GaN HEMTs are Still Ongoing

Kazutaka Takagi

Microwave Solid-state Engineering Dept.,

Komukai Complex, Toshiba Corporation

***Abstract* — Many newGaN/AlGaN HEMTs products have begun to bloom. On the other hand, the development and improvement of GaN/AlGaN HEMTs has continued. In this paper, we show the current status of GaN HEMTs. We also show two of our new works. The first one is an optimization of a source-field-plate for harmonics control. The second one is an MMICs in Ka-band.**

Index Terms — GaN HEMTs, efficiency, harmonics. Ka-band

I. INTRODUCTION

The first DC performance of AlGaN/GaN HEMT was shown in 1993 [1] and the first RF performance was demonstrated in 1996 with 1.1 W/mm of the output power density with 18.6 % of Power-Added-Efficiency (PAE) at 2 GHz for an AlGaN/GaN HEMT [2].

Many AlGaN/GaN HEMTs showed a discrepancy between the predicted output powers from static I-V curves because of a current-collapse that was a trap-related phenomenon to which both surface and bulk traps contributed. The current-collapse made the output power and PAE low. Some field-plates were adopted in order to compensate for the quality of epitaxial wafers and to reduce the current-collapse [22]-[24].

The output power density increased with the help of steadily improved growth techniques, material qualities, enhanced processing technologies and more optimum device designs including a gate-field-plate and source-field-plate structures. Then, a 32 W/mm in 2004 [3] and 41 W/mm in 2006 [4] were reported.

The high power density needed a high efficiency for reducing the generation of heat. The PAE also increased in each frequency. 85% of PAE with 16.5 W of output power at 2 GHz in 2006 [5], 80% of PAE with 4 W of output power at 4 GHz in 2010 [6], 79% of PAE with 2.1 W of output power at 5.65 GHz in 2012 [7], over 70% of PAE with 10 W of output power at 10 GHz in 2012 [8], 50% of PAE with 3.7 W of output power at 15 GHz in 2011 [9], and 52% of PAE with 1.2 W of output power at 30 GHz in 2013 [10] were reported.

After that, many products for radar systems were released. Products with 50% to 65% of PAE with over 300 W of output power were released at S-band [11], [12]. Products with 40% to 54% of PAE with over 80 W of output power were released at X-band [14], [15].

Many products for satellite communication systems were also released. Products with around 50% of PAE with over 100 W of output power were released at C-band [16]. Products with around 40% of PAE with over 100 W of output power were released at X-band [17], [18]. Products with around 30% of PAE with over 50 W of output power were released at Ku-band [19] from several companies. Products with around 30% of PAE with around 10 W of output power were released at Ka-band [20], [21].

On the other hand, the development and improvement of GaN/AlGaN HEMTs continued. Now the quality of epitaxial wafers has become much better. And harmonics controls have been adopted. Next, it was determined that the optimum device designs should be changed.

Interest has also moved to higher frequencies. Here, we show two of our new works. The first one is an optimization of a source-field-plate for harmonics control. The second one is an MMICs in Ka-band.

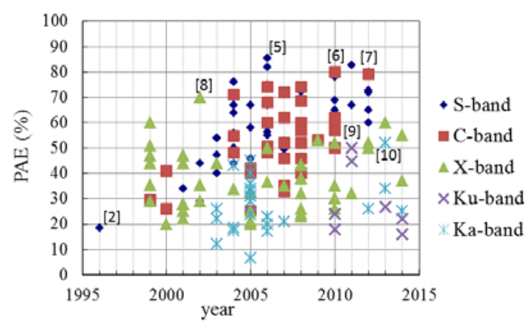

Fig. 1. PAE of AlGaN/GaN HEMTs versus year.

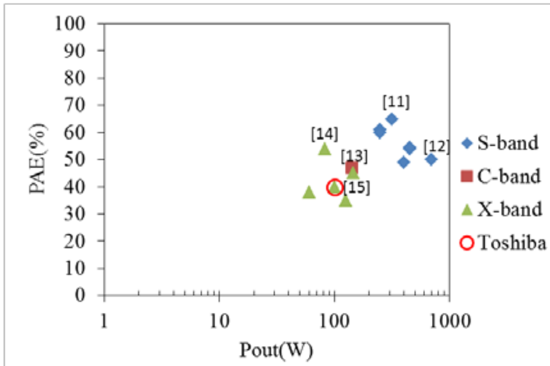

Fig. 2. PAE of recent AlGaN/GaN HEMTs products for radar systems versus Pout.

