X-band AlGaN/GaN HEMT with over 80W Output Power

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***Abstract* — AlGaN/GaN High Electron Mobility Transistors (HEMTs) were developed for X-band applications. The operating voltage and temperature dependence of output power characteristics in CW operating conditions were investigated. The developed AlGaN/GaN HEMT with combined two dies of 11.52 mm gate periphery exhibits output power of over 81.3W with a power added efficiency (PAE) of 34% under V_{DS}=30V, CW operating condition at 9.5GHz, and a gain compression level of 3dB.**

***Index Terms* — GaN, HEMT, power amplifier, X-band**

I. INTRODUCTION

As a promising candidate for next generation of microwave power devices, AlGaN/GaN HEMTs have attracted much research interest due to the inherent advantages of their high voltage and high power density. There are many reports related to high output power characteristics for L-band applications including wireless base station [1]-[2], and for C-band applications, such as satellite communication systems and fixed wireless access systems [3]-[5]. However, there's not many papers reported for high power characteristics of AlGaN/GaN HEMTs in X-band applications. AlGaN/GaN HEMTs are very attractive for power application at X-band and above because they have higher saturation velocity and power density. The higher power density is a large advantage to achieve higher output power at higher frequencies, because the physical dimensions are limited for considering the resonance frequencies of the package. Therefore, it is difficult for GaAs FETs to surpass over 30W of output power at X-band because of the thermal and electrical design constraint in the limited package size.

In this work, we present the highest packaged power AlGaN/GaN HEMT for X-band frequency range. The operating voltage and temperature dependence of output power characteristics in CW operating conditions were individually investigated with full gate width. The fabricated device demonstrated over 80 W output power under CW operating conditions at 9.5GHz.

II. DEVICE STRUCTURE AND FABRICATION

Fig. 1 shows a cross sectional view of fabricated HEMTs. An undoped AlGaN/GaN HEMT structure was grown on a 4H SiC substrate by MOCVD.

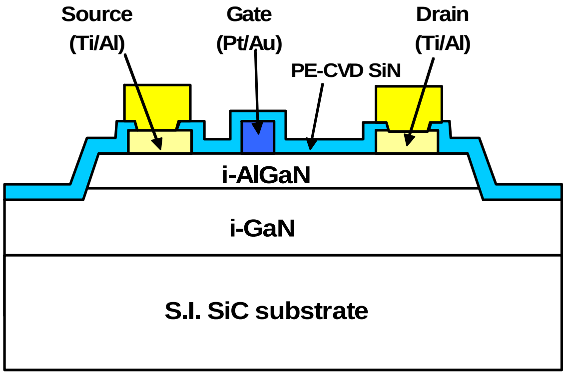

Fig. 1. Schematic cross-section of fabricated AlGaN/GaN HEMT.

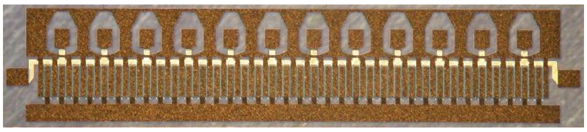

Fig. 2. Photograph of AlGaN/GaN HEMT die with a unit and total gate width of 160um and 11.52mm, respectively. Die size is 2.9mm x 0.7mm.

The fabrication process began with mesa isolation by Cl_2/Ar electron cyclotron resonance reactive ion beam etching (ECR-RIBE). After mesa-isolation, Ti/Al were evaporated by E-beam and annealed by RTA in N_2 ambient to form source and drain electrodes. A square shaped Schottky gate electrode was formed with E-beam evaporated Pt/Au. We used SiN film deposited by conventional PE-CVD for surface passivation. The interconnection, air-bridges and pads were formed with a standard Au-plating process. The gate length was chosen to be 0.7mm, which was easily achieved by standard i-line stepper lithography. Fig. 2 is a photograph of a single 11.52mm gate width die. The backside of the die was thinned to 150um by mechanical polishing to reduce thermal resistance.

