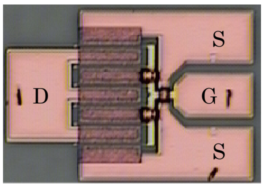
1. Introduction

AlGaN/GaN based high electron mobility transistors (HEMTs) have been developed for high-power and high-frequency applications for a long time [1]-[2]. Although state-of-the-art technologies have brought enormous improvement on the performance of AlGan/GaN HEMTs, a power collapse phenomenon still remains as a fundamental problem that limits their rf performance. There have been various theories concerning the mechanism underlying the power collapse in AlGaN/GaN HEMTs [3]. Among others, self-heating effect in the conducting channel is considered as one of the major causes. Self-heating effect leads to reduced electron mobility and drift velocity [4]-[5], thus degrading device performance, especially in rf output power at higher voltages. Severe self-heating may even damage the device itself. To address the self-heating problem, various heat dissipation methods have been discussed in literature with effective thermal management. For example, one approach is to modify the device topology [3], [6]. Another approach is to adopt heat-sink structures such as flip-chip bumps [7].

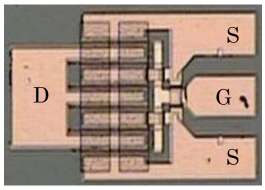
In this paper, we propose a separate ohmic pattern to improve heat spreading. First, a finite-element thermal simulation is performed to determine an optimum value of ohmic separation. Then, with the modified layout, an AlGaN/GaN HEMT on Si is fabricated. Improvement on heat spreading is demonstrated by the infrared (IR) thermography. Finally, output power characteristic is measured to confirm the heat spreading effect.

2. Thermal Simulation of Separate Ohmic Pattern

The separation of ohmic pattern was firstly proposed in [8]. In our work, we applied the similar method to manage self-heating of AlGaN/GaN HEMTs. The idea is to separate the center of the ohmic like shown in Fig. 1(b) so that the generated heat can be effectively spread out. To study the thermal behavior of the AlGaN/GaN HEMTs within this structure, three-dimensional finite element simulations were performed. We defined the gates as the heat sources and the heat generation was assumed to be uniform among all the heat sources. The gate width, gate pitch, and the substrate thickness were 150 μm, 50 μm, 120 μm, respectively. The constant temperature (T = 25℃) at the backside of the devices was defined as a boundary condition. To determine an optimum value for ohmic separation, ohmic spacing was splited as 10 μm, 25 μm, and 50 μm, respectively. Figure 2 shows the two-dimensional results of the thermal simulation over varying ohmic spacing. For each simulation structure, we obtained a disspate power density at the device temperature of 200℃ because the performance of the AlGaN/GaN HEMTs is deteriorated when device maximum temperature rises up to 200℃ [3]. Since the dissipated power density ($P_{Dissipated}$) is a value directly proportional to the maximum output power (P_{OUT}) as described in Eqs. (1) and (2), we can use these simulation results to predict the ouput power peformance of the device under the assumption that the other parameters such as power gain (G) and power added efficiency (P.E.A) be the same.

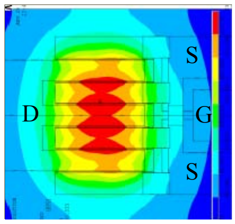


(a) Conventional

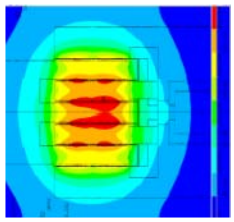


(b) Modified (separate ohmic)

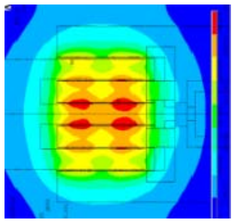
Fig. 1. Layout of the AlGaN/GaN HEMT (2×6×150 μm).



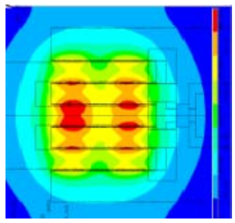
(a) Ohmic spacing 0 μm
D.P.D : 5.3W/mm



(b) Ohmic spacing 10 μm
D.P.D: 7.5 W/mm



(c) Ohmic spacing 25 μm
D.P.D: 8.2 W/mm



(d) Ohmic spacing 50 μm
D.P.D: 8.4 W/mm

(D.P.D: Dissipated Power Density)

Fig. 2. Thermal simulation results over varying ohmic spacing for AlGaN/GaN HEMTs on Si.

$$P_{Dissipated} + P_{OUT} = P_{IN} + P_{DC} \quad (1)$$

$$P_{OUT} = \frac{P.E.A}{100 - P.E.A} \times \frac{G}{G-1} \times P_{Dissipated} \rightarrow \mathbf{P_{OUT} \propto P_{Dissipated}} \quad (2)$$

The dissipated power density over varyring ohmic spacing is plotted in Fig. 3. As shown, the disspate power density increases as the ohmic spacing increased up to 25 µm. However, when the ohmic spacing is larger than 25 µm the increase in disspate power density was negligible. Considering the area efficiency as well, 25 µm was determined as an optimum value for ohmic spacing in our device.