II. ALGAN/GAN HEMTS WITH FIELD-PLATE

Field-plates were necessary for reducing the current collapse, but they also decreased the gain by increasing the parasitic capacitance.

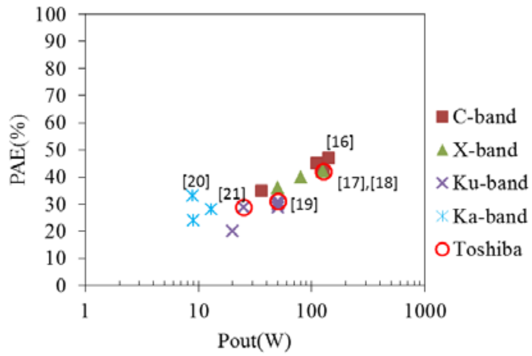

Fig. 3. PAE of recent AlGaN/GaN HEMTs products for satellite communication systems versus Pout.

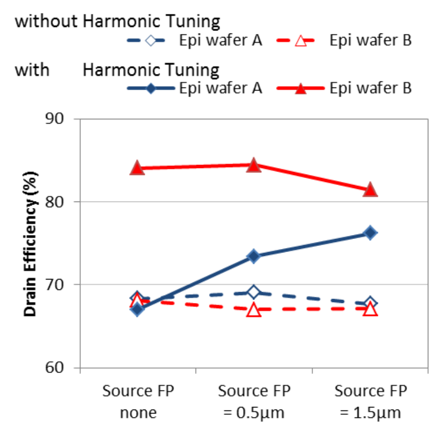

Fig. 4. Dependency of the drain efficiency on the epitaxial wafer and the device structure. The devices were biased at Vds=40 V.

Two kinds of AlGaN/GaN epitaxial wafers were used in this study, called "Epi wafer A" and "Epi wafer B" [25]. The wafers were grown on SI SiC substrates by MOCVD with a difference in the GaN buffer layer. "Epi wafer B" has considerably lower-density trap states than "Epi wafer A".

Three device structures were then fabricated on both wafers. They were (a) without a source field plate, (b) with a source field plate Lsfp=0.5µm and (c) Lsfp=1.5µm. All devices had the same gate length (Lg) of 0.6µm and a total gate width of 540µm (270µm x 2).

Fig.4 shows the drain efficiencies of the devices when the devices were biased at 40V drain supply at a fundamental frequency of 3.0 GHz on a harmonic tuning active loadpull system.

When the harmonics were shorted, each device showed almost the same drain efficiency. But when the harmonics were optimized, each device showed a difference.

For devices fabricated on "Epi wafer A", the drain efficiency increased with the longer source field plate. In contrast, for devices fabricated on "Epi wafer B", the drain efficiency decreased with the longer source field plate. And the drain efficiencies of "Epi wafer B" were higher than those of "Epi wafer A". The device without a source field plate on "Epi wafer B" showed a drain efficiency of 84% which was about 20% higher than that of "Epi wafer A". To achieve high efficiency, the harmonics control needed a gain at the harmonics frequencies which were two or three times higher than the fundamental frequency.

Two 35mm-gate-width dies which had a source field plate of 0.5µm were attached with internal matching circuits into a conventional copper package. Fig.5 shows the power characteristics under the pulsed condition of 200 µs pulse width and 10% duty cycles. The measured output power reached 461W (56.64dBm) with a 15.44dB related gain and 59.4% of PAE at a drain voltage of 50V.

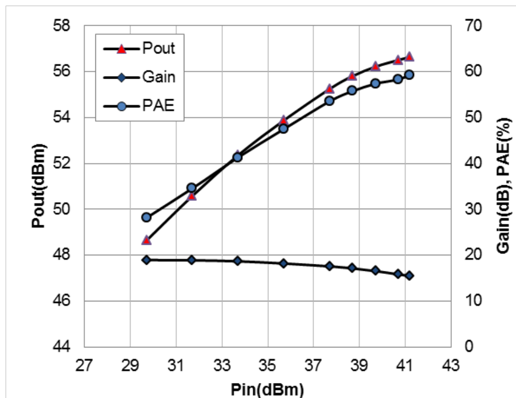

Fig. 5. A device with two 35mm-gate-width dies which had a source field plate of 0.5µm produced output power reached 461W (56.64dBm) with a 15.44dB related gain and 59.4% of PAE at a drain voltage of 50V under the pulsed condition of 200 µs pulse width and 10% duty cycles.

