0.25μm Gate-Length AlGaN/GaN Power HEMTs on Sapphire with f_T of 77GHz

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Abstract: MOCVD-grown 0.25μm gate-length AlGaN/GaN high electron mobility transistors (HEMTs) are fabricated on sapphire substrates. A peak extrinsic transconductance of 250mS/mm and a unity current gain cutoff frequency (f_T) of 77GHz are obtained for a 0.25μm gate-length single finger device. These power devices exhibit a maximum drain current density as high as 1.07A/mm. On-chip testing yielded a continuous-wave output power of 27.04dBm at 8GHz with an associated power-added efficiency of 26.5% for an 80×10μm device.

Key words: GaN; sapphire substrate; high electron mobility transistor
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1 Introduction

Microwave power devices with conventional semiconductors are approaching their performance limits. To meet future needs in wireless communication, research is being directed to wide bandgap semiconductors such as SiC and GaN[1].

AlGaN/GaN high electron mobility transistors (HEMTs) are excellent candidates for high power and high frequency applications at elevated temperatures due to their superior material properties[2,3]. As a result of improvements in material growth and processing technology, microwave power densities five to ten times greater than those of corresponding GaAs-based devices have been demonstrated. These higher power densities will lead to the simplification of the design and fabrication of monolithic microwave integrated circuits (MMICs). GaN-based HEMTs are typically grown on either SiC or sapphire substrates. GaN HEMTs grown on SiC have demonstrated power densities beyond 9W/mm at the X-band (compared to 6.4W/mm for GaN HEMTs grown on sapphire[4,5]) and the thermal conductivity of SiC is superior to that of sapphire, but sapphire is cheaper. Mainly for this reason, we have fabricated our GaN HEMTs on sapphire substrates. Flip-chip (FC) technology can help solve the thermal conduction problem[6].

In this paper, we present the microwave performance of MOCVD-grown 0.25μm gate-length AlGaN/GaN high electron mobility transistors fabricated on sapphire substrates. These single finger devices exhibit a maximum peak extrinsic transconductance of 250mS/mm and a unity current gain cutoff frequency (f_T) of 77GHz. On the same wafer, a maximum drain current density of 1.07A/mm is obtained for the 80×10μm gate-length device.

2 Device fabrication

A 50mm-diameter wafer was supplied by the Department of Electrical and Electronic Engineering at HKUST. The device structures in this study were grown by metal-organic chemical vapor deposition (MOCVD) on sapphire substrates. The typical epitaxial structure is shown in Fig. 1, which consists of a 2.5μm undoped GaN layer followed by a 3nm undoped AlGaN layer. Above that

2nm undoped $Al_xGa_{1-x}N$ $x = 0.33 \sim 0.38$
15nm n-$Al_xGa_{1-x}N$ $3.5 \times 10^{18} cm^{-3}$
3nm undoped $Al_xGa_{1-x}N$
2.5μm GaN
Sapphire

Fig. 1 Epitaxial structure of the GaN wafer

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is a 15nm AlGaN layer with a doping density of about 3.5 $\times 10^{18} cm^{-3}$. The top layer is a 2nm undoped AlGaN cap layer. The sheet resistance is about 350Ω/□.

Device processing included mesa isolation using a chlorine-based inductively coupled plasma (ICP) etch, followed by Ti-Al-Ti-Au-based ohmic contact deposition and annealing[7]. Air-bridge technology was used for the multi-finger gate power device. Electron-beam lithography was then used to define the Ni-Au T-gates with footprints of 0.25μm, and a multi-layer photoresistor structure[8] was optimized and used to obtain the T-shaped gate. Figure 2 shows an SEM photo of the T-shaped gate.

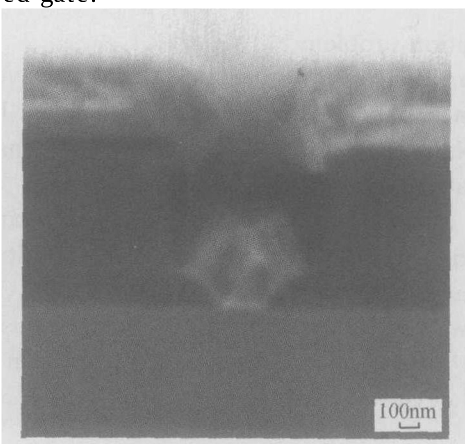

Fig. 2 SEM photo of 0.25μm T-shaped gate

3 Results and discussion

DC measurements were performed on the fabricated devices using a HP4155A semiconductor parameter analyzer. The maximum peak transconductance was 250mS/mm at a gate voltage of -4.6V. The pinch-off voltage was -5.2V, as demonstrated in Fig. 3. Figure 4 shows the forward and reverse gate diode characteristics. The forward turn-on voltage (measured under a 1mA/mm forward gate current) was 1.85V, and the reverse gate current was -10.75μA/mm at -20V. On an 80 $\times$10μm power device, an on-chip maximum drain current density as high as 1.07A/mm was obtained when the gate voltage was 0.5V, as shown in Fig. 5.

An extrapolation of the unity current gain cutoff frequency (f_T) to 77GHz was obtained for the single finger gate (40 $\times$0.25μm) device, as shown in Fig. 6. A continuous-wave output power of 27.04dBm at 8GHz and a drain voltage of 10V with an associated power-added efficiency of 26.5% were obtained for a 80 $\times$10μm device (Fig. 7).