III. DEVICE CHARACTERISTICS

Fig. 3 shows the DC characteristics for small gate width of 100um periphery device. The fabricated HEMT exhibited a saturation drain current of 0.6A/mm with a pinch-off voltage of -4 V.

Fig.4 shows the operating drain voltage (Vds) dependence of saturated output power (Psat) and power-added efficiency (PAE) of gate width of 400um periphery device at 6GHz. These results were measured on wafer with tuned for each operating drain voltages. It is noticed that the output power increased linearly and the PAE kept constant.

Two 11.52mm gate width dies were attached with internal matching circuits into a conventional Copper package, which size is 11.0mm x 12.9mm (Fig. 5). The device was optimized for power-match condition at Vds=20V and Ids=4.0A.

Fig.6 shows an operating voltage dependence of output power characteristics and PAE of the packaged device. As the operating drain voltage increased, the saturated output power increased almost linearly. The packaged device showed output power as almost same as the 400um periphery device. You may also notice that the PAE of the packaged device was smaller than that of the 400um periphery device. It came from the difference of the gain between the 23.04mm periphery packaged device at 9.5GHz and the 400um periphery at 6GHz.

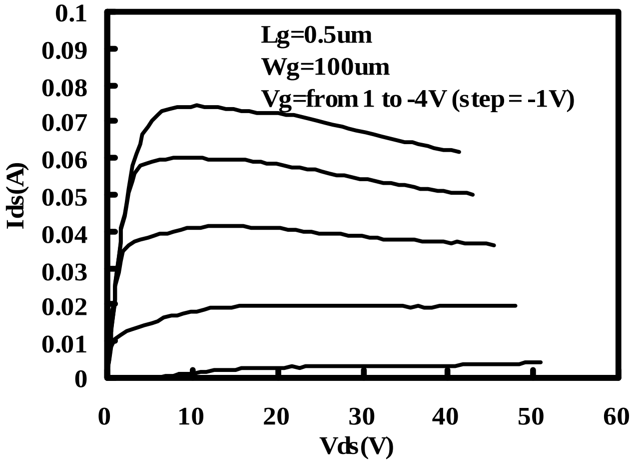

Fig. 3. Drain current-voltage characteristics of 100um periphery device.

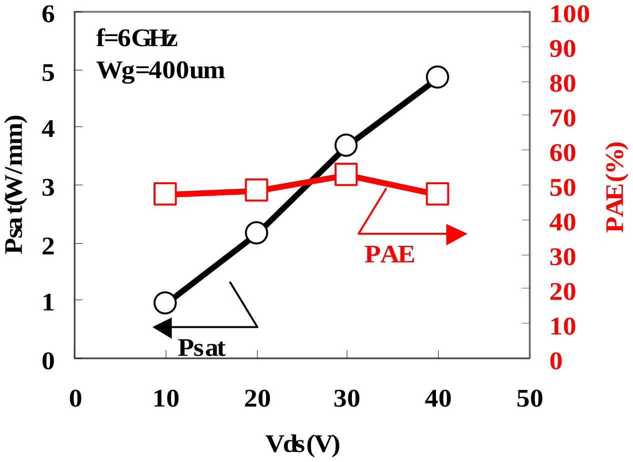

Fig. 4. Operating voltage dependence of saturated output power and power-added efficiency under CW operating condition at 6GHz. Wg=400um.

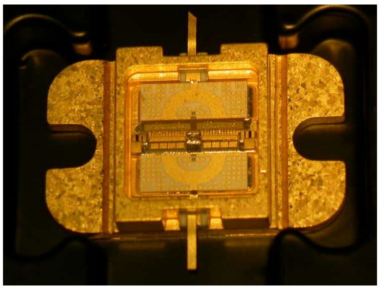

Fig. 5.Photograph of the packaged device with internal matching circuits.

