GaN HEMTs with pre-match for Ka-Band with 18W

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***Abstract* — AlGaN/GaN High Electron Mobility Transistors(HEMTs) were developed with an achievable fmax of 138GHz. A 6.4mm gate periphery device was thereafter designed with pre-match circuits on the die and matching circuits on an alumina substrate at Ka-band. A saturated output power of 18.5W was achieved at 31GHz which to the best of our knowledge is the highest ever reported at Ka-band.**

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

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 × 100 μm of gate width [6], 6.9 W/mm (1.04 W) at 30 GHz with 2 × 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].

In this paper, we demonstrated the RF performance of AlGaN/GaN HEMTs with impedance matching circuits at Ka-band and the performances of these circuits with and without pre-match design were then compared.

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.

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 0.05um 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 0.15um gate length was subsequently used for further studies in this work.

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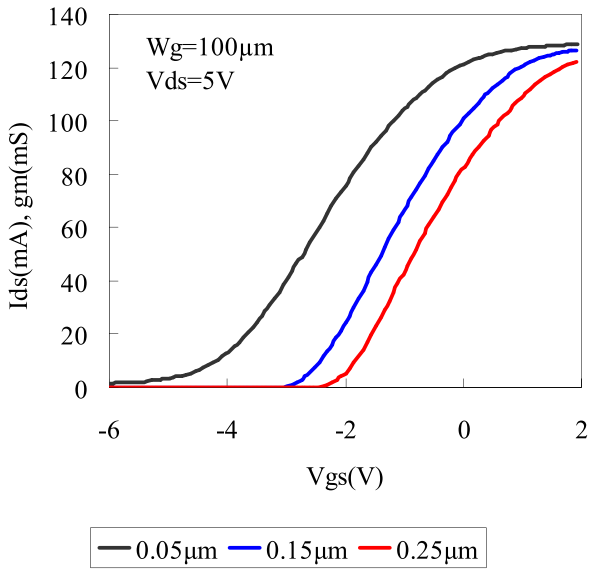

Fig. 1 Measured 100µm AlGaN/GaN HEMT drain current curves and transfer curves at Vds=5V.

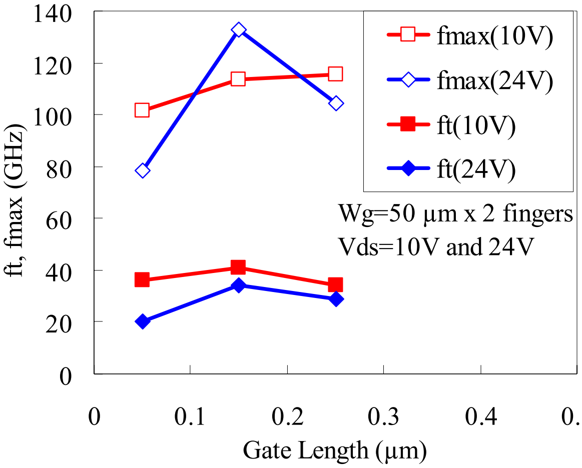

Fig. 2 fmax as a function of the gate length for 50µm x 2 devices. Vds=24V and 10V and Ids=16mA

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 shows the operating drain voltage (Vds) dependence of 3dB compression output power (P3dB) and the power-added efficiency (PAE) of the measured 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.

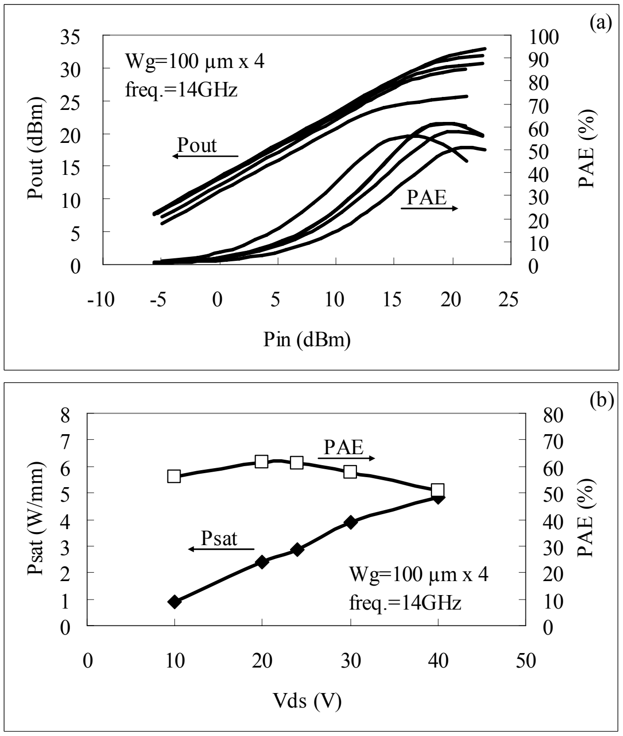

Fig. 3 (a) Output power and power-added efficiency of HEMT as a function of input power under CW operating conditions at 14GHz. Wg=100µm x 4 and Lg=0.15µm, (b) Operating voltage dependence of saturated output power and power-added efficiency under CW operating conditions at 14GHz. Wg=100µm x 4 and Lg=0.15µm.

