A Ku-band 3.4 W/mm power AlGaN/GaN HEMT on a sapphire substrate*

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Abstract: This paper describes the first domestic Ku-band power AlGaN/GaN HEMT fabricated on a sapphire substrate. The device with a gate width of 0.5 mm and a gate length of 0.35 μm has exhibited an extrinsic current gain cutoff frequency of 20 GHz and an extrinsic maximum frequency of oscillation of 75 GHz. Under $V_{\rm DS}$ = 30 V, CW operating conditions at 14 GHz, the device exhibits a linear gain of 10.4 dB and a 3-dB-gain-compressed output power of 1.4 W with a power added efficiency of 41%. Under pulse operating conditions, the linear gain is 12.8 dB and the 3-dB-compressed output power is 1.7 W. The power density reaches 3.4 W/mm.

Key words: AlGaN/GaN HEMT; Ku band; power
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1. Introduction

Wide band-gap AlGaN/GaN high-electron-mobility transistors (HEMTs) are attracting considerable attention for microwave high power and high frequency applications. This is because GaN-based materials exhibit high current density, high saturation velocity and high breakdown field. At 2 GHz, AlGaN/GaN HEMTs have exhibited 100 W output power[1]. And Ku-band, even W-band operations have been reported abroad[2, 3]. The domestic progresses of AlGaN/GaN HEMTs are also remarkable. At 8 GHz, the maximum output power has reached 12.3 W[4]. Yet so far there are no application over Ku-band reported.

In this paper, DC and RF performance of a Ku-band AlGaN/GaN HEMT is reported. The device was fabricated on a domestic wafer with sapphire substrate. The device exhibits an extrinsic current gain cutoff frequency ($f_{\rm T}$) of 20 GHz and an extrinsic maximum frequency of oscillation ($f_{\rm max}$) of 75 GHz. Under $V_{\rm DS}$ = 30 V, pulse operating conditions at 14 GHz, the linear gain is 12.8 dB and the 3-dB-gain-compressed output power ($P_{\rm 3dB}$) is 1.7 W. The power density reaches 3.4 W/mm. To the best of our knowledge, no other domestic AlGaN/GaN HEMTs at the Ku-band have so far been reported, either on sapphire substrate or on SiC substrate, so this is the first domestic Ku-band AlGaN/GaN HEMT.

2. Device structure and fabrication

The two-inch epitaxial wafer was provided by the Institute of Semiconductors of the Chinese Academy of Sciences. $\rm Al_{0.25}Ga_{0.75}N/AlN/GaN$ multilayers were grown on a sapphire substrate by MOCVD and the sheet resistance is 354 Ω /□.

Ti/Al/Ni/Au for ohmic contact was deposited by evaporation，followed by rapid thermal annealing at 870 °C for 50 s. The ohmic contact resistivity measured by the 4-probe method was 8.7×10^{-6} $\Omega\cdot$ cm^2. Surface passivation was done with SiN film (120 nm) deposited by PECVD. The T-shape Ni/Au (40 nm/300 nm) gate was formed by the combined processes of electron-beam lithography, dry-etch and evaporation. The completed gate length is 0.35 μm.

In order to improve the frequency characteristics of the devices, the device structure was carefully designed to minimize parasitical parameters. The source–drain spacing is 4 μm. The unit gate width is 50 μm, and the gate-head of the T-shaped gate is 0.7 μm. A gate-finger periodical interval ($G_{\rm P}$) value of 20 μm is adopted in consideration of both the thermal resistance and the signal propagation uniformity to each gate. Figure 1 shows a device with a gate width of 50 μm × 10.

3. DC and small-signal characteristics

Figure 2 shows the drain I–V characteristics of a 50 μm × 10 gate-width device. The device exhibits a saturation drain current of 681 mA/mm. The knee voltage is 3.15 V. Figure 3 shows the transconductance ($g_{\rm m}$) and the $I_{\rm DS}$–$V_{\rm g}$ characteristics. A maximum $g_{\rm m}$ of 282 mS/mm is obtained, and the pinch-off voltage is –2.1 V. The breakdown voltage was measured about 100 V.

Figure 4 shows the small signal RF-gains of the device. An extrinsic $f_{\rm T}$ of 20 GHz and an extrinsic $f_{\rm max}$ of 75 GHz

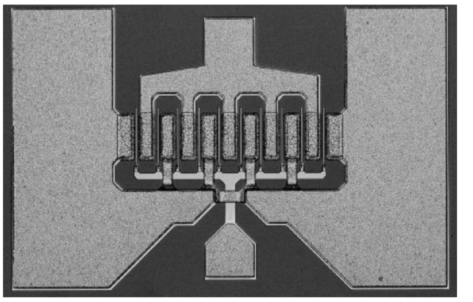

Fig. 1. A Ku-band AlGaN/GaN HEMT with a gate width of 50 μm × 10. The chip size is 420 × 275 μm^2.

