Ku-Band AlGaN/GaN-HEMT with over 30% of PAE

Kazutaka Takagi#, Shinji Takatsuka#, Yasushi Kashiwabara#, Shinichiro Teramoto#,
Keiichi Matsushita#, Hiroyuki Sakurai#, Ken Onodera#, Hisao Kawasaki#,
Yoshiharu Takada* , Kunio Tsuda*

#Microwave Solid-state Engineering Dept., Komukai Operations, Toshiba Corporation
1, Komukai-Toshiba-cho, Saiwai-ku, Kawasaki, 212-8581, Japan
Kazu.taka@toshiba.co.jp

*Electron Devices Laboratory, Corporate R&D Center, Toshiba Corporation
1, Komukai-Toshiba-cho, Saiwai-ku, Kawasaki, 212-8581, Japan

***Abstract* — AlGaN/GaN High Electron Mobility Transistors (HEMTs) were improved for X-band and Ku-band applications. The power added efficiency (PAE) was achieved over 40% for X-band and over 30% for Ku-band. The developed devices combined two AlGaN/GaN HEMTs of 12 mm gate periphery and exhibited the output power of over 50W. An AlGaN/GaN HEMT with four dies of 12 mm gate periphery was developed and exhibited the output power of over 120W.**

***Index Terms* — AlGaN, GaN, HEMT, PAE, X-band, Ku-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 voltage and high power density. A kW-class AlGaN/GaN HEMT pallet amplifier was reported for S-band High Power Applications [1]. C-band GaN HEMT Power Amplifier with 220W[2] and with 300W[3] were reported for satellite communication systems and fixed wireless access systems. AlGaN/GaN HEMTs were reported for X-band applications including radar systems with 80W [4], 60W[5] and 110W[6]. And AlGaN/GaN HEMTs was reported for Ku-band applications, such as satellite communication systems and satellite newsgathering systems with 65W [7].

The kW-class AlGaN/GaN HEMT for S-band and C-band GaN HEMT with 300W had around 50% of PAE, and brought kW-class or 300W of dispersion power.

Improvement of PAE is one of the most important issues for AlGaN/GaN HEMTs to handle higher power. Many methods of improving PAE were applied. Class-F operation achieved 68.7% of PAE at 5.7GHz [8].

But it is difficult for X-band and Ku-band to get 50% of PAE or class-F operation. The AlGaN/GaN HEMT for X-band has around 35% of PAE [4]. The AlGaN/GaN HEMT for Ku-band has 19.5% of PAE [7]. In this situation, the junction temperature limits the maximum output power from the device for the systems that are operated on continuous wave (CW) mode.

In this paper, we present our results from packaged devices combined with two or four 12mm-gate-width-dies.

II. Device Structure and Fabrication

An undoped AlGaN/GaN HEMT structure was grown on a 4H SiC substrate by MOCVD. The fabrication process began with mesa isolation by Cl2/Ar electron cyclotron resonance reactive ion beam etching (ECR-RIBE). After the mesa-isolation, ohmic metals were evaporated by E-beam and annealed by RTA in N2 ambient to form source and drain electrodes. A square shaped Schottky gate electrode was formed with E-beam evaporation. 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 0.4µm, which was easily achieved by standard i-line stepper lithography.

III. Device Characteristics

Fig. 1 shows the DC characteristics for the small gate width of the 100um periphery device. The fabricated HEMT exhibited a saturation drain current of 0.7A/mm at drain voltage Vd=5V. The pinch-off voltage was -4 V. A maximum transconductance (gm) of 225mS/mm was obtained at Vd=10V.

Fig.1 shows that the current collapse of the device is very small. The bold lines are the current swept from 5V of the drain voltage and the fine lines are the current swept from 70V. We achieved this result without field-plate by optimizing the fabrication process.

When designing the layout configuration, the gain was one of the 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 a signal-phase rotation of pai/32 radians. Even though the gate finger has capacitance, the signal-phase rotation should be less than pai/16 radians.

