第28卷　第4期　　半 导 体 学 报　　Vol.28　No.4
2007年4月　　CHINESE JOURNAL OF SEMICONDUCTORS　　Apr.,2007

AlGaN/GaN HEMTs Power Amplifier MIC with Power Combining at C-Band*

Yao Xiaojiang[1,†], Li Bin[2], Chen Yanhu[1], Chen Xiaojuan[1], Wei Ke[1], Li Chengzhan[1], Luo Weijun[3], Wang Xiaoliang[3], Liu Dan[1], Liu Guoguo[1], and Liu Xinyu[1]

(1 *Institute of Microelectronics*, *Chinese Academy of Sciences*, *Beijing*　100029, *China*)
(2 *Longrui Microelectronic Corporation*, *Chengdu*　610041, *China*)
(3 *Institute of Semiconductors*, *Chinese Academy of Sciences*, *Beijing*　100083, *China*)

Abstract: A power amplifier MIC with power combining based on AlGaN/GaN HEMTs was fabricated and measured. The amplifier consists of four $10\times120\mu m$ transistors. A Wilkinson splitters and combining were used to divide and combine the power. By biasing the amplifier at $V_{DS}=40V$, $I_{DS}=0.9A$, a maximum CW output power of 41.4dBm with a maximum power added efficiency (PAE) of 32.54% and a power combine efficiency of 69% was achieved at 5.4GHz.

Key words: AlGaN/GaN HEMTs; power combining; MIC; power amplifiers
EEACC: 1350F; 1350H
CLC number: TN325$^+$.3　　**Document code**: A　　**Article ID**: 0253-4177(2007)04-0514-04

1　Introduction

With the development of the wireless communications, telecommunications, date communications and aerospace systems, the demand for solid-state power amplifiers has been continually increasing over the last decade. GaAs technology is currently used to realize power amplifiers at high frequencies. However in many applications, GaAs will not meet the future system requirements because of the thermal and electrical limitations of the GaAs transistors. Under such circumstance, the third generation wide band-gap semiconductors with an order of magnitude or higher breakdown voltage along with excellent thermal properties began to emerge.

As the representation of the third generation semiconductors, the GaN high electron mobility transistors (HEMTs) on SiC are very attractive for power applications for microwave and millimeter wave. In recent years there have been several reports on the large-signal performance of AlGaN/GaN HEMTs as devices with high output power[1~3]. So far there have been few reports on microwave integrated circuits based on AlGaN/GaN transistors[4~6]. In this paper we report on design, fabrication and performance of a MIC C-band power amplifier.

2　Technology and fabrication

Figure 1 shows the layer structure of the transistor which is an $Al_{0.2}Ga_{0.8}N$-AlN-GaN multilayer grown on a semi-insulation 4H-SiC substrate. The wafer was grown by MOCVD. An averaged electron mobility of $1250cm^2/(V\cdot s)$ and a sheet carrier density of $1.4\times10^{13}cm^{-2}$ were obtained by Hall measurement. The transistor was fabricated using for ion implant mesa isolation and Ti/Al/Ti/Au for ohmic contacts resulting in a contact resistance of $1.2\Omega\cdot mm$, and Ni/Au for $0.8\mu m$ gate. A $10\times120\mu m$ transistor delivers 1340mA corresponding to the current density $I_{DSS}=1.11A/mm$. A $120\mu m$ device demonstrates a maximum tranconductance of 240mS/mm and a threshold voltage of $V_{th}=-5.2V$. Small signal measurements yield a cutoff frequency of $f_T=13GHz$ and a maximum frequency of oscillation of

---

* Project supported by the State Key Development Program for Basic Research of China (No.2002CB311903) and the Key Knowledge Innovation Program of the Chinese Academy of Sciences (No.KGCX2-SW-107)

† Corresponding author. Email: yaoxiaojiang@gmail.com

Received 8 October 2006, revised manuscript received 27 October 2006

©2007 Chinese Institute of Electronics

$f_{\max} = 18\mathrm{GHz}$.

i-AlGaN　5nm
n-AlGaN　10nm
i-AlGaN　5nm
AlN　1nm
GaN　3μm
4H-SiC

Fig.1　Layer structure for transistor grown by MOCVD

3　Circuit design

Figure 2 shows a picture of the amplifier which is one stage C-band internal match power amplifier consisting of four 10 × 120μm transistors, Wilkinson splitters and Wilkinson combining. The input and output ports are matched to 50Ω. With the increase of the device power, the input impedance of the device decreases rapidly. Thus the input port was difficult to match to 50Ω. However, power combining is a good idea to solve this problem. A Wilkinson combining and dividers were used to combine and split the power and use to transform the impedance of the transistor[7]. This transformation allows for easier matching of the HEMTs and for less area consumption than the tradition Wilkinson combining. Because of the small signal model is given at the bias point V_{DS} = 30V, I_{DS} = 0.5A, the design is based on the model.