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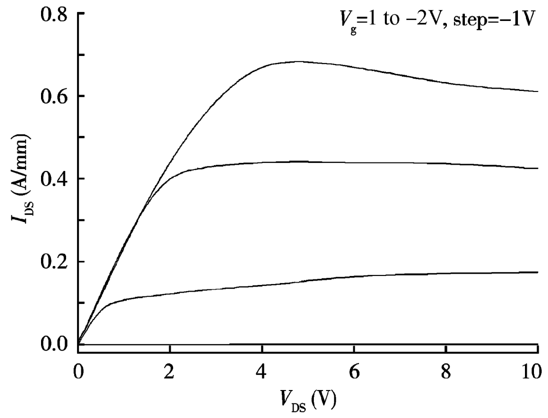

Fig. 2. Drain I–V characteristics.

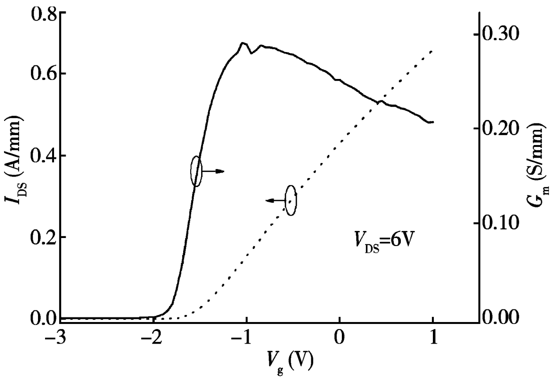

Fig. 3. Transconductance (g_m) and I_{DS}–V_g characteristics.

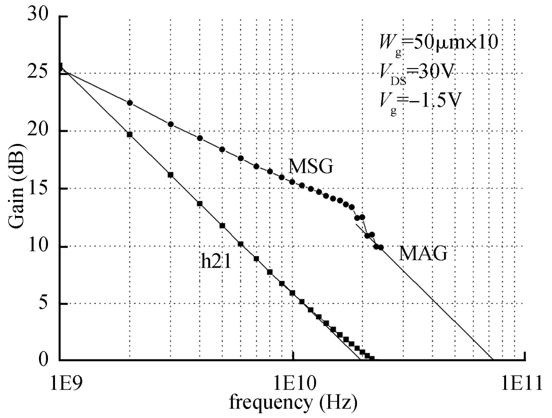

Fig. 4. Extrinsic small-signal RF-gains.

are obtained at V_{DS} = 30 V. The turning frequency at which the device switches from MSG-state (maximum stable gain) to MAG-state (maximum available gain) is 18 GHz. At 14 GHz, the MSG is 14.35 dB and, at 18 GHz, it is 13.40 dB.

4. Power operation

Figure 5 shows the output power, gain and power added efficiency (PAE) of the device. The device was measured both under CW and pulse operating conditions at 14 GHz. Under V_{DS} = 30 V, CW operating conditions at 14 GHz, the device exhibits a linear gain of 10.4 dB and a 3-dB-gain-compressed output power of 31.5 dBm (1.4 W) with a power added efficiency (PAE) of 41%. Under 10%-duty-circle pulse operating conditions, the linear gain is 12.8 dB and the 3 dB-gain-compressed output power is 32.3 dBm (1.7 W). The power density reaches 3.4 W/mm.

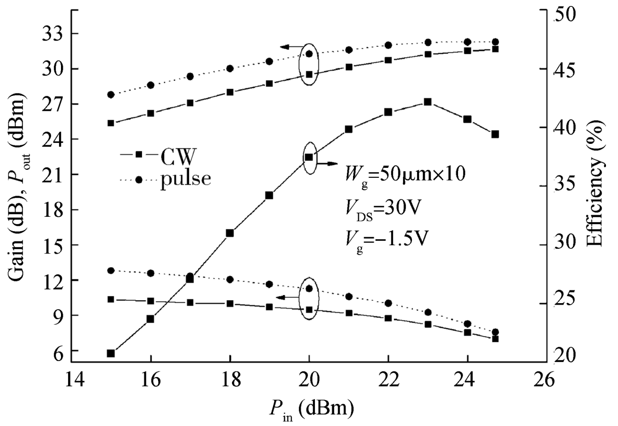

Fig. 5. Output power, gain and PAE at 14 GHz.

To realize further improvements in the device performance, some issues are still to be developed, for example:

(1) Fabrication of the device on SiC substrates;
(2) Fabrication of devices with larger periphery;
(3) Reduction of the gate length.

5. Conclusion

In this study, we presented the performance of a Ku-band AlGaN/GaN HEMT. The device was fabricated on a domestic epitaxial wafer with a sapphire substrate, and the device structure was carefully designed to minimize parasitical parameters. The device with a gate width of 0.5 mm and a gate length of 0.35 μm has exhibited an extrinsic f_T of 20 GHz and an extrinsic f_{max} of 75 GHz. The linear gain is 12.8 dB and the power density reaches 3.4 W/mm. To the best of our knowledge, this is the first domestic Ku-band AlGaN/GaN HEMT.

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