# Developing GaN HEMTs for High Efficiency

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***Abstract* — An efficiency of AlGaN/GaN High Electron Mobility Transistors(HEMTs) were improved for Ku band. The AlGaN/GaN HEMTs were developed with an achievable fmax of 138GHz, which depended on the thickness of the AlGaN barrier layer and the gate length. A 6.4mm gate periphery device was thereafter designed with matching circuits on an alumina substrate on a metal carrier plate. The output power achieved 20 W at 26GHz.**

***Index Terms* — AlGaN, GaN, HEMT, Ka-band.**

## I. INTRODUCTION

As a promising candidate for the next generation of microwave power devices, AlGaN/GaN HEMTs have attracted much research interest due to the inherent advantages of their high breakdown field and high current density. In X-band and Ku-band, AlGaN/GaN HEMTs have been reported [1, 2] and products using this technology have been released.

In Ku-band, Satellite Communications, SATCOM is one application that has been adopting Solid State Amplifiers, SSPA. However, in Ka-band, Traveling Wave Tube Amplifiers, TWTA are still dominant in SATCOM due to the insufficient output power of GaAs pHEMT [3, 4]. This limitation can be resolved by AlGaN/GaN HEMTs technology and GaN devices operating at millimeter-wave frequencies has been drawing a great deal of interests.

AlGaN/GaN HEMTs on-wafer load-pull systems were reported for 5.8 W/mm (5.8 W) at 30GHz with $10 \times 100$ µm of gate width [6], 6.9 W/mm (1.04 W) at 30 GHz with $2 \times 75$ µm [10], and 5.4 W/mm (8.05 W) at 30 GHz with 1.5 mm [9]. AlGaN/GaN HEMTs with impedance matching circuits exhibiting 3.3 W/mm (20.7 W) at 26 GHz has been demonstrated [15]. AlGaN/GaN HEMT MMICs were also reported for 3.1 W/mm (5.0 W) at 26.5 GHz with 1.6 mm of gate width in the final stage, and 3.3 W/mm (4.0 W) at 35 GHz with 1.2 mm of gate width in the final stage [13, 14].

Efficiency is important for any systems. In order to improve efficiency, we need to improve a drain efficacy and a gain.

In this paper, we demonstrate the RF performance of the AlGaN/GaN HEMTs with impedance matching circuits by comparing the thickness of the AlGaN barrier layer.

## II. DEVICE STRUCTURE AND FABRICATION

An undoped AlGaN/GaN HEMT structure was grown on a SiC substrate by MOCVD. As the gate length becomes shorter, the AlGaN barrier layer thickness becomes thinner. We had determined this layer to be of 15µm thick and of 30% Aluminum content [16]. A square shaped Schottky gate electrode was formed with E-beam evaporation. We used SiN film deposited by a conventional PE-CVD for surface passivation. The interconnection, air-bridges and pads were formed with a standard Au-plating process. To determine the gate length dependency of fmax, gate-length of 0.05, 0.15, and 0.25µm were fabricated.

Our conventional AlGaN/GaN HEMT which was compared the RF performance had a 25µm thick and 25% Aluminum content [1].

## III. DEVICE CHARACTERISTICS

Fig. 1 shows the DC characteristics of a 100µm gate-width periphery device. The developed HEMTs exhibited an approximate 125mA/mm of saturation drain current at Vds=5V. Depending on the gate length, the pinch-off voltages varied from -2V to -5V. Maximum transconductance (gm) of 400mS/mm was obtained at Vds=5V.

Fig. 2 shows the ft and fmax for a two finger 50µm HEMT device biased at Vds=10V and 24V with Ids=16mA. At Vds=24V, the fmax of the device increased with shorter gate length from 0.25µm to 0.15µm whereby it achieved fmax of 138GHz and ft of 34GHz. However, at 0.05µm gate length, the fmax of the device reduced.

By comparing the performance of the 0.05µm gate length device biased at Vds=10V and 24V, it can be observed that the decline of fmax is smaller at Vds=10V than at Vds=24V. It can be concluded that the drop in fmax was due to the short channel effect. Device of 0.15µm gate length was subsequently used for further studies in this work.

