

# Ku-band AlGaIn/GaN HEMT with Over 30W

Kazutaka Takagi<sup>#1</sup>, Yasushi Kashiwabara<sup>#2</sup>, Kazutoshi Masuda<sup>#3</sup>, Keiichi Matsushita<sup>#4</sup>, Hiroyuki Sakurai<sup>#5</sup>,  
Ken Onodera<sup>#6</sup>, Hisao Kawasaki<sup>#7</sup>, Yoshiharu Takada<sup>\*8</sup>, Kunio Tsuda<sup>\*9</sup>

<sup>#</sup>Microwave Solid-state Engineering Dept., Komukai Operations, Toshiba Corporation  
1, Komukai-Toshiba-cho, Saiwai-ku, Kawasaki, 212-8581, Japan

1Kazu.taka@toshiba.co.jp

<sup>\*</sup>Advanced Electron Devices Laboratory, Corporate R&D Center, Toshiba Corporation  
1, Komukai-Toshiba-cho, Saiwai-ku, Kawasaki, 212-8581, Japan

**Abstract**— AlGaIn/GaN High Electron Mobility Transistors (HEMTs) were developed for Ku-band applications. The operating voltage characteristics in CW operating conditions were investigated. The developed AlGaIn/GaN HEMT with combined two dies of 12 mm gate periphery exhibits output power of over 30W with a power added efficiency (PAE) of 12% under  $V_{DS}=30V$ , CW operating condition at 14.25GHz, and a gain compression level of 3dB.

## I. INTRODUCTION

As a promising candidate for the next generation of microwave power devices, AlGaIn/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 are not many papers that reported high power characteristics for AlGaIn/GaN HEMTs in Ku-band applications. AlGaIn/GaN HEMTs are very attractive for power application at Ku-band and above because they have a higher saturation velocity and power density. A higher power density is a large advantage for achieving 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 Ku-band because of the thermal and electrical design constraints in the limited package size.

In this work, we present the highest packaged power AlGaIn/GaN HEMT for Ku-band frequency range. The operating voltage dependence of output power characteristics in CW operating conditions were individually investigated with full gate width. The fabricated device demonstrated over 30 W output power under CW operating conditions at 14.25GHz.

## II. DEVICE STRUCTURE AND FABRICATION

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

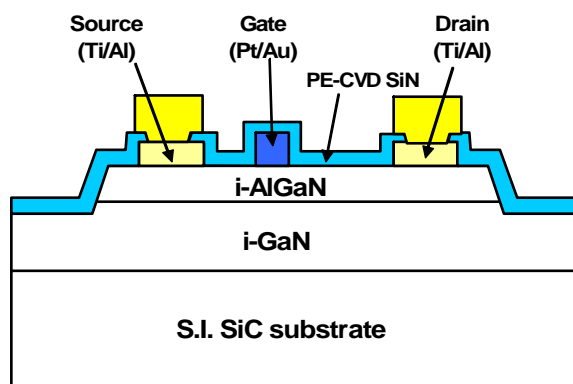


Fig.1 Schematic cross-section of fabricated AlGaIn/GaN HEMT.

The fabrication process began with mesa isolation by Cl<sub>2</sub>/Ar electron cyclotron resonance reactive ion beam etching (ECR-RIBE). After the mesa-isolation, Ti/Al were evaporated by E-beam and annealed by RTA in N<sub>2</sub> 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.

## III. DEVICE CHARACTERISTICS

Fig. 2 shows the DC characteristics for small gate width of the 100um periphery device. The fabricated HEMT exhibited a saturation drain current of 0.6A/mm at drain voltage  $V_d=10V$ . The pinch-off voltage was -4 V. A maximum transconductance (gm) of 225mS/mm was obtained at  $V_d=10V$ .

Designing the layout configuration, gain was one of top priorities, because gain affects the efficiency and the consumption power of the device. The unit gate-finger length was determined as 100um. The line of 100um on SiC substrate makes only signal-phase rotation of  $\pi/32$  radians. Even though the gate finger has capacitance, the signal-phase rotation should be less than  $\pi/16$  radians.

Fig.3 shows the operating drain voltage ( $V_{ds}$ ) dependence of 3dB compression output power ( $P_{3dB}$ ) and power-added efficiency (PAE) of gate width of four fingers of 100um periphery device at 6GHz. These results were measured on wafer with the source and load conditions tuned to maximum efficiency for each operating drain voltages and  $I_{ds}=0.02A$ . It was noted that the output power increased linearly and the PAE kept constant.

