AlGaN/GaN High Electron Mobility Transistors on Sapphires with f_{max} of 100GHz*

Li Xianjie, Zeng Qingming, Zhou Zhou, Liu Yugui, Qiao Shuyun, Cai Daomin, Zhao Yonglin, and Cai Shujun

(Hebei Semiconductor Research Institute, Shijiazhuang 050051, China)

Abstract: AlGaN/GaN high electron mobility transistors grown on sapphire substrates with a 0.3μm gate length and 100μm gate width are fabricated. The device reveals a drain current saturation density of 0.85A/mm at a gate voltage of 0V and a peak transconductance of 225mS/mm. The unity current gain cutoff frequency and maximum frequency of oscillation are obtained as 45 and 100GHz, respectively. The output power density and gain are 1.8W/mm and 9.5dB at 4GHz, and 1.12W/mm and 11.5dB at 8GHz.

Key words: AlGaN/GaN; HEMT; sapphire
EEACC: 2560
CLC number: TN386 **Document code:** A **Article ID:** 0253-4177(2005)11-2049-04

1 Introduction

GaN-based high electron mobility transistors (HEMTs) are one of the most promising candidates for high power, high speed, and high temperature applications due to the inherent advantages of the material. These advantages include high breakdown voltage, high carrier velocity, and very high two-dimensional electron gas (2DEG) concentration resulting from strong polarization and piezo effects with a heterojunction structure[1,2]. With the great development in the epitaxial growth and fabricating process, excellent frequency characteristics and microwave power performances of AlGaN/GaN HEMTs have been reported[1~7]. Output power densities of 6.4W/mm and above 10W/mm in the X-band have been measured on AlGaN/GaN HEMTs grown on sapphire and SiC, respectively[1,4]. As well as being the best component for X band high power microwave applications, GaN HEMTs are attractive for the application of high temperature circuits at even higher frequencies. A current gain cutoff frequency f_T of 121GHz and a maximum oscillation frequency f_{max} of 162GHz for AlGaN/GaN HEMTs have been reported[7].

In this paper, we report a high frequency AlGaN/GaN HEMT grown by MOCVD on sapphire with a f_T of 45GHz and a f_{max} of 100GHz fabricated in our in-house 0.3μm T-type gate process.

2 Device structure and fabricating process

The epitaxial structure of the AlGaN/GaN HEMTs was grown by the metal organic chemical vapor deposition (MOCVD) system on a 50mm commercially available sapphire substrate. A 20nm thick nucleation AlN layer was grown on the sapphire, and followed by a 2μm undoped GaN buffer layer and a 3nm undoped $Al_{0.3}Ga_{0.7}N$ space layer; a 15nm Si-doped $Al_{0.3}Ga_{0.7}N$ layer with Si dopant

* Project supported by the State Key Development Program for Basic Research of China (No. 51327030201) and the National Natural Science Foundation of China (No. 60136020)

Received 30 April 2005, revised manuscript received 15 June 2005

density of 5 $\times 10^{18}$ cm^{-3} was then grown to form the 2DEG and capped by a 2nm undoped $Al_{0.3}Ga_{0.7}N$ Schottky barrier layer. Hall measurement at room temperature reveals a low field Hall mobility of 980cm^2/(V·s), a sheet resistance of 383Ω·cm^{-2} and a sheet carrier density of 1.66 $\times 10^{13}$ cm^{-2} in the 2DEG formed at the AlGaN/GaN interface; at 77K, a low field mobility of 2820cm^2/(V·s), a sheet resistance of 125Ω·cm^{-2}, a sheet carrier density of 1.77 $\times 10^{13}$ cm^{-2} were recorded.

The fabricating process started with mesa isolation-removing the AlGaN/GaN of about 100nm outside the active mesa using a BCl_3/Ar based inductively coupled plasma (ICP) dry etching process. To enhance the isolation effect, He^+ implantation was added when the quality of the GaN buffer layer was poor. Ti/Al/Ni/Au was deposited through E-beam evaporation followed by lift-off and annealing at 890℃ for 30s to form the ohmic contacts for source and drain. A specific contact resistance of 0.88Ω·mm was measured through the TLM (transmission line method) pattern. The Schottky gate was patterned using E-beam lithography and metalized with Ni/Au by evaporation and lift-off. The gate with length and width of 0.3μm and 100μm, respectively, was offset to be closer to the source contact in the 3μm source-drain space. An 80nm thick SiN_x was then deposited by PECVD for surface passivation to suppress the effect of current collapse. Finally, interconnecting metal and air-bridge structure were achieved with electrical plating Au of about 2μm thickness.