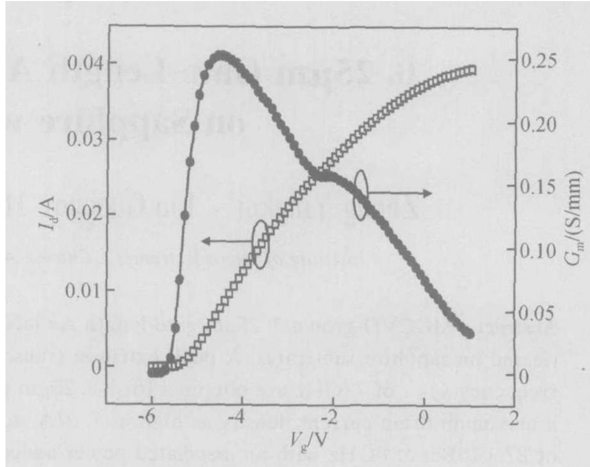

Fig. 3 Performance of transconductance

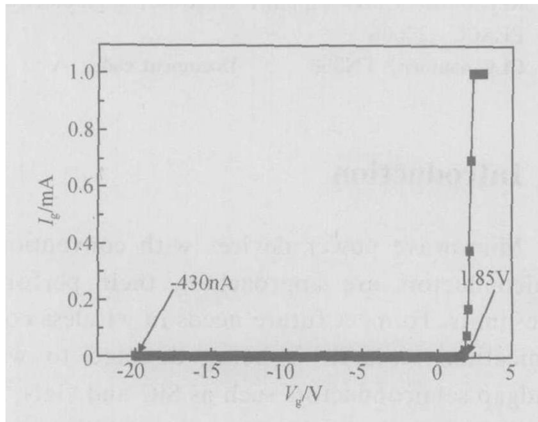

Fig. 4 Forward and reverse gate diode characteristics (W_g = 40μm)

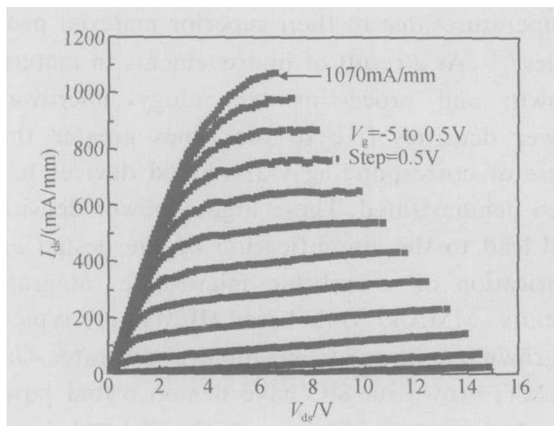

Fig. 5 Pulse measurement of 80 $\times$10μm power device's I-V curves

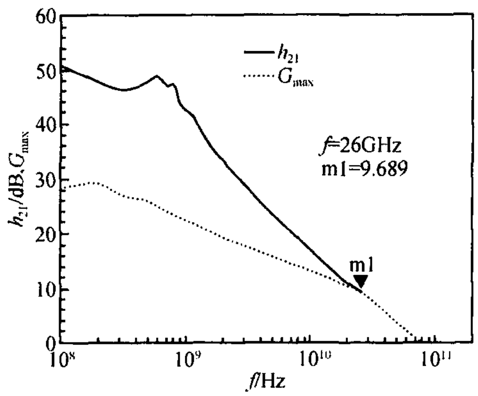

Fig. 6　RF characteristic: extrapolation to approximately 77GHz of current gain cutoff frequency (f_T)

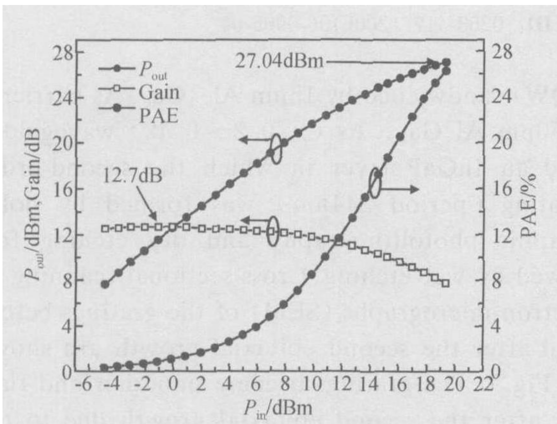

Fig. 7　Power performance of the 80 ×10μm device (f = 8GHz; V_{ds} = 10V)

4　Conclusion

We have fabricated 0. 25μm gate-length microwave power AlGaN/ GaN HEMTs on sapphire substrates. A maximum peak transconductance of 250mS/ mm at a gate voltage of - 4. 6V was obtained. On the power device on-chip test, a CW output power of 27. 04dBm with an associated PAE of 26. 5 % was achieved at 8GHz and 10V drain bias. The good performance of GaN/ AlGaN HEMTs on the sapphire substrate shows their potential for applications in microwave power circuits.

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f_T 为 77GHz 的蓝宝石衬底 0. 25μm 栅长 AlGaN/ GaN 高电子迁移率功率器件

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摘要: 在蓝宝石衬底上用 MOCVD 技术生长的 AlGaN/ GaN 结构上制作出 0. 25μm 栅长的高电子迁移率功率晶体管. 0. 25μm 栅长的单指器件测到峰值跨导为 250mS/ mm, 特征频率为 77GHz. 功率器件的最大电流密度达到 1. 07A/ mm. 8GHz 频率下在片测试 80 ×10μm 栅宽器件的输出功率为 27. 04dBm, 同时功率附加效率达到 26. 5 %.

关键词: GaN; 蓝宝石; HEMT

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