A High Performance AlGaN/GaN HEMT with a New Method for T-Gate Layout Design

Chen Zhigang[1,†], Zhang Yang[1], Luo Weijun[2], Zhang Renping[1], Yang Fuhua[1], Wang Xiaoliang[2], and Li Jinmin[2]

(1 *State Key Laboratory of Superlattices and Microstructures, Institute of Semiconductors, Chinese Academy of Sciences, Beijing* 100083, *China*)
(2 *Key Laboratory of Semiconductor Materials Science, Institute of Semiconductors, Chinese Academy of Sciences, Beijing* 100083, *China*)

Abstract: We propose and fabricate an AlGaN/GaN high electron mobility transistor (HEMT) on sapphire substrate using a new kind of electron beam (EB) lithography layout for the T-gate. Using this new layout, we can change the aspect ratio (ratio of top gate dimension to gate length) and modify the shape of the T-gate freely. Therefore, we obtain a 0.18μm gate-length AlGaN/GaN HEMT with a unity current gain cutoff frequency (f_T) of 65GHz. The aspect ratio of the T-gate is 10. These single finger devices also exhibit a peak extrinsic transconductance of 287mS/mm and a maximum drain current as high as 980mA/mm.

Key words: GaN; HEMT; T-gate; layout
EEACC: 2560
CLC number: TN386　　**Document code**: A　　**Article ID**: 0253-4177(2008)09-1654-03

1 Introduction

In order to meet the future needs of wireless communication, a number of studies have been carried out for wide bandgap semiconductors such as SiC and GaN[1]. AlGaN/GaN high electron mobility transistors (HEMT) are an excellent candidate for high power and high frequency applications at elevated temperatures due to their superior material properties[2,3].

The improved growth in combination with new device structures, such as an AlN interlayer between barrier and buffer, and field-plated technology has allowed devices with an output power in excess of 30W/mm at 4GHz[4], more than one order of magnitude higher than in state-of-the-art GaAs devices. One of the main challenges for these transistors is to increase the frequency of operation to the Ka-band (26 ~ 40GHz). As the gate length (L_g) decreases, the reliability of transistors decreases and gate resistance (R_g) increases, which are dominant factors limiting HEMTs' high frequency performance.

In an attempt to alleviate such detrimental problems associated with the decrease of L_g, researchers have proposed various technologies to produce a T-gate. Historically, there were two main technologies to form a T-gate: the multiresist process and the dielectric-defined process. Comparing the two technologies, the multiresist process is simple but offers a lower aspect ratio (ratio of top gate dimension to gate length); the dielectric-defined process modifies the aspect ratio and the shape of the T-gate, but its efficiency is poor since it needs EB lithography twice.

In this paper, we provide a new method to form T-gates that combines the merits of the two technologies. We retain the triple-layer resist structure (PMMA/ PMMA-MAA/PMMA), but change the design of the T-gate layout. As shown in Fig. 1, we divided the layout of the T-gate into three zones: Zone 1 defines the foot of the T-gate; Zone 2 forms the head of the T-gate, and Zone 3 improves the shape of the T-gate. Therefore, by changing the distance between Zone 1 and Zone 2, we can change the aspect ratio. Through changing the exposure dose of Zone 3 and its distance from Zone 1, we can control the shape of the T-gate.

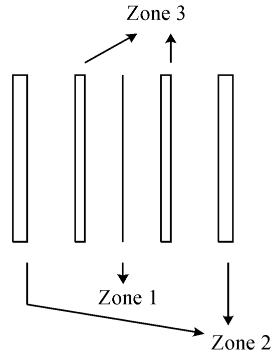

Fig. 1　Layout of T-gate

† Corresponding author. Email: czg20001@hotmail.com
Received 29 February 2008, revised manuscript received 23 April 2008

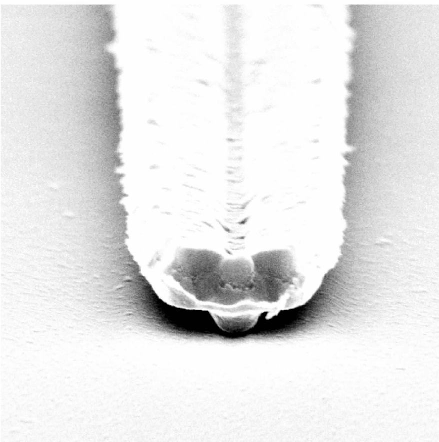

Fig.2　SEM photo for T-gate of AlGaN/GaN HEMT

As a result, we obtain a T-gate with an aspect ratio of 10 and a current gain cutoff frequency of 65GHz.