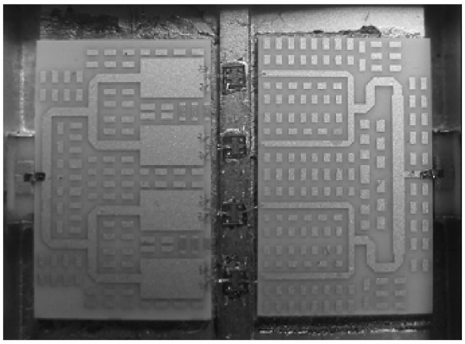

Fig.2　AlGaN/GaN based C-band MIC consisting of four 10 × 120μm transistors, Wilkinson splitters and Wilkinson combining

4　RF performance

The amplifier was been packaged in a package, the size of which was 13mm × 12.5mm. All the measurements have been carried out on the test fixture in 50Ω environment (Fig. 3).

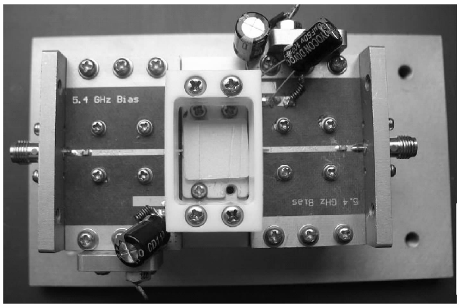

Fig.3　Amplifier test fixture

4.1　Small signal performance

The measured small signal performance of the amplifier at the bias point V_{DS} = 30V, I_{DS} = 0.5A is shown in Fig. 4. Under small signal conditions the amplifier shows the optimal frequency of around 5GHz, but at the large signal conditions it shifts to 5.4GHz at the bias point V_{DS} = 40V, I_{DS}

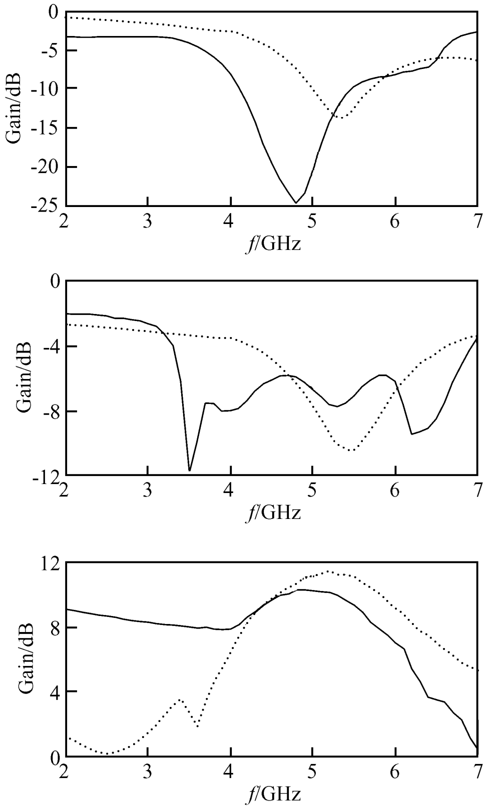

Fig. 4　Small signal performance difference between the design (dotted line) and the measure (solid line)

= 0.9A. Figure 4 also shows the difference between the small signal simulation and measurement at the bias point $V_{DS}=30V$, $I_{DS}=0.5A$. The difference is caused by the indetermination for the length of the bond wire.

4.2 Large signal performance

Figure 5 shows the power performance of the amplifier at 5.4GHz. By biasing the MIC at $V_{DS}=40V$, $I_{DS}=0.9A$, a maximum CW output power of 41.4dBm (13.8W) and a maximum PAE of 32.54% were measured. The output power at 1dB gain compression point is 39.8dBm (9.5W). At this bias point, it consumes 42.4W DC power with a total DC current of 1.06A, and a DC voltage 40V.

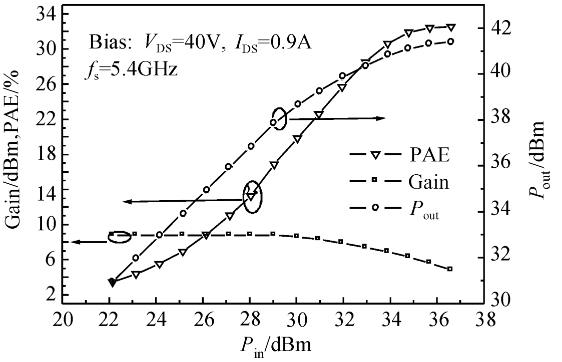

Fig.5 CW power performance of the amplifier at 5.4GHz Bias point: $V_{DS}=40V$, $I_{DS}=0.9A$. $P_{outmax}=41.4dBm$, $PAE_{max}=32.54\%$ and $P_{1dB}=39.8dBm$

For a 10 × 120μm device at bias point $V_{DS}=40V$, $I_{DS}=0.26A$, the transistors are capable of delivering a maximum RF power of 37dBm at 5.4GHz. Thus we can obtain the power combine efficiency of about 69%.