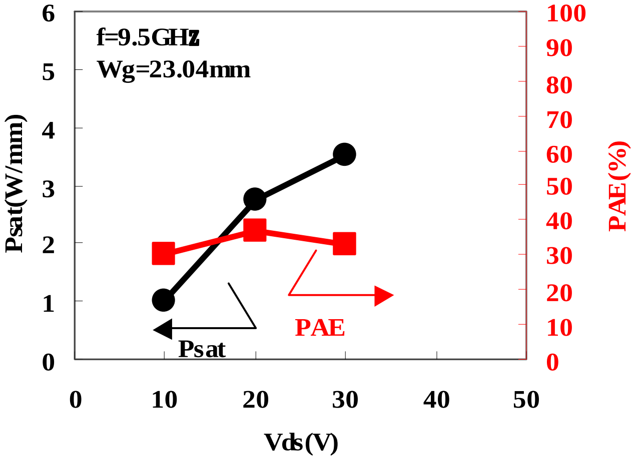

Fig. 6. Operating voltage dependence of saturated output power and power-added efficiency under CW operating condition at 9.5GHz. Wg=23.04mm.

For the present, it may be useful to look more carefully into those operating voltage dependences that we observed. It is clear that operating temperature is also increased with drain voltage. In other words, the operating voltage dependence includes temperature dependence.

For example, the flange temperatures were 18degC and 36degC at 10V and 30V operating voltage in Fig.6, respectively. So a 50ohm test fixture with the device was prepared on a temperature controlled cooling plate to measure the individual temperature dependence. Fig.7 shows the flange temperature dependence of output power and gain. The operating voltage and frequency were fixed at 20V and 9.5GHz. The temperature coefficients of gain and saturated power are -0.016 dB/degC and -0.004 dB/degC, respectively.

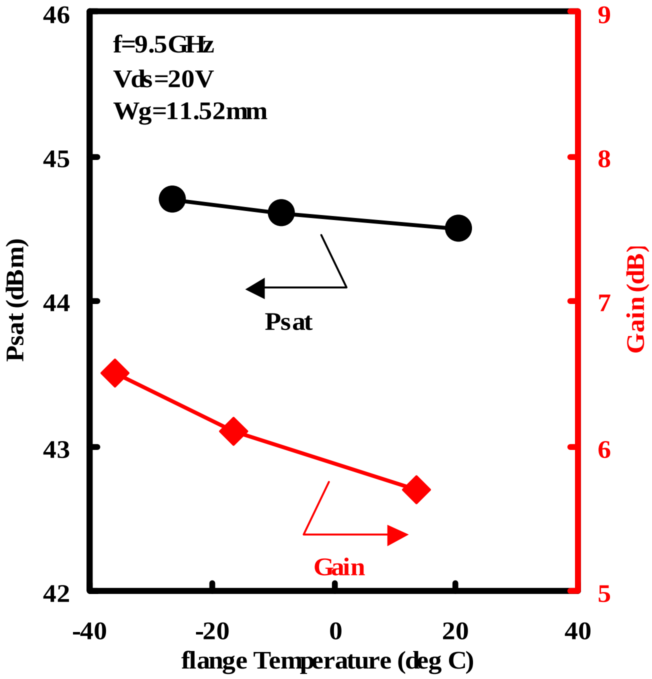

Fig. 7. Flange temperature dependence of saturation Power and gain under CW operating condition at 9.5GHz and operating voltage at 20V. Wg=11.52mm.

To calculate the channel temperature, the thermal resistance of the device was measured. Fig.8 shows an infrared image of 11.52mm die in the un-lidded package under DC operation. It indicated the thermal resistance from the channel to the flange was 2.8degC/W at the channel temperature of 175degC. The channel temperatures at saturated operation of each condition in Fig.7 were calculated as around 107degC, 121degC and 146degC, respectively. With those data points, the temperature coefficients of gain and saturated power for the channel temperature were calculated as -0.018 dB/degC and -0.005 dB/degC, respectively. These temperature coefficients of gain and saturated power almost agree with a previous work [17].