Fig.2 shows the operating drain voltage (Vds) dependence of 3dB compression output power (P3dB) and power-added efficiency (PAE) of a gate width with four fingers of 100um periphery device at 6GHz. These results were measured on a wafer with the source and load conditions tuned to maximum efficiency for each operating drain voltage and Ids=0.02A. It was noted that the output power increased linearly and the PAE remained constant.

Fig. 3 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.

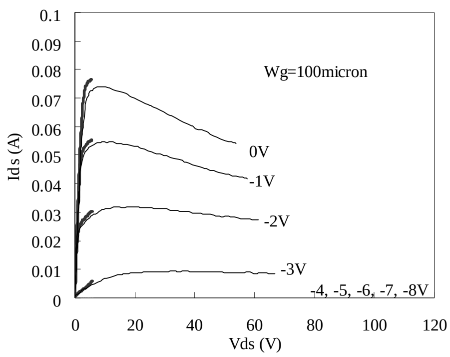

Fig.1 Drain current-voltage characteristics of 100micron periphery device.

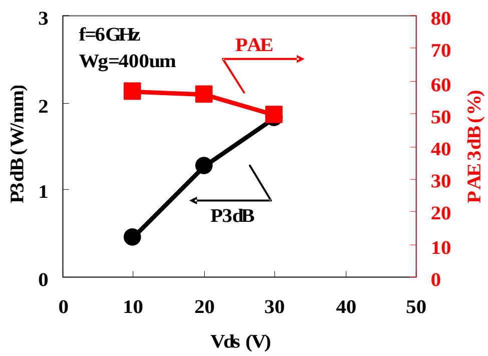

Fig.2 Operating voltage dependence of saturated output power and power-added efficiency under CW operating condition at 6GHz. Wg=400micron.

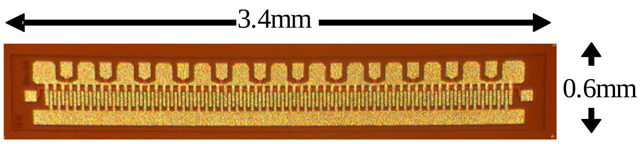

Fig.3 Photograph of AlGaN/GaN HEMT die with a unit and total gate width of 100um and 12mm, respectively. Die size is 3.4mm x 0.6mm.

IV. X-BAND

Two 12mm-gate-width dies were attached with internal matching circuits into a conventional copper package, which was 11.0mm x 12.9mm. The device was optimized for the PAE-matched condition at Vds=24V, Ids=2.0A and 8.5GHz.

Fig.4 shows the power characteristics under CW operating conditions. The measured output power reached 51W (47.1dBm) with 12.9dB linear gain and 43.7% of maximum PAE at a drain voltage of 24V.

To get more output power without increasing the junction temperature, four 12mm-gate-width dies were attached with internal matching circuits into a conventional copper package, which was 17.4mm x 24.4mm. The device was optimized for the PAE-matched condition at Vds=24V, Ids=4.0A and 8.1GHz.

Fig.5 shows the power characteristics under CW operating conditions. The measured output power reached 129W (51.1dBm) with 12.1dB linear gain and 47.8% of maximum PAE at a drain voltage of 24V.

V. KU-BAND

To develop the device for Ku-band, improving the gain was necessary. Fig.6 shows a simulation of the maximum gain dependence of GaN HEMT with 10 fingers whose length was 100μm and with grounding inductance changing from 0 to 100pH. The maximum frequency at which MSG-state is maintained is determined by source inductance. In X-band, the maximum gain of the GaN HEMT with 100nH of the source inductance was high enough. So the devices were grounded by wires.