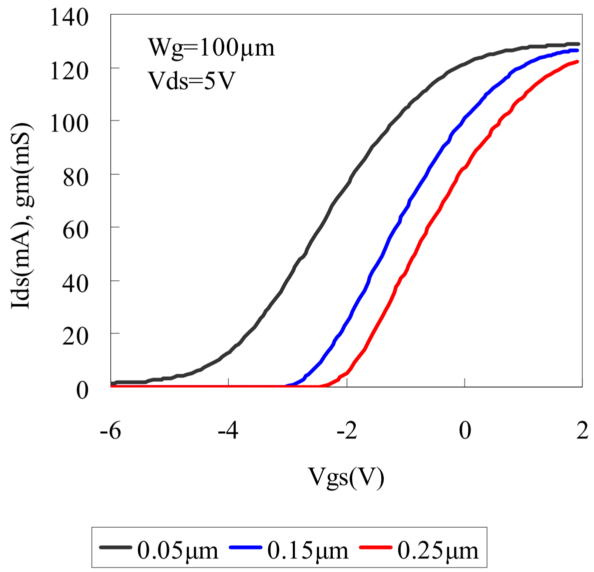


Fig. 1 Measured 100µm AlGaN/GaN HEMT drain current curves and transfer curves at Vds=5V.

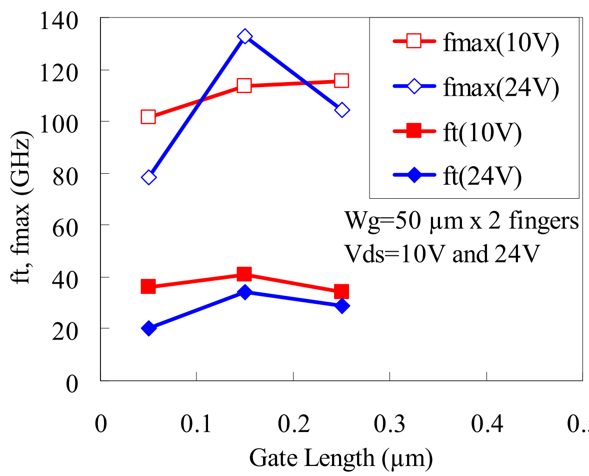


Fig. 2 fmax as a function of the gate length for 50µm x 2 devices. Vds=24V and 10V and Ids=16mA

## IV. OUTPUT POWER PERFORMANCE OF THE UNIT CELLS

Output power densities were measured with a load-pull system to estimate the capability of each structure. The frequency was set at 14 GHz whereby the tuners in our system could produce the optimum impedance for the devices with 4 × 100 µm of gate width.

Fig.3 (a) and (b) shows the operating drain voltage (Vds) dependence of 3dB compression output power (Psat) and the power-added efficiency (PAE) of the newly developed device at 14GHz. These results were achieved from on-wafer measurement with the source and load conditions tuned to the maximum efficiency for each operating drain voltage. It was noted that the output power increased linearly and the PAE remained relatively constant with increasing Vds. These results showed that the device has a power density of 2.9 W/mm at Vds=24V, and 4.8 W/mm at Vds=40V.