III. ALGAN/GAN HEMTS WITHOUT FIELD-PLATED

At a higher frequency, since it is difficult to realize a high gain, structures which do not drop the gain are needed. In order for the GaN devices to achieve optimal performance at millimeter-wave frequencies, special attention was paid to the formation of the epitaxial layer structure, the gate fabrication techniques and the layout pattern.

A 50µm gate-width 8-finger cell was designed for the frequency. A Loadpull measurement was performed on the FET cell to determine the optimum load impedance using a passive-tuner system at 31GHz [26]. The cell achieved a saturated output power of 31.2dBm (3.3W/mm), an associated gain of 7dB and PAE of 40%.

A 2-stage MMIC was designed with 16 cells for the output power stage (6.4mm) which was driven by 8 FET cells for the driver stage (3.2mm). At VDD=28V under pulse condition of 100 µs pulse width and 10% duty cycles, the MMIC achieved a saturated output power of 42.8dBm (19W) to 43.3dBm (21W) across 29GHz to 31GHz as shown in Fig. 6.

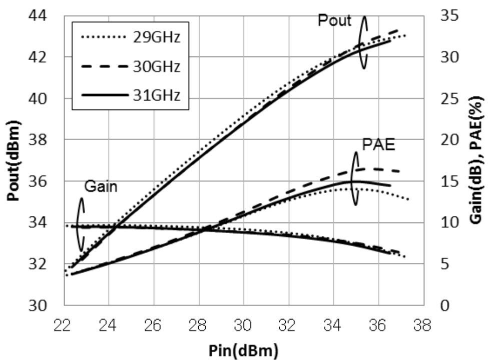

Fig. 6. MMIC 16 cells for an output power stage (6.4mm) which was driven by 8 FET cells for the driver stage (3.2mm) achieved a saturated output power of 42.8dBm (19W) to 43.3dBm (21W) across 29GHz to 31GHz at VDD=28V under pulse condition of 100 µs pulse width and 10% duty cycles.

IV. Conclusion

The device without a source field plate on “Epi wafer B” which had a low-density trap state showed a drain efficiency of 84% at 3.0 GHz. Two 35mm-gate-width dies which had a source field plate of 0.5µm achieved 461W (56.64dBm) with 15.44dB related gain and 59.4% of PAE at a drain voltage of 50V.

A 50µm gate-width 8-finger cell showed a saturated output power of 31.2dBm (3.3W/mm), an associated gain of 7dB and PAE of 40%. A 2-stage MMIC achieved a saturated output power of 42.8dBm (19W) to 43.3dBm (21W) across 29GHz to 31GHz.

In order to realize high PAE, harmonics control is effective. The harmonics control requires a high breakdown voltage and a high gain of devices, so the GaN HEMT is the best device for high power and high efficiency.

References

[1] M. Asif Khan, A. Bhattarai, J. N. Kuznia, and D. T. Olson, "High electron mobility transistor based on a GaN-AlxGa1-xN heterojunction, "Applied Physics Letters, vol. 63, no. 9, pp. 1214–1215, Aug. 1993.

[2] Y.-F. Wu, B. P. Keller, S. Keller, D. Kapolnek, S. P. Denbaars, and U. K. Mishra, "Measured microwave power performance of AlGaN/GaN MODFET," IEEE Electron Device Letters, vol. 17, no. 9, pp. 455–457, Sep. 1996.

[3] Y.-F. Wu, A. Saxler, M. Moore, R. P. Smith, S. Sheppard, P. M. Chavarkar, T. Wisleder, U. K. Mishra, and P. Parikh, "30-W/mm GaN HEMTs by field plate optimization," IEEE Electron Device Letters, vol. 25, no. 3, pp. 117–119, Mar. 2004.

[4] Y.-F. Wu, B. P. Keller, S. Keller, D. Kapolnek, S. P. Denbaars, and U. K. Mishra, "Measured microwave power performance of AlGaN/GaN MODFET," IEEE Electron Device Letters, vol. 17, no. 9, pp. 455–457, Sep. 1996.

[5] David Schmelzer and Stephen I. Long, "A GaN HEMT Class F Amplifier at 2GHz with >80% PAE," 2006 IEEE CSIC Symp., pp96-98, Nov. 2006.