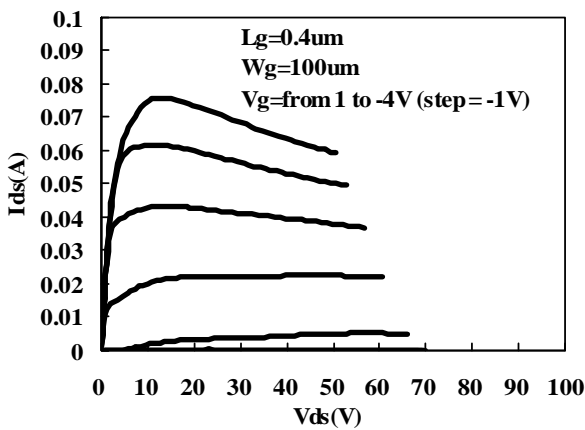


Fig.2 DRAIN CURRENT-VOLTAGE CHARACTERISTICS OF 100UM PERIPHERY DEVICE.

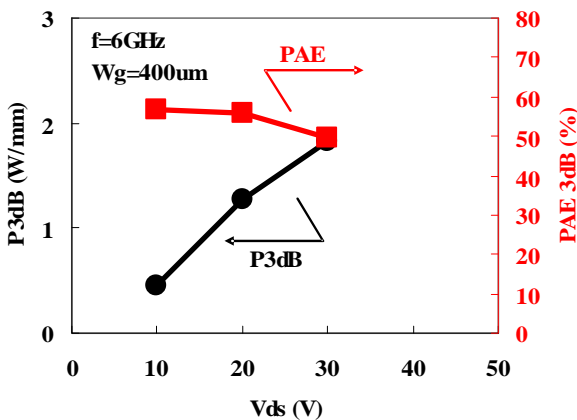


Fig.3 Operating voltage dependence of saturated output power and power-added efficiency under CW operating condition at 6GHz.  $W_g=400\mu m$ .

Fig.4 shows small-signal characteristics of two, four, six and ten fingers of 100um periphery devices. The maximum frequency at which MSG-state was maintained was decreased with the number of fingers, and MSG-state was maintained up to ten fingers at 14.25GHz. So the configuration of one-cell was determined as ten fingers of 100um.

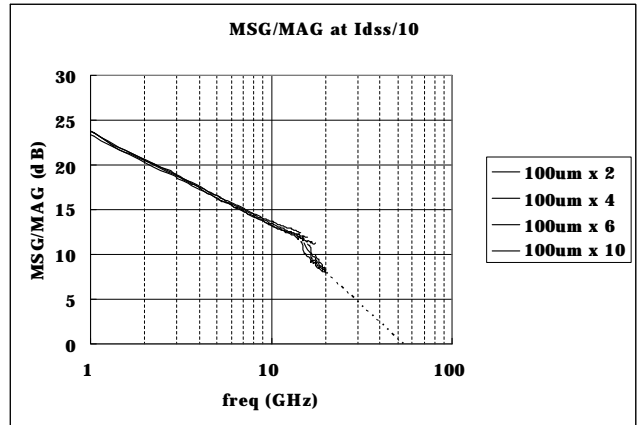


Fig.4 Small signal gains of 100um x 2, x 4, x 6 and x 10 periphery devices.

Fig. 5 is a photograph of a 12mm gate width die. The die has 12 cells. The backside of the die was thinned to 150um by mechanical polishing to reduce thermal resistance.

Two 12mm gate width dies were attached with internal matching circuits into a conventional copper package, which was 11.0mm x 12.9mm (Fig. 6). The device was optimized for power-match condition at  $V_{ds}=20V$  and  $I_{ds}=2.0A$ .

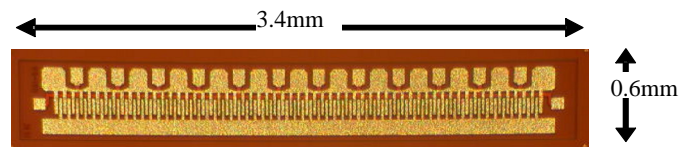


Fig.5 Photograph of AlGaIn/GaN HEMT die with a unit and total gate width of 100um and 12mm, respectively. Die size is 3.4mm x 0.6mm.

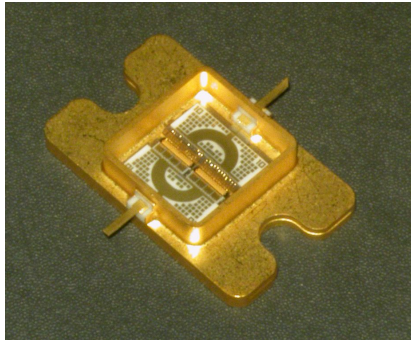


Fig.6 Photograph of the packaged device with internal matching circuits.

Fig.7 shows an operating voltage dependence of P3dB characteristics and PAE of the packaged device. At  $V_{ds}=20V$ , the packaged device showed almost the same output power that the 400um periphery device showed. As the operating drain voltage increased, the P3dB increased. It can also be seen that the PAE of the packaged device was smaller than that of the 400um periphery device. This came from the difference of the gain between the 24mm periphery packaged device at 14.25GHz and the 400um periphery at 6GHz.

