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 temperature dependence of output power characteristics in CW operating conditions was investigated. The developed AlGaN/GaN HEMT with 11.52 mm gate periphery exhibits output power of over 40W with a power added efficiency (PAE) of 42% under V_{DS}=22V, CW operating condition at 9.5GHz, and a gain compression level of 3dB. And combined 2-die exhibits output power of over 80W.**

***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 high saturation velocity and high power density. The high 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. It is hard 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 amplifier for X-band frequency range. The temperature dependence of output power characteristics in CW operating conditions was investigated with full gate width. The fabricated device demonstrated over 40 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.

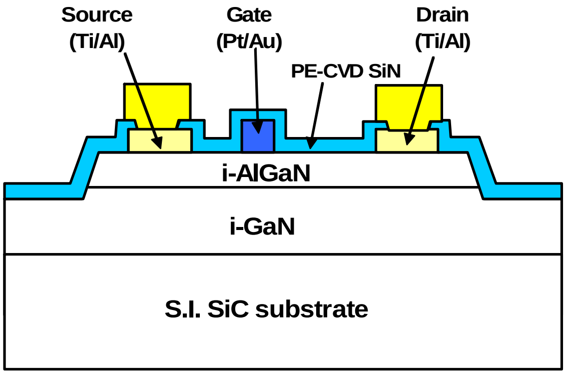

Fig. 1. Schematic cross-section of fabricated AlGaN/GaN HEMT.

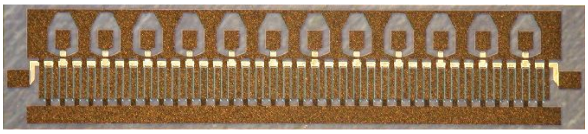

Fig. 2. Photograph of AlGaN/GaN HEMT die with a unit and total gate width of 160um and 11.52mm, respectively. Die size is 2.9mm x 0.7mm.

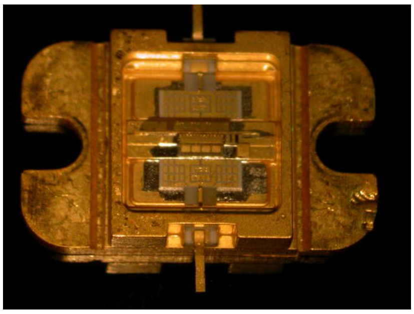

Fig. 3. Photograph of packaged device with internal matching circuits.

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 100um by mechanical polishing to reduce thermal resistance.

The transistor die was attached with internal matching circuits into a conventional Cu package, which size is 11.0mm x 12.9mm (Fig. 3).

III. DEVICE CHARACTERISTICS

Fig. 4 and 5 show the DC characteristics for small gate width of 100um device. The fabricated HEMT exhibited a maximum drain current of 0.8A/mm with a pinch-off voltage of -5 V and a maximum transconductance of 193mS/mm.

The device was optimized for power-match condition at Vd=15V and Id=2.5A. Fig.6 shows an operating voltage dependence of output power characteristics and power-added efficiency (PAE) of the device. As the operating voltage increases, the saturated output power increases linearly, even if it is beyond the voltage early optimized for power-match conditions. It is also observed that PAE also increases as raising the operating voltage. This increase of PAE comes from the effect of non-zero knee voltage of the devices.

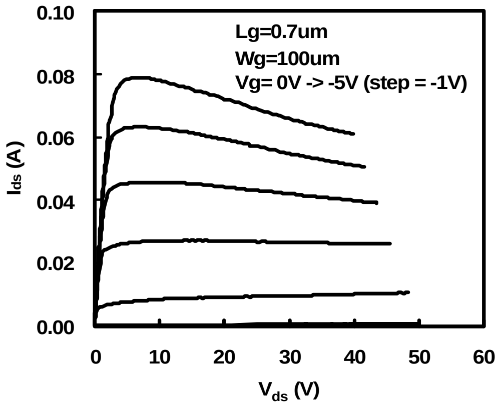

Fig. 4. Drain current-voltage characteristics of 100um periphery device.