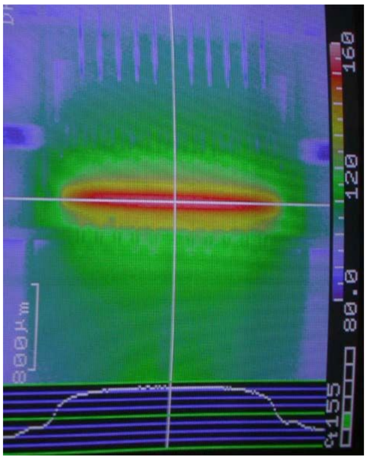

Fig. 8. Infrared image of 11.52mm die in the un-lidded package

Fig.9 shows the power characteristics under CW operating conditions. The measured output power reached 81.3W(49.1dBm) with 8.5dB linear gain and 34% PAE at a drain voltage of 30V. The flange temperature was 36degC.

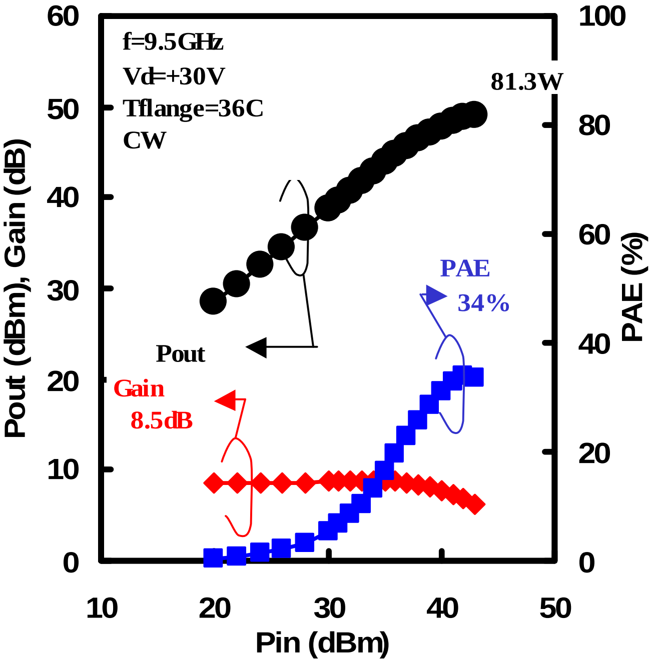

Fig. 9. Output Power, gain and power-added efficiency for a packaged AlGaN/GaN HEMT as a function of input power under CW operating condition at 9.5GHz. Wg=11.52mm x 2 dies.

Fig. 10 shows the saturated output power for AlGaN/GaN HEMT reported as a function of the operating frequency [1]-[16] and [18]-[21]. To the best of our knowledge, the saturated output power of over 80W under CW operation in X-band is a top level.

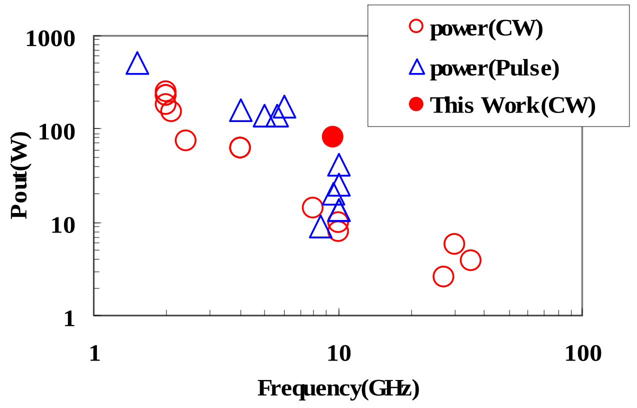

Fig. 10. Power performance of AlGaN/GaN HEMT developed in this work and that of previously reported.

IV. Conclusion

In this study, we showed the operating voltage and temperature dependences of output power and gain characteristics in CW operating conditions with full gate width of 11.52mm. The temperature coefficient of gain and saturated power for the channel temperature were calculated as -0.018 dB/degC and -0.005 dB/degC, respectively. These are similar to GaAs MESFET. The fabricated device demonstrated over 80 W output power under CW operating conditions at 9.5GHz and the channel temperature was calculated as 221 degC when the flange temperature was 36degC.

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