Fig.8 shows the power characteristics under CW operating conditions. The measured output power reached 34.7W (45.4dBm) with 5.3dB linear gain and 15% of maximum PAE at a drain voltage of 30V. The flange temperature was 40degC at 3dB compression.

Fig. 9 shows the saturated output power for AlGaIn/GaN HEMT reported as a function of the operating frequency [1]-[24]. To the best of our knowledge, the saturated output power of over 30W under CW operation in Ku-band is the top level.

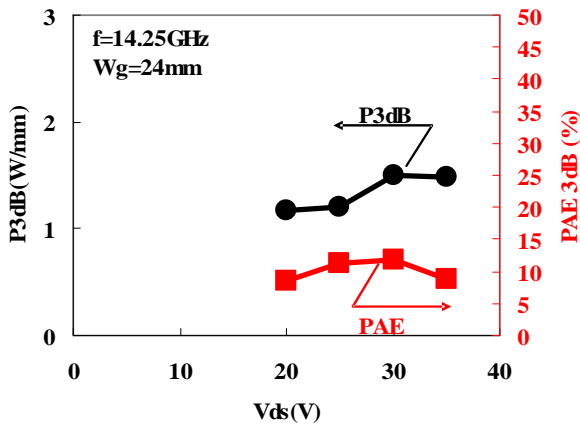


Fig.7 Operating voltage dependence of saturated output power and power-added efficiency under CW operating condition at 14.25GHz.  $W_g=12mm \times 2$  dies.

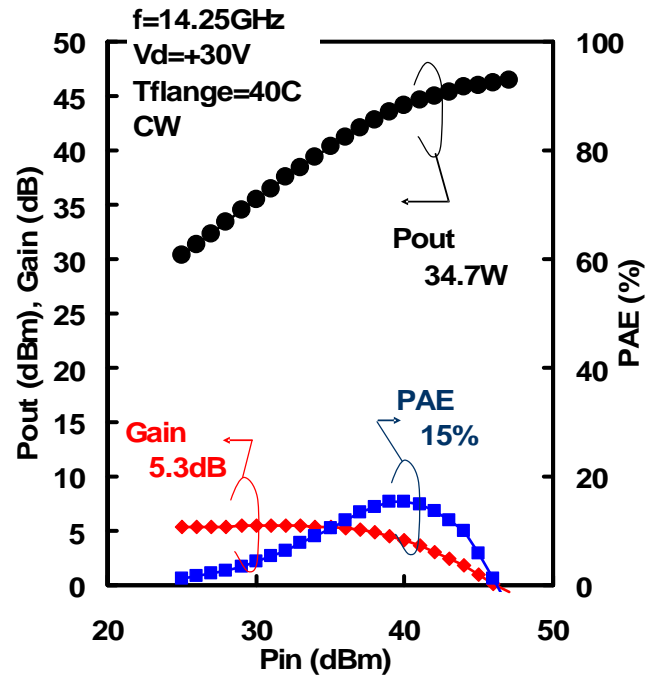


Fig.8 Output Power, gain and power-added efficiency for a packaged AlGaIn/GaN HEMT as a function of input power under CW operating condition at 14.25GHz.  $W_g=12mm \times 2$  dies.

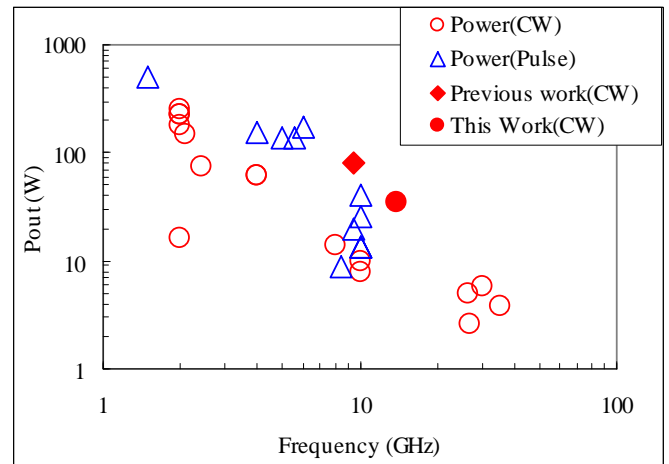


Fig.9 Power performance of AlGaIn/GaN HEMT developed in this work and the works previously reported.

#### IV. CONCLUSION

In this study, we showed the operating voltage of output power and gain characteristics in CW operating conditions with full gate width of 24mm. The fabricated device demonstrated over 30 W output power under CW operating conditions at 14.25GHz and the channel temperature was

calculated as 204 degC when the flange temperature was 40degC.

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