To achieve an output power of 18W, the HEMT with a power density of 2.9 W/mm at 24V requires more than 6.2 mm of gate width, this amount to a gate finger of more than 124 for a 50um device. Fig. 4 (a) shows the MSG/MAG and Mason’s U of the 50um devices with the number of fingers (N) at 2, 4, 8 and 12. Fig. 4 (b) shows the fmax and maximum gain of the devices at 26GHz and 30GHz as a function of the number of fingers (N). It can be observed that increasing the number of fingers of the device decreases its fmax performance.

The developed GaN HEMT had multi cell which had substrate via-hole for each which determined the unit-cell minimum size. The number of cell was limited by the chip width and the number of 50µm-fingers for the unit-cell was determined at eight by the RF gain at 31GHz. The designed die consisted of 16-cell and 128 pieces of 50µm-fingers.

V. OUTPUT POWER PERFORMANCE OF A 6.4-MM-WIDE DEVICE

Two types of matching circuits were designed as shown in fig.5. The first design was a discrete type which had the transformation consisting of bond-wires and microstrip lines on alumina substrates for each of the input and output matching circuits. The other design was a pre-match type which besides the matching circuits on the alumina substrate, had a second transformation consisting of two microstrip lines on the semiconductor chip for each of the input and output matching circuits. The difference between these two designs is the position of the bond-wire which connected the semiconductor chip and the alumina substrate. The inductance which applied for the second transformation is larger than that of the first transformation. Generally, to increase the operating frequency of the circuit, the inductance has to be small.

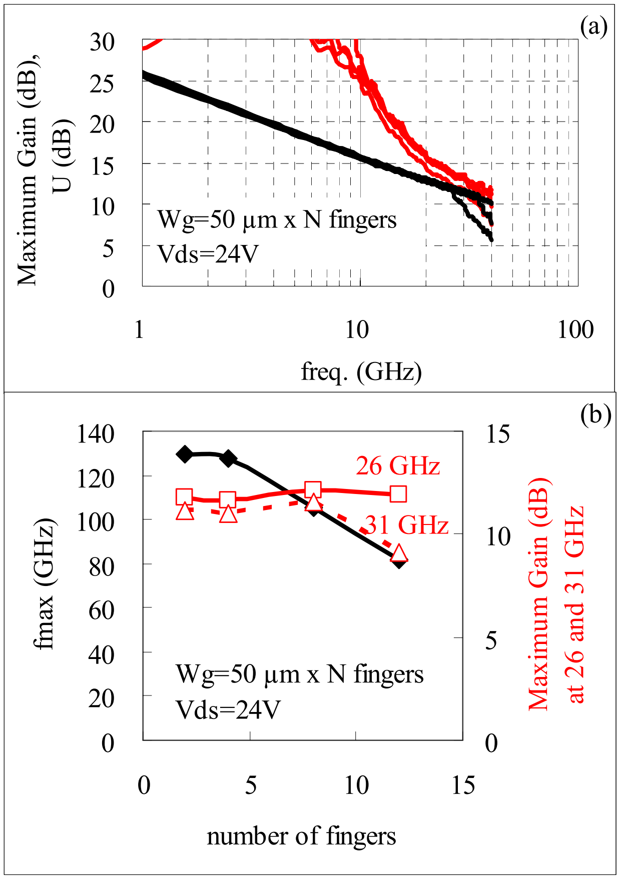

Fig. 4 (a) MSG/MAG and Mason's U. The number of 50µm-fingers (N) were 2, 4, 8 and 12, (b) fmax and maximum gain at 26 and 31GHz as a function of the number of 50µm-fingers (N).

Fig. 6 shows the input-output characteristics of the 16-cell HEMT with discrete type matching circuits measured on a metal carrier plate at 26GHz. A saturated output power of 20W (43.0dBm) was achieved at drain voltage of 30V. The maximum PAE was 18.5% with 15.8W of output power.

Fig. 7 shows the input-output characteristics of the 16-cell HEMT pre-match type measured on a metal carrier plate at 31GHz. A saturated output power of 18.5W (41.7dBm) was achieved at drain voltage of 24V. The maximum PAE was 21.9% with 13.5W of output power.

Fig. 8(a) shows the saturated output power for AlGaN/GaN HEMT reported as a function of the operating frequency. Fig.8 (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, this work achieved the highest saturated output power of 18.5W under CW operation and a power added efficiency of 21.9% ever reported in Ka-band.