[6] T. Yamasaki, Y. Kittaka, H. Minamide, K. Yamauchi, S. Miwa, S. Goto, M. Nakayama, M. Kohno, and N. Yoshida, "A 68% Efficiency, C-Band 100W GaN Power Amplifier for Space Applications," 2010 IEEE MTT-S Int. Microwave Symp., Dig., pp. 1384-1387, June 2010.

[7] Masahiro Kamiyama, Ryo Ishikawa, and Kazuhiko Honjo, "5.65-GHz High-Efficiency GaN HEMT Power Amplifier with Harmonics Treatment up to Fourth Order," IEEE Microwave and Wireless Components Letters 2012, vol. 22, No. 6, pp.315-317.

[8] J. R. Shealy, V. Kaper, V. Tilak, T. Prunty, J. A. Smart, B. Green, and L. F. Eastman, "An AlGaN/GaN high-electron-mobility transistor with an AlN sub-buffer layer," J. Phys.: Condens. Matter, vol. 14, p. 3499, 2002.

[9] Kazuhisa Yamauchi, Hifumi Noto, Hiroyuki Nonomura, Satoshi Kunugi, Masatoshi Nakayama and Yoshihito Hiran, "A 45% Power-Added-Efficiency, Ku-band 60W GaN Power Amplifier," 2011 IEEE MTT-S Int. Microwave Symp., Dig.

[10] Charles F. Campbell, Yueying Liu, Ming-Yih Kao and Sabyasachi Nayak, "High Efficiency Ka-Band Gallium Nitride Power Amplifier MMICs," IEEE COMCAS, Oct. 21-23, 2013.

[11]"EGN21C320IV", http://www.sedi.co.jp/pdf/EGN21C320IV_Edition1_0.pdf

[12]"SGN2933-600D-R", http://www.sedi.co.jp/pdf/SGN2933-600D-R_ED2-0.pdf

[13]"SGK5254-120A-R", http://www.sedi.co.jp/pdf/SGK5254-120A-R_ED1-0.pdf

[14]"CGHV96050F2", http://www.cree.com/RF/Products/SBand-XBand-CBand/Packaged-Discrete-Transistors/CGHV96050F2

[15]"TGI9098-100P", https://www.toshiba.co.jp/sis/des/micro/prod/prodlist/semicon/d-sheet/tgi9098-100p_0_20140110_no1228.pdf

[16]MGFC50G5867", http://www.mitsubishielectric.co.jp/semiconductors/content/product/hf/gantransistor/intnly_gan/intnly_gan_lv4/mgfc50g5867_sep-2012.pdf

[17]"TGI7785-120L", http://www.toshiba.co.jp/sis/en/des/micro/prod/prodlist/semicon/d-sheet/tgi7785-120L_3_20131204_no1225.pdf

[18]"SGK7785-100A", http://www.sedi.co.jp/pdf/SGK7785100A_ED1-0.pdf

[19]"TGI1314-50L", http://www.toshiba.co.jp/sis/des/micro/prod/prodlist/semicon/d-sheet/tgi1314-50l_1_20130711_no1218.pdf

[20]"APN180", http://www.northropgrumman.com/BusinessVentures/Microelectronics/Products/Documents/pageDocs/APN180.pdf

[21]"APN228", http://www.northropgrumman.com/BusinessVentures/Microelectronics/Products/Documents/pageDocs/APN228rev0514.pdf

[22] Y. Ando, Y. Okamoto, H. Miyamoto, T. Nakayama, T. Inoue, and M. Kuzuhara, "10-W/mm AlGaN–GaN HFET With a Field Modulating Plate," IEEE Electron Device Lett., vol. 24, no. 5, pp. 289–291, 2003.

[24] Y.-F. Wu, M. Moore, A. Saxler, T. Wisleder, and P. Parikh, "40-W/mm double field-plated GaN HEMTs," IEEE 64th Device Research

[25] Keiichi Matsushita, Hiroyuki Sakurai, Akio Miyao, Yukio Takahasi, Kazutaka Takagi, "Effects of Field Plate and Epi Wafer on AlGaN/GaN HEMTs with Active Harmonic Tuning," CS MANTECH Conference, May 19th - 22nd, 2014, Denver, Colorado, USA pp.237-239

[26] C.Y. Ng, K. Takagi, T. Senju, K. Matsushita, H. Sakurai, K. Onodera, S. Nakanishi, K. Kuroda, T. Soejima, "A 20-Watt Ka-Band GaN High Power Amplifier MMIC," 2014 European Microwave Integrated Circuits Conference, Oct. 2014.