The bandwidth of the amplifier under large signal conditions is also tested. We have a frequency sweep with a constant input power which made the output power near the 1dB gain compression. Figure 6 shows the bandwidth about 800MHz (5～5.8GHz) with a ± 0.5dB gain flatness.

5 Conclusion

Microwave integrated power amplifiers consisting of four parallel 10 × 120μm AlGaN/GaN HEMTs and Wilkinson combiner were designed, fabricated and measured. The highest CW output power at 5.4GHz was 41.4dBm with a maximum PAE of 32.54% and the power combine efficiency of 69%.

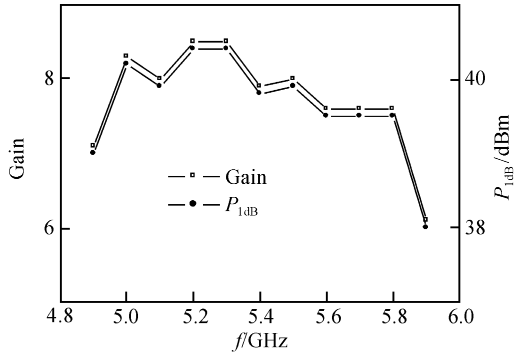

Fig. 6 Output power and gain versus frequency at fixed input power near 1dB gain compression Bias point: $V_{DS}=40V$, $I_{DS}=0.9A$

Acknowledgment The author would like to thank Professor Wang Xiaoliang from the Institute of Semiconductors of Chinese Academy of Sciences, for providing the GaN HEMTs epitaxial wafer.

References

[1] Chu K K, Chao P C, Pizzella M T, et al. 9.4-W/mm power density AlGaN-GaN HEMTs on free-standing GaN substrates. IEEE Electron Device Lett, 2004, 25(9): 596

[2] Wu Y F, Saxler A, Moore M, et al. 30-W/mm GaN HEMTs by field plate optimization. IEEE Electron Device Lett, 2004, 25: 117

[3] Chini A, Buttari D, Coffie R, et al. 12W/mm power density AlGaN/GaN HEMTs on sapphire substrate. IEEE Electron Device Lett, 2004, 40(1): 73

[4] Wu Y F, York R A, Keller S, et al. 3—9-GHz GaN-based microwave power amplifiers with L-C-R broad-band matching. IEEE Microw Guided Wave Lett, 1999, 9(8): 314

[5] Pyrtel S G, Lentijo S, Koudymov A, et al. AlGaN/GaN MOSHFET integrated circuit power converter. 35th Annual IEEE Power Electronics Specialists Conference, 2004

[6] Shapiro E S, Xu J, Nagra A S, et al. A high-efficiency traveling-wave power amplifier topology using improved power-combining techniques. IEEE Microw Guided Wave Lett, 1998, 8(3): 133

[7] Behtash R, Tobler H, Berlec F J, et al. Coplanar AlGaN/GaN HEMT power amplifier MMIC at X-band. IEEE MTT-S Digest, 2004

基于 AlGaN/GaN HEMT 的 C 波段混合集成功率合成放大器的设计*

姚小江[1,†]　李　宾[2]　陈延湖[1]　陈小娟[1]　魏　珂[1]　李诚瞻[1]　罗卫军[3]
王晓亮[3]　刘　丹[1]　刘果果[1]　刘新宇[1]

（1 中国科学院微电子研究所，北京　100029）
（2 四川龙瑞微电子有限公司，成都　610041）
（3 中国科学院半导体研究所，北京　100083）

摘要： 研制了一种基于 AlGaN/GaN HEMT 的功率合成技术的混合集成放大器电路.该电路包含 4 个 10×120μm 的 HEMT 晶体管以及一个 Wilkinson 功率合成器和分配器.在偏置条件为 $V_{DS}=40V$，$I_{DS}=0.9A$ 时，输出连续波饱和功率在 5.4GHz 达到 41.4dBm，最大的 PAE 为 32.54%，并且功率合成效率达到 69%.

关键词：AlGaN/GaN HEMT；功率合成器；混合集成电路；微波功率放大器
EEACC：1350F；1350H
中图分类号： TN325⁺.3　　**文献标识码：** A　　**文章编号：** 0253-4177(2007)04-0514-04

---

* 国家重点基础研究发展计划（批准号：2002CB311903）及中国科学院重点创新工程（批准号：KGCX2-SW-107）资助项目

† 通信作者.Email：yaoxiaojiang@gmail.com

2006-10-08 收到，2006-10-27 定稿

©2007 中国电子学会