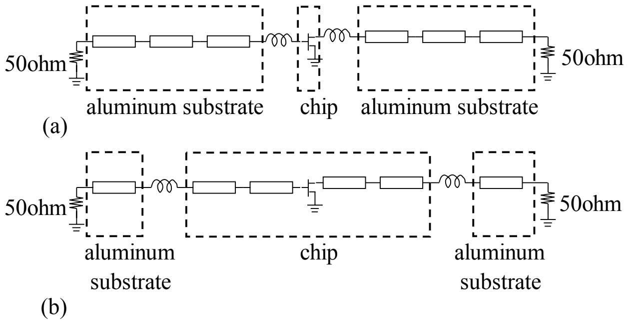

Fig. 5 Two types of matching circuits. (a) discrete type (b) pre-match type

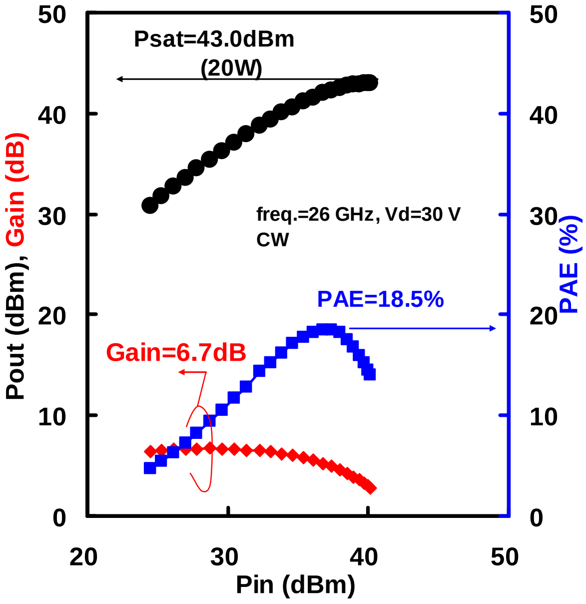

Fig. 6 Input-output characteristics of a discrete type 16-cell HEMT on a metal carrier plate with input and output matching circuits for Vds=30V at 26GHz.

VI. CONCLUSION

In this study, we have developed AlGaN/GaN HEMTs for Ka-band with pre-match chip. The HEMT with a gate width of 6.4mm achieved a saturated output power of 18.5W under CW operating conditions at 31GHz.

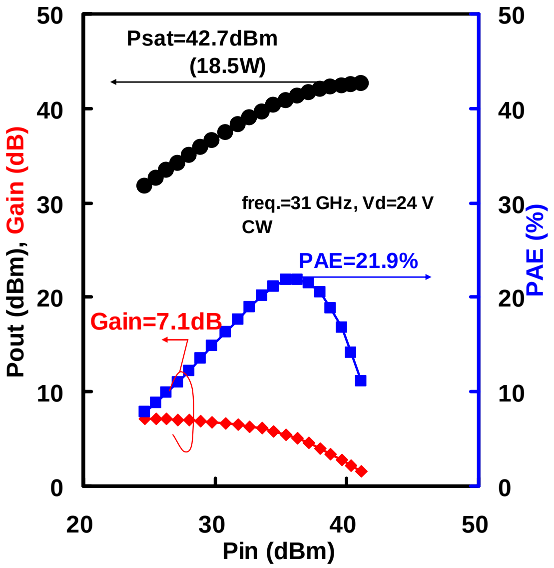

Fig. 7 Input-output characteristics of a pre-match type 16-cell HEMT on a metal carrier plate with input and output matching circuits for Vds=24V at 31GHz.

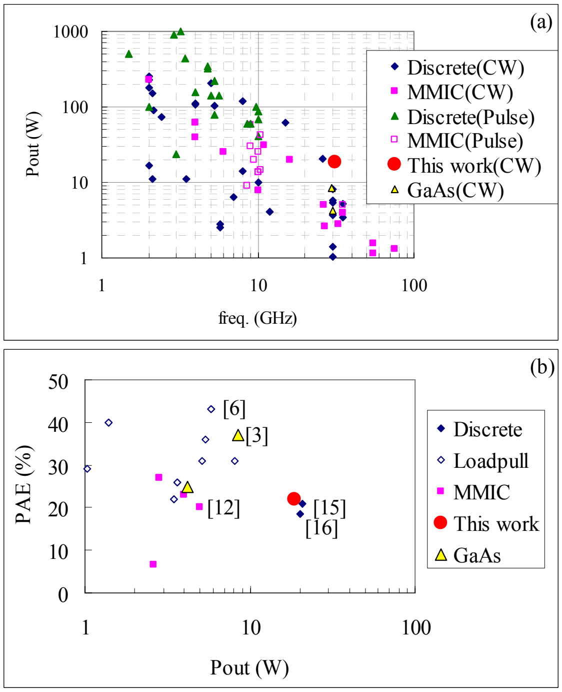

Fig. 8 (a) Power performance of AlGaN/GaN HEMT developed in this work and the works previously reported. (b) PAE performance of AlGaN/GaN HEMT developed in this work and the works previously reported at Ka-band.

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