3 DC and microwave performances

The DC current-voltage and transfer characteristics of the fabricated 100μm-gate-width device were measured on wafer with the Keithely 4200 semiconductor parameter analyzer as shown in Figs. 1 and 2. The saturation drain current density was 0.85A/mm at a gate voltage of 0V and the threshold voltage was typically -5V. The peak transconductance was 225mS/mm. A self-heating effect at large current was observed from the I-V characteristic in Fig. 2, which was due to the poor thermal conductivity of the sapphire substrate.

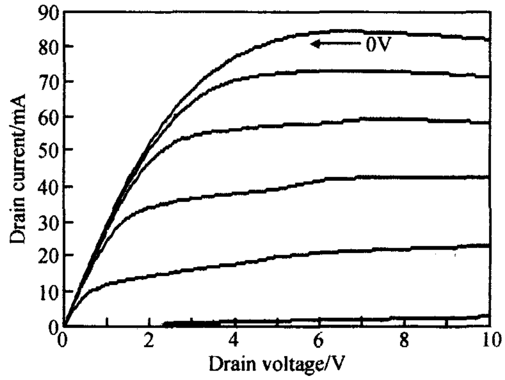

Fig. 1 Drain current-voltage characteristics of AlGaN/GaN HEMT with 0.3μm ×100μm gate Gate voltage: -1V/step

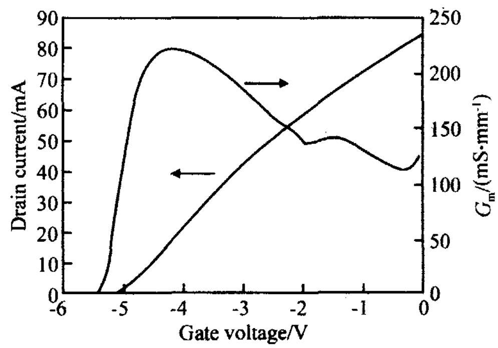

Fig. 2 Transfer characteristics of AlGaN/GaN HEMT with 0.3μm ×100μm gate

The microwave characteristics were measured on wafer by using an Agilent 8722ES network analyzer from 1 to 40GHz. Both short-circuit current gain h_{21} and unilateral power gain U were calculated from the measured S-parameters and extrapolated at -20dB/decade to find f_T and f_{max}, respectively. As shown in Fig. 3, the f_T and f_{max} were measured to be 45 and 100GHz, respectively. Furthermore, microwave output power performances were evaluated on wafer using MT 986 load-pull measurements at different frequencies. Figures 4 and 5 reveal output power and gain versus input power for the above devices at 4 and 8GHz. The continuous wave (CW) output power performance was limited by three reasons. The first reason is that the maximum input power of the measurement system was 8dBm. If the input power is larger, the output power can then be higher. Another reason is that the breakdown voltage of source and gain was only about 13V and limited the power performance seriously. This was believed to be a result of the lower quality of the GaN buffer epitaxial layer. Finally, the poor thermal conductivity of the sapphire substrate also affected the power characteristics.

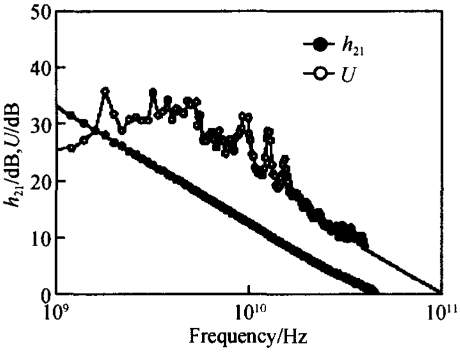

Fig. 3　Short-circuit current gain h_{21} and unilateral power gain U versus frequency

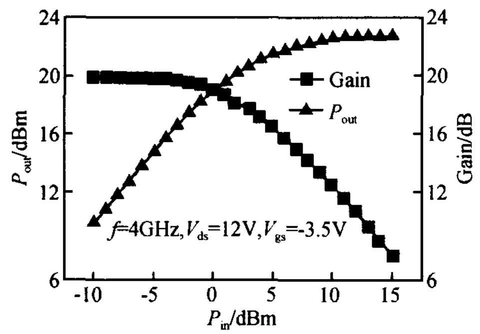

Fig. 4　Microwave output power performances of AlGaN/ GaN HEMT with 0.3μm ×100μm gate at 4GHz