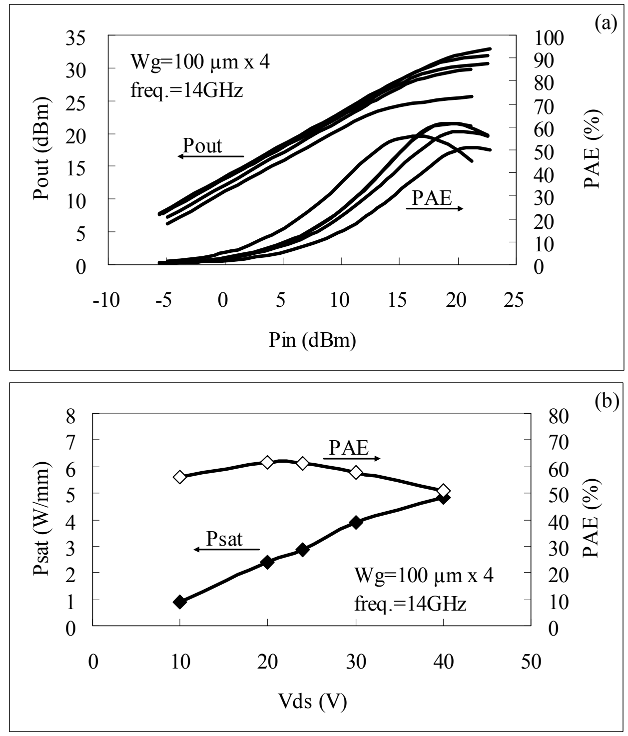


Fig. 3 (a) Output power and power-added efficiency of HEMT on 15nm/30% as a function of input power under CW operating conditions at 14GHz. Wg=100µm x 4, (b) Operating voltage dependence of saturated output power and power-added efficiency under CW operating conditions at 14GHz. Wg=100µm x 4, (c) Solid lines show the drain efficiencies and the saturated output powers of the device of 0.15µm gate length on 15nm/30%, and broken lines show ones of the conventional device of 0.35µm gate length on 25nm/25%.

Fig.4 (a) and (b) shows Vds dependence of Psat and PAE of the conventional device at 14GHz. Fig.4 (c) shows a comparison with Vds dependence of Psat and the drain efficiency (DE) of the newly developed device and our conventional device. The newly developed device achieved around five percents higher drain efficiency than the one of the conventional device.

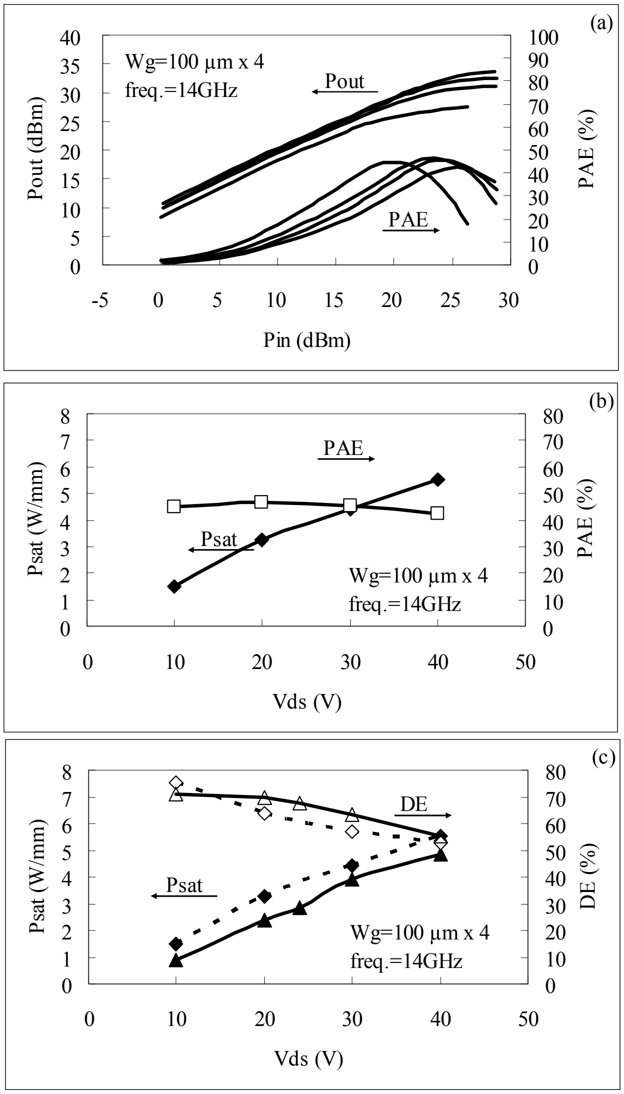


Fig. 4 (a) Output power and power-added efficiency of HEMT on 25nm/25% as a function of input power under CW operating conditions at 14GHz. Wg=100µm x 4, (b) Operating voltage dependence of saturated output power and power-added efficiency under CW operating conditions at 14GHz. Wg=100µm x 4, (c) Solid lines show the drain efficiencies and the saturated output powers of the device of 0.15µm gate length on 15nm/30%, and broken lines show ones of the conventional device of 0.35µm gate length on 25nm/25%.

## V. Output Power Performance of a 6.4-mm-wide Device

The wafer was thinned to 50µm to reduce the thermal resistance and diced into unit-cells. The unit-cell of Wg=0.6mm which had twelve 50µm-fingers.