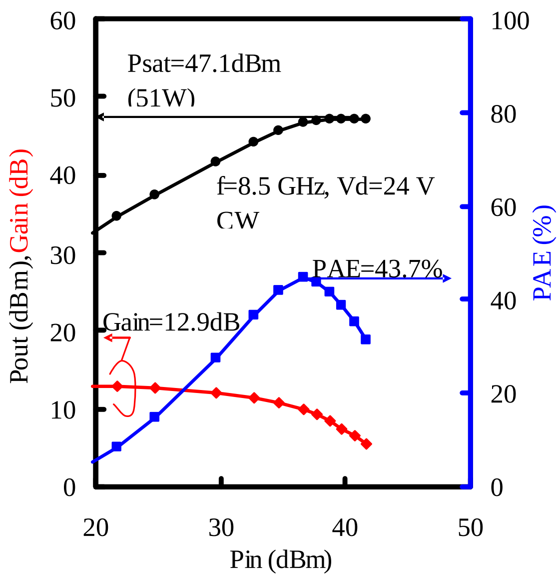

Fig.4 Output Power, gain and power-added efficiency for a packaged AlGaN/GaN HEMT as a function of input power under CW operating condition at 8.5GHz. Wg=12mm x 2 dies.

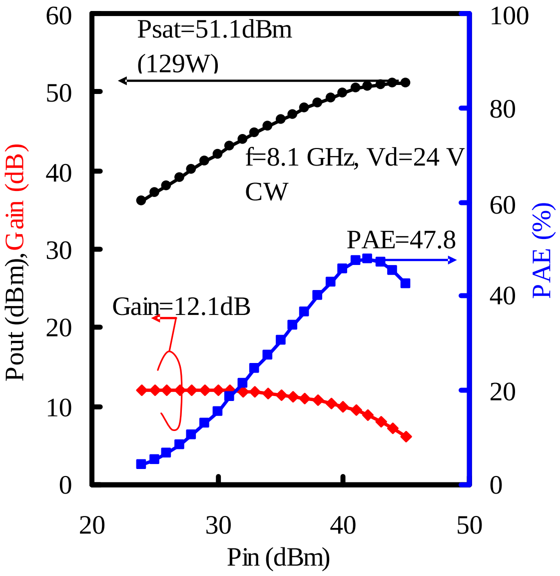

Fig.5 Output Power, gain and power-added efficiency for a packaged AlGaN/GaN HEMT as a function of input power under CW operating condition at 8.1GHz. Wg=12mm x 4 dies.

However in Ku-band, it was not high enough. Reducing the source inductance is also important when using over 14GHz. So, we adopted via holes instead of the wires for reducing the source inductance.

Fig. 7 is a photograph of a cross section of the die with the via hole under the source pad. The die has 12 via holes. The backside of the die was thinned to 50um by mechanical polishing to reduce the source inductance. Two dies with a 12mm gate width were attached with internal matching circuits into a conventional copper package, which was 11.0mm x 12.9mm.

Two 12mm-gate-width dies were attached with internal matching circuits into a conventional copper package, which was 11.0mm x 12.9mm. The device was optimized for PAE-matched condition at Vds=24V, Ids=2.0A and 11.4GHz. Fig.8 shows the power characteristics under CW operating conditions. The measured output power reached 65W (48.2dBm) with 10.9dB linear gain and 40.7% of maximum PAE at a drain voltage of 24V.

The device was optimized for PAE-matched condition at Vds=24V, Ids=2.0A and 14.0GHz. Fig.9 shows the power characteristics under CW operating conditions. The measured output power reached 53W (47.3dBm) with 10.2dB linear gain and 33.2% of maximum PAE at a drain voltage of 24V.

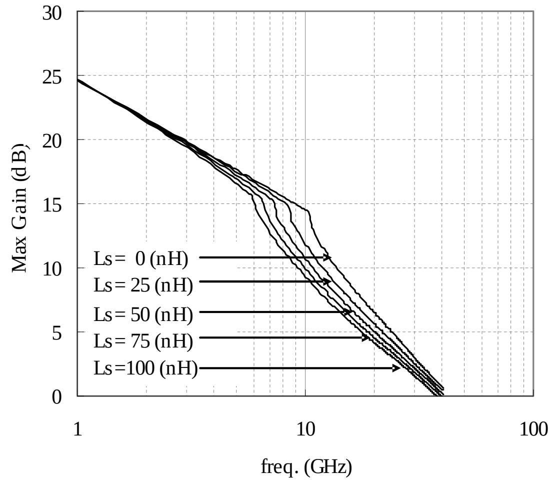

Fig.6 A Simulation of the maximum gain dependence of GaN HEMT with 10 fingers whose length was 100 micron and with grounding inductance changing from 0 to 100pH.