2　Device fabrication

AlGaN/GaN HEMT epitaxial layers were grown on c-plane (0001) sapphire substrates by metal organic chemical vapor deposition (MOCVD). We employed a typical AlGaN/GaN epitaxial structure. The layers were a 2μm GaN buffer layer and a 20nm $Al_xGa_{1-x}N$ barrier layer. The mole fraction, x, was 0.27. Neither layer was intentionally doped. From Hall measurement (at room temperature), the structure showed a two-dimensional electron gas (2DEG) sheet density N_s of $1.0\times10^{13}cm^{-2}$ and a 2DEG mobility μ of $1645cm^2/(V\cdot s)$.

Device processing began with a mesa isolation using Cl_2-based inductively coupled plasma (ICP) etch. A Ti/Al/Ni/Au multilayer[5] was deposited by e-beam evaporation to form the ohmic contact. The evaporation was followed by rapid thermal annealing at 830℃ in N_2 atmosphere for 35s, and the specific contact resistance, as estimated by the transmission line model, was about $7\times10^{-5}\Omega\cdot cm^2$. After rinsing, the surfaces of the devices were coated with an optimized triple-layer E-beam resist (PMMA/PMMA-MAA/ PMMA) and the T-gate pattern was defined by a Raith 150 electron-beam lithography system. After depositing Ni/Au for a Schottky contact and lift-off, we obtained the T-gate of the device, as shown in Fig. 2.

3　Results and discussion

Figure 3 shows the current-voltage (I-V) characteristics of a 0.18μm AlGaN/GaN HEMT. This HEMT is well pinched off. The maximum drain-source current I_{ds} is about 980mA/mm under a gate-

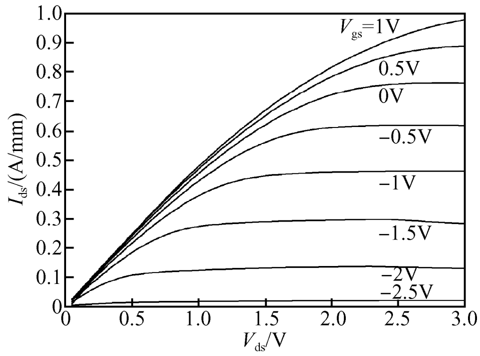

Fig.3　I-V characteristics of the device under CW measurement

source voltage (V_{gs}) of 1V. The pinch-off voltage is −2.7V (Fig. 4(a)). The maximum DC transconductance $g_{m,max}$ is 287mS/mm under a drain-source voltage V_{ds} of 6V and a V_{gs} of −1.8V, as shown in Fig. 4(b).

The S-parameters were measured in a frequency range from 0 to 20GHz in 0.05GHz steps using an HP8720D vector network analyzer. An extrapolation of the unity current gain cutoff frequency (f_T) to 65GHz was obtained for the single finger gate (40 × 0.18μm) under a V_{ds} of 9V and V_{gs} of −1.5V, as shown in Fig. 5.

Though we obtained a 0.18μm gate-length AlGaN/GaN HEMT with a current gain cutoff frequency f_T of 65GHz, the highest f_T of AlGaN/GaN HEMTs with a similar length has reached 77GHz[2]. The expression for the f_T of a AlGaN/GaN HEMT is:

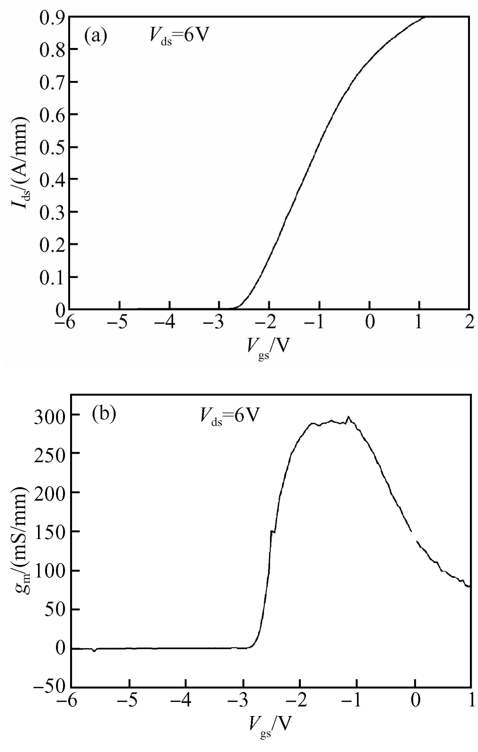

Fig.4　Transfer characteristics (a) and transconductance performance (b) of devices