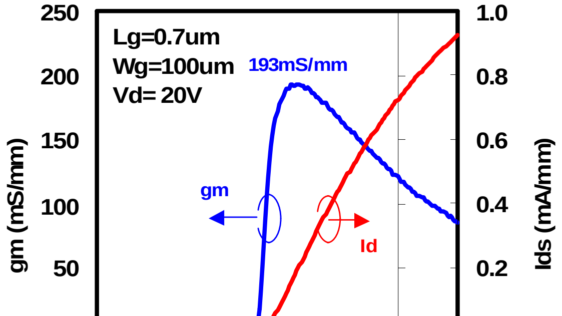

Fig. 5. Transfer characteristics and transconductance of 100um periphery device.

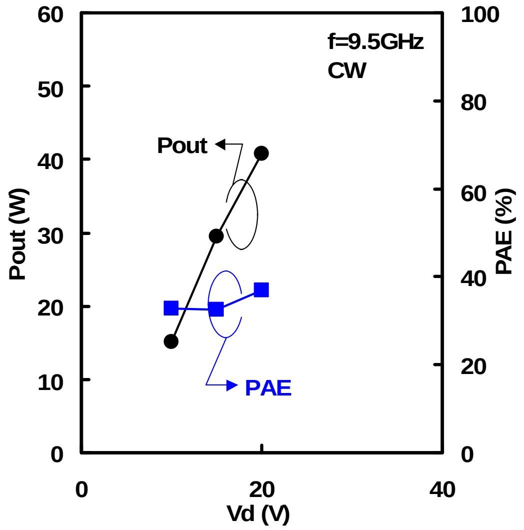

Fig. 6. Operating voltage dependence of saturated output power, gain and power-added efficiency under CW operating condition at 9.5GHz. Wg=11.52mm.

Operating temperature also increased with drain voltage. The flange temperatures were 30degC and 50degC at 10V and 20V operations in Fig.6, respectively. Operating voltage dependence includes temperature dependence. A 50ohm test fixture with the device was put on a temperature controlled cooling plate to measure the temperature dependencies. Fig.7 shows the flange temperature dependence of output power and gain. The operating voltages and frequency were fixed at 15V and 9.5GHz. The temperature coefficients of gain and saturated power are -0.022 dB/degC and -0.016 dB/degC, respectively.

To calculate the channel temperature, the thermal resistance of the device was measured. Fig.8 shows 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 102degC, 116degC and 143degC, respectively. With those data points, the temperature coefficients of gain and saturated power for the channel temperature were calculated as -0.022 dB/degC and -0.015 dB/degC, respectively.

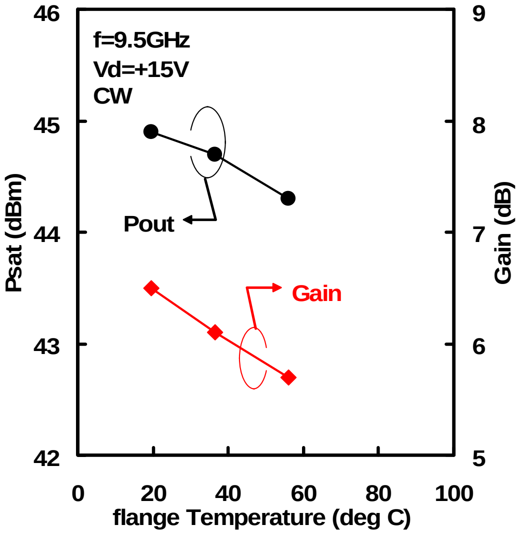

Fig. 7. Flange temperature dependence of saturation Power and gain under CW operating condition at 9.5GHz and operating voltage at 15V. Wg=11.52mm.

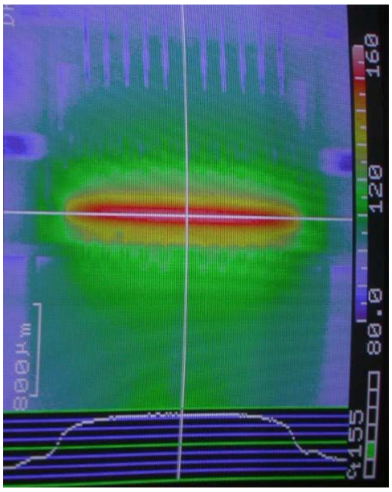

Fig. 8. Infrared image of 11.52mm die in the un-lidded package

This temperature coefficient of gain is almost as same as a previous work of -0.025 dB/degC[17]. However the temperature coefficient of saturated power is larger than the previous work of -0.006 dB/degC[17].