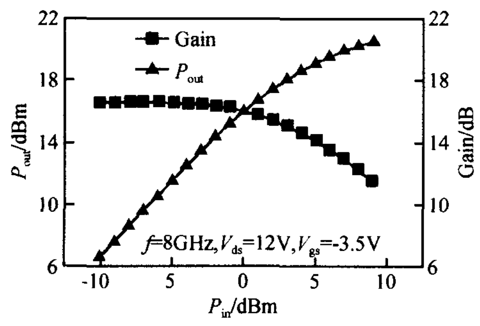

Fig. 5　Microwave output power performances of AlGaN/ GaN HEMT with 0.3μm ×100μm gate at 8GHz

4　Conclusion

AlGaN/ GaN HEMTs grown by MOCVD on sapphire with a gate length and width of 0.3 and 100μm, respectively, were demonstrated. The saturation drain current density was 0.85A/ mm at a gate voltage of 0V and the threshold voltage was typically -5V. The peak transconductance was 225mS/ mm. The f_T and f_{max} were measured as 45 and 100GHz, respectively. The output power density and the gain were 1.8W/ mm and 9.5dB at 4GHz, and 1.12W/ mm and 11.5dB at 8GHz.

Acknowledgement　The authors would like to thank Prof. Chen Kevin and Dr. Cheng Zhiqun with HKUST for the help of microwave performance measurement.

References

[1] Wu Y F, Kapolnek D, Ibbetson J P, et al. Very-high power density AlGaN/ GaN HEMTs. IEEE Trans Electron Devices, 2001, 48(3): 586

[2] Nguyen N X, Micovic M, Wong W S, et al. High performance microwave power GaN/ AlGaN MODFETs grown by RF-assisted MBE. Electron Lett, 2000, 36(5): 468

[3] Chen Q, Yang J W, Khan M A, et al. High transconductance AlGaN/ GaN heterostructure field effect transistors on SiC substrates. Electron Lett, 1997, 33(7): 1413

[4] Tilak V, Green B, Kaper V, et al. Influence of barrier thickness on the high-power performance of AlGaN/ GaN HEMTs. IEEE Electron Device Lett, 2001, 22(11): 504

[5] Micovic M, Nguyen N X, Janke P, et al. GaN/ AlGaN high electron mobility transistors with f of 110GHz. Electron Lett, 2000, 36(2): 358

[6] Chen C, Coffie R, Krisnamurthy K, et al. Dual-gate AlGaN/ GaN modulation-doped field-effect transistors with cut-off frequencies f > 60GHz. IEEE Electron Device Lett, 2000, 21(12): 549

[7] Kumar V, Lu W, Schwindt R. AlGaN/ GaN HEMTs on SiC with f_T of over 120GHz. IEEE Electron Device Lett, 2002, 23(8): 55

f_{max}为 100 GHz 的蓝宝石衬底 AlGaN/ GaN 高电子迁移率晶体管*

李献杰 曾庆明 周 州 刘玉贵 乔树允 蔡道民 赵永林 蔡树军

(河北半导体研究所，石家庄 050051)

摘要：制作了蓝宝石衬底上生长的 AlGaN/ GaN 高电子迁移率晶体管. 0V 栅压下，0. 3μm 栅长、100μm 栅宽的器件的饱和漏电流密度为 0. 85A/ mm，峰值跨导为 225mS/ mm；特征频率和最高振荡频率分别为 45 和 100GHz；4GHz 频率下输出功率密度和增益分别为 1. 8W/ mm 和 9. 5dB，8GHz 频率下输出功率密度和增益分别为 1. 12W/ mm 和 11. 5dB.

关键词：AlGaN/ GaN；HEMT；蓝宝石
EEACC： 2560
中图分类号：TN386 **文献标识码**：A **文章编号**：0253-4177(2005)11-2049-04

* 国家重点基础研究发展规划(批准号：51327030201)和国家自然科学基金(批准号：60136020)资助项目
2005-04-30 收到，2005-06-15 定稿