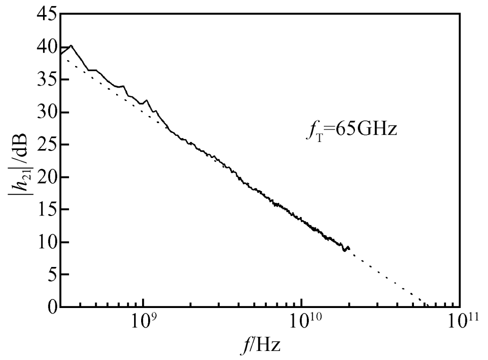

Fig. 5 Measured current gain of a 40 × 0.18μm AlGaN/GaN HEMT (V_{ds} = 9V, V_{gs} = − 1.5V)

$$f_T = \left\{ 2\pi \left[\frac{L_g}{v_{sat}} + C_{gd}(R_s + R_d) + \tau_{cc} \right] \right\}^{-1}$$

where v_{sat} is the electron saturation velocity, C_{gd} is the gate-drain parasitic capacitance, R_s and R_d are the source and drain parasitic resistance, respectively, and τ_{cc} is the channel charging time. Current gain cutoff frequency f_T is decided not only by gate length L_g but also by many other parameters. Among them, electron saturation velocity v_{sat} and channel charging time τ_{cc} are related to the quality of epitaxial layers. The source and drain parasitic resistance R_s and R_d are controlled by the ohmic contact resistance. In the future, we can modify the quality of epitaxial layers and decrease the ohmic contact resistance to obtain higher current gain cutoff frequency.

4 Conclusion

In summery, using a new method for the T-gate layout design, we obtained a T-gate with an aspect ratio of 10 and a 0.18μm gate-length AlGaN/GaN HEMT with a current gain cutoff frequency of 65GHz. Moreover, the peak transconductance of the device is 287mS/mm when V_{gs} = − 1.8V and the maximum drain current I_{ds} is about 980mA/mm under a V_{gs} of 1V. The good performance of AlGaN/GaN HEMTs on sapphire substrates shows their potential for application in microwave circuits.

References

[1] Wu Yifeng. AlGaN/GaN microwave power high-mobility-transistors. PhD Dissertation, University of California Santa Barbara, 1997

[2] Zheng Yingkui, Liu Guoguo, He Zhijing, et al. 0.25μm gate-length AlGaN/GaN power HEMTs on sapphire with of 77GHz. Chinese Journal of Semiconductors, 2006, 27(6): 963

[3] Sheppard S T, Doverspike K, Pribble W L, et al. High power microwave GaN/AlGaN HEMTs on silicon carbide. IEEE Electron Device Lett, 1999, 20: 161

[4] 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

[5] Yang Yan, Wang Wenbo, Hao Yue. Ohmic contact to an AlGaN/GaN heterostructure. Chinese Journal of Semiconductors, 2006, 27(10): 1823 (in Chinese) [杨燕, 王文博, 郝跃. AlGaN/GaN 异质结构的欧姆接触. 半导体学报, 2006, 27(10): 1823]

应用一种新 T 形栅版图设计方法的 AlGaN/GaN 高电子迁移率晶体管

陈志刚[1,†] 张 杨[1] 罗卫军[2] 张仁平[1] 杨富华[1] 王晓亮[2] 李晋闽[2]

(1 中国科学院半导体研究所 超晶格国家重点实验室, 北京 100083)
(2 中国科学院半导体研究所 半导体材料科学重点实验室, 北京 100083)

摘要: 在蓝宝石衬底上制作 AlGaN/GaN 高电子迁移率晶体管. 由于使用了一种全新的 T 形栅电子束曝光版图, 因此可以自由地改变 T 形栅的宽窄比(T 形栅头部尺寸与栅长的比值)并优化 T 形栅的形状. 所得的 0.18μm 栅长的器件, 其特征频率(f_T)为 65GHz, T 形栅的宽窄比为 10. 同时, 测得的峰值跨导为 287mS/mm, 最大电流密度为 980mA/mm.

关键词: GaN; HEMT; T 形栅; 版图
EEACC: 2560
中图分类号: TN386 **文献标识码:** A **文章编号:** 0253-4177(2008)09-1654-03

† 通信作者. Email: czg20001@hotmail.com
2008-02-29 收到, 2008-04-23 定稿