Fig.9 shows the power characteristics under CW operating conditions. The measured output power reached 42.7W(46.3dBm) with 6.1dB linear gain and 35.4% PAE at a drain bias of 22V. The flange temperature was 50degC without active cooling and the channel temperature was calculated as 174degC. The maximum PAE is 40.0% at 38.0W(45.8dBm).

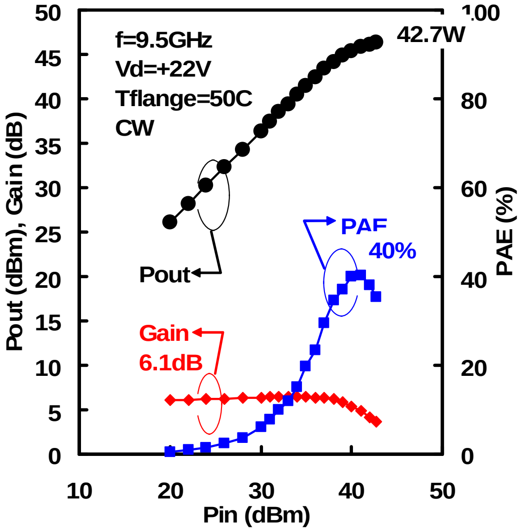

Fig. 9. Output Power, gain and power-added efficiency for a packaged AlGaN/GaN HEMT as a function of input power under CW operating condition at 9.5GHz. Wg=11.52mm.

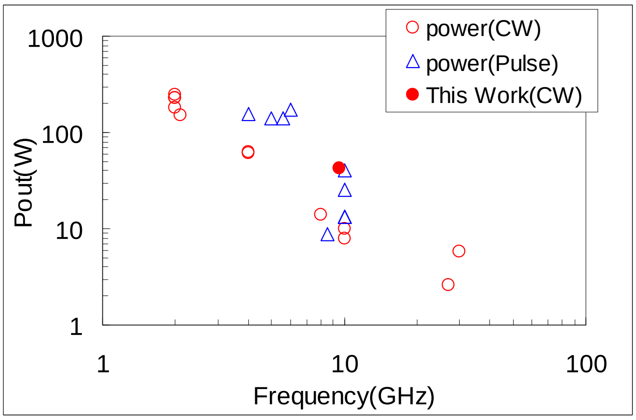

Fig. 10. Power performance of AlGaN/GaN HEMT developed in this work and that of previously reported.

Fig. 10 shows the saturated output power for AlGaN/GaN HEMT reported as a function of the operating frequency [1]-[16]. To the best of our knowledge, the saturated output power of over 40W under CW operation in X-band is a top level.

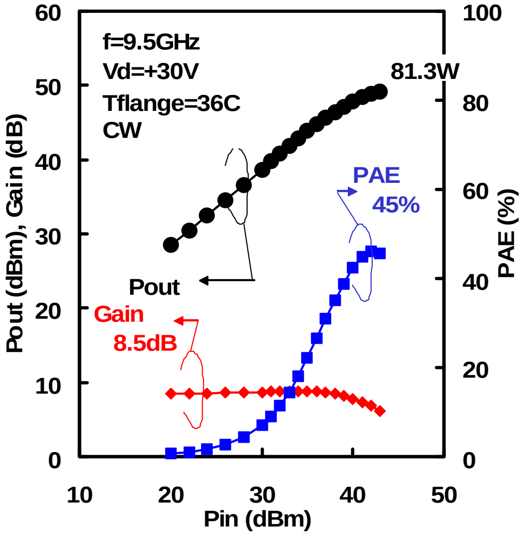

Fig.11 shows the power characteristics under CW operating conditions. The measured output power reached 81.3W(49.1dBm) with 8.5dB linear gain and 45% PAE at a drain bias of 30V. The flange temperature was 36degC and the channel temperature was calculated as 221degC.

Fig. 11. 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.

VII. Conclusion

In this study, we showed the 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 -0.022 dB/degC and -0.015 dB/degC, respectively. 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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