Fig.7 Cross section of the die with via-hole under the source pad.

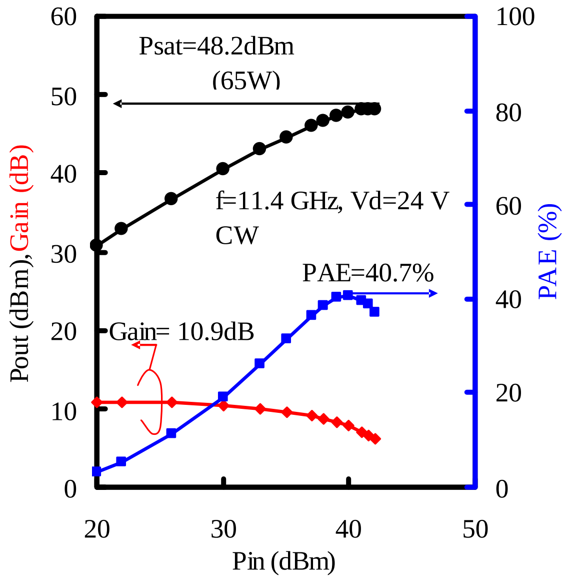

Fig.8 Output Power, gain and power-added efficiency for a packaged AlGaN/GaN HEMT as a function of input power under CW at 11.4GHz. Wg=12mm x 2 dies.

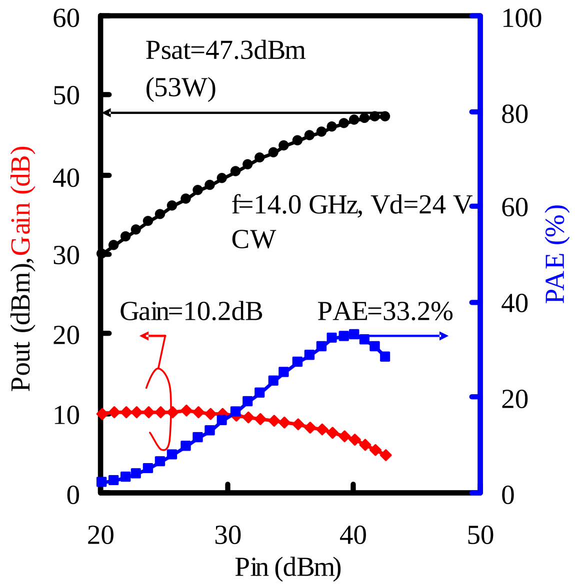

Fig.9 Output Power, gain and power-added efficiency for a packaged AlGaN/GaN HEMT as a function of input power under CW at 14.0GHz. Wg=12mm x 2 dies.

Fig.10 shows the power added efficiency for AlGaN/GaN HEMT reported in X-band or Ku-band as a function of the saturated output power [4]-[16]. To the best of our knowledge, the power added efficiency of 47.8% with the saturated output power of 129W in X-band is the top level. And the power added efficiency of 33.2% with the saturated output power of 53W in Ku-band is also the top level.

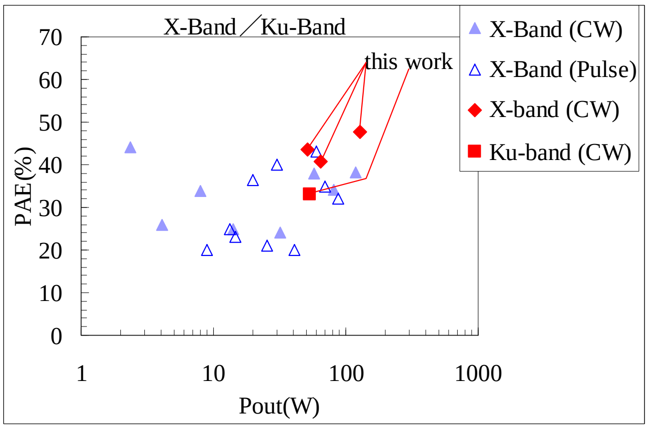

Fig.10 PAE performance of AlGaN/GaN HEMT developed in this work and the works previously reported.