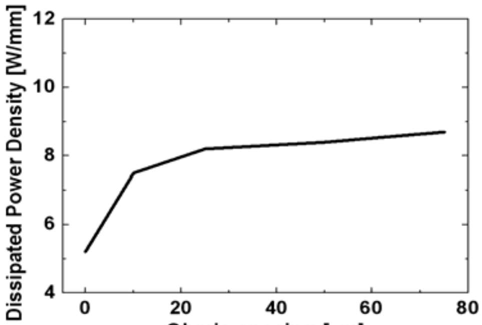
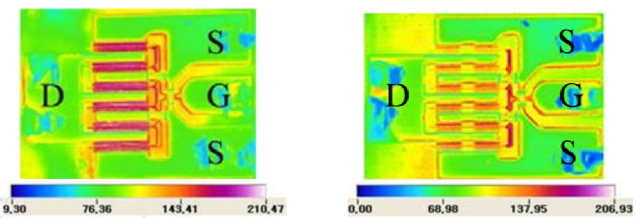


Fig. 3. Ohmic spacing versus dissipated power density at a device maximum temperature (T = 200℃) .

2. Device Fabrication and Measurement

To confirm the concept of the separate ohmic and its thermal simulation results, we fabricated two types of AlGaN/GaN HEMTS on silicon substrate: one without ohmic separation and the other with ohmic spacing of 25 µm. The device heterostructure consisted of 1µm thick GaN buffer, followed by 17.5nm of AlGaN (26% Al fraction), capped with a 2nm GaN layer. Firstly, all samples were passivated with 1200 Å SiN_x using remote ICP-CVD[9]. Then SiN_x was etched using an ICP-RIE with CF_4/O_2 for ohmic opening. Ohmic contacts were attained by e-beam evaporation of Si/Ti/Al/Mo/Au followed by annealing at 835℃ for 30 s. This procedure resulted in a contact resistance of 0.45Ω-mm. Mesa isolation was accomplished by Cl_2 plasma etching. The gate was defined by E-beam lithography, followed by e-beam evaporation of a Ni/Ir/Au schottky metal stack and lift-off. The fabricated devices had gate length×width of 0.3×150 µm^2, gate field plate of 1.5µm in length. To improve thermal spreading, the device substrate was thinned from 500 µm to 110 µm. A Ti/Au metalization process was appied to the backside of the



(a) Conventional layout (b) Separated ohmic

Fig. 4. IR temperature maps of fabricated AlGaN/GaN HEMTs with (a) no ohmic separation (b) ohmic separation of 25µm at V_{GS} = -1.5V and V_{DS} = 20V.

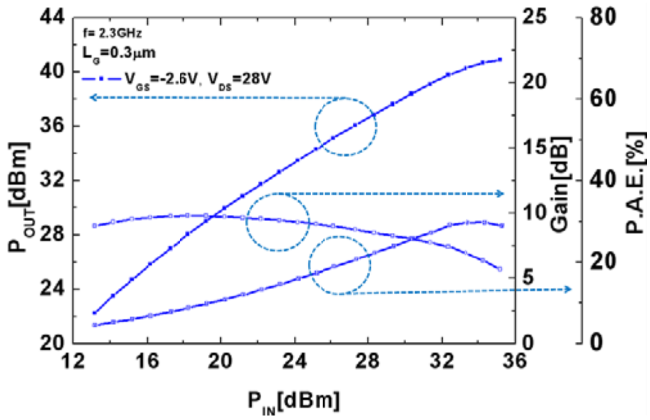


Fig. 5. Output power characteristics of the device with separate ohmic measured at V_G = -2.6V, V_{DS} = 28V. Output power (P_{out}) and Power density (P.D) is 12.3W and 3.42W/mm, respectively.

Figure 4 demonstrates IR thermography of the fabricated devices. As shown, the heat near gate junction is effectively dispersed by seperate ohmic layout. The maxium gate junction temperature of the two devices are 210℃ and 171℃, respectively, showing that the separation of ohmic lowers the maxium temperature by 19 %. Measured output power characteristics are illustrated in Fig. 5. For the device with ohmic spacing of 25 µm, the output power and the power density were obtained as 12.3 W and 3.42 W/mm, respectively, at the drain bias of 28 V. This result is about 13 % increase in output power density compared with that of the device without ohmic separation.

3. Conclusions

We have developed a thermally enhanced AlGaN/GaN HEMT with separate ohmic structure. By the thermal simulation, an optimum value for ohmic spacing was determined. IR thermography confirmed that the newly designed ohmic pattern suppresses the concentration of heat in the vicinity of the gate junction. The fabricated AlGaN/GaN HEMT on Si with optimized ohmic spacing showed output power density of 3.42 W/mm at the drain bias of 28 V, which is a 13 % increase compared with that of the device without ohmic separation.

Acknowledgements

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