Fig. 5 shows the input-output characteristics of a 16-cell HEMT on a metal carrier plate with input and output matching circuits for Vds=24V at 26GHz. The measured output power reached 15W (41.7dBm) at a drain voltage of 24V. The maximum PAE was 13.3% with 9W of output power.

Fig. 6 (a) shows the saturated output power for AlGaN/GaN HEMT reported as a function of the operating frequency. To the best of our knowledge, the saturated output power of over 20W under CW operation in Ka-band is the top level. Fig.6 (b) shows the power added efficiency for AlGaN/GaN HEMT reported in Ka-band as a function of the saturated output power. To the best of our knowledge, the power added efficiency of 18.5% with the saturated output power of 20W in Ka-band is the top level.

## VI. Conclusion

In this study, we developed AlGaN/GaN HEMTs for Ka-band by optimizing the AlGaN thickness and aluminum content. We showed the gate length dependency of fmax for some AlGaN barrier layers. The output power density and output power of the unit-cell on the AlGaN with a thickness of 15µm and a 30% Aluminum content were 3.6 W/mm and 2.1W. The HEMT with a gate width of 6.4mm demonstrated a saturated output power of 20W under CW operating conditions at 26GHz. This is our first step in developing GaN MMIC for Ka-band.

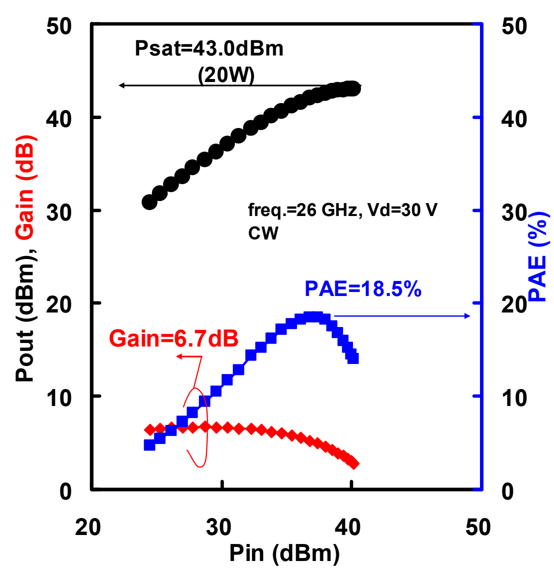


Fig. 6 Input-output characteristics of a 16-cell HEMT on a metal carrier plate with input and output matching circuits for Vds=24V at 26GHz.

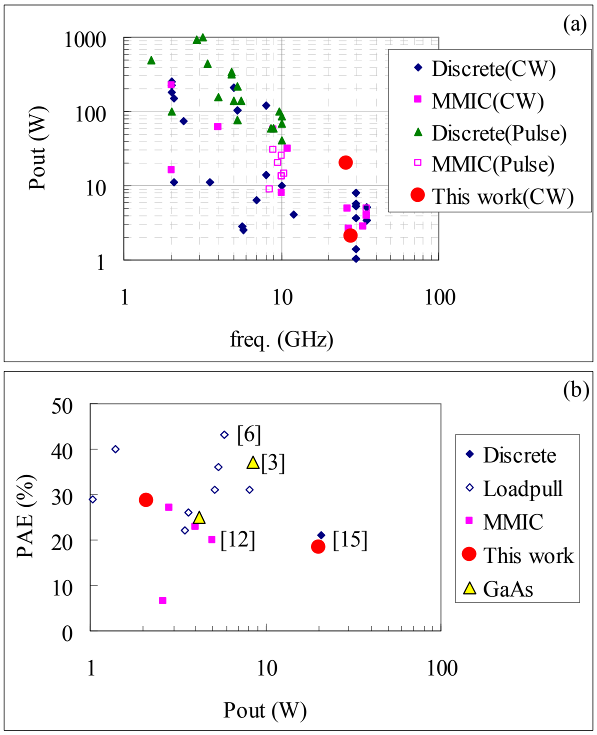


Fig. 7 (a) Power performance of AlGaN/GaN HEMT developed in this work and the works previously reported. (b) PAE performance of AlGaN/GaN HEMT developed in this work and the works previously reported at Ka-band.

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