VI. Conclusion

In this study, we showed the operating voltage of output power and gain characteristics of CW operating conditions with full gate width of 24mm without a field-plate. The fabricated device demonstrated over 30% power added efficiency with the saturated output power of over 50W under CW operating conditions at 14.0GHz.

References

[1] E. Mitani, M. Aojima and S. Sano,"A kW-class AlGaN/GaN HEMT Pallet Amplifier for S-band High Power Application", 2007 European Microwave Integrated Circuits Conference, pp176-179, Oct. 2007.

[2] K.Yamanaka, et.al,"C-band GaN HEMT Power Amplifier with 220W Output Power", 2007 IEEE MTT-S Int. Microwave Symp., Dig., pp. 1251-1254, June 2007.

[3] H. Shigematsu, et.al, "C-band GaN-HEMT Power Amplifier with Over 300-W Output Power and Over 50-% Efficiency", 2008 IEEE CSIC Symp., Oct. 2008.

[4] K. Takagi, et.al., "X-band AlGaN/GaN HEMT with over 80W Output Power", 2006 IEEE CSIC Symp., pp265-268, Nov. 2006.

[5] T.Yamamoto, E.Mitani, K.Inoue, M.Nishi and S.Sano, "A 9.5-10.5GHz 60W AlGaN/GaN HEMT for X-band High Power Application", 2007 European Microwave Integrated Circuits Conference, pp173-175, Oct. 2007.

[6] ShiChang Zhong, et.al, "AlGaN/GaN HEMT with over 110 W Output Power for X-Band", 2008 European Microwave Integrated Circuits Conference, pp91-94, Oct. 2008.

[7] Keiichi Matsushita, "Ku-band AlGaN/GaN HEMT over 65W", ISCS2007, TuA LN-1, p159, Oct. 2007.

[8] Kenta Kuroda, Ryo Ishikawa, and Kazuhiko Honjo, "High-Efficiency GaN-HEMT Class-F Amplifier Operating at 5.7 GHz", 2008 European Microwave Integrated Circuits Conference, pp440-443, Oct. 2008.

[9] R. Thompson, et.al., "Improved Fabrication Process for Obtaining High Power Density AlGaN/GaN HEMTs", 2003 IEEE GaAs IC Symp., pp298-300, Nov. 2003.

[10] R. Behtash, et.al., "Coplanar AlGaN/GaN HEMT power amplifier MMIC at X-band", 2004 IEEE MTT-S Int. Microwave Symp., Dig., pp. 1657-1659, June 2004.

[11] F. van Raay, et.al., “A Microstrip X-Band AlGaN/GaN Power Amplifier MMIC on s.i. SiC Substrate”, 13th GAAS Symp. Proceedings, Paris, France, October 2005, pp233-236

[12] D. M. Fanning, et.al., “25W X-Band GaN on Si MMIC”, CS MANTECH 2005 Conf. Proc., New Orleans, USA, April 11th-14th, 2005.

[13] F. van Raay, et.al., “A Coplanar X-Band AlGaN/GaN Power Amplifier MMIC on s.i. SiC Substrate”, IEEE Microwave and Wireless Components Letters, vol.15 no.7, July 2005, pp460-462

[14] C.Tangsheng, et.al,"X-Band Microstrip AlGaN/GaN HEMT Power MMICs", 2008 IEEE CSIC Symp., Oct. 2008.

[15] Y. Inoue, et.al,"A CW 7-12 GHz GaN Hybrid Power Amplifier IC with High PAE Using the Load-Impedance Change Compensation Technique", 2008 IEEE CSIC Symp., Oct. 2008.

[16] P. Schuh, H. Sledzik, et.al., "GaN MMIC based T/R-Module Front-End for X-Band Applications", 2008