Vol. 31, No. 3 Journal of Semiconductors March 2010

High performance AlGaN/GaN HEMTs with 2.4 μm source–drain spacing*

Wang Dongfang(王东方)[1, 2, †], Wei Ke(魏珂)[1], Yuan Tingting(袁婷婷)[1, 2], and Liu Xinyu(刘新宇)[1]

(1 Institute of Microelectronics, Chinese Academy of Sciences, Beijing 100029, China)
(2 Graduated University of the Chinese Academy of Sciences, Beijing 100049, China)

Abstract: This paper describes the performance of AlGaN/GaN HEMTs with 2.4 μm source–drain spacing. So far these are the smallest source–drain spacing AlGaN/GaN HEMTs which have been implemented with a domestic wafer and domestic process. This paper also compares their performance with that of 4 μm source–drain spacing devices. The former exhibit higher drain current, higher gain, and higher efficiency. It is especially significant that the maximum frequency of oscillation noticeably increased.

Key words: AlGaN/GaN HEMT; high frequency; source–drain spacing
DOI: 10.1088/1674-4926/31/3/034001 **EEACC:** 2520D

1. Introduction

Wide-bandgap AlGaN/GaN high-electron-mobility transistors (HEMTs) are being developed for high power and high frequency applications. This is because GaN-based materials exhibit high current density, high saturation velocity and high breakdown field. 40 W/mm power operation has been demonstrated at 4 GHz[1]. There is also an increasing interest in applications at higher frequencies. Ka-band and even W-band operations have been reported abroad [2–4].

An important feature of most millimeter-wave devices is that they have small source–drain spacings ($L_{\rm sd}$). Some studies have indicated that the gate–drain spacing ($L_{\rm gd}$) can influence the maximum frequency of oscillation ($f_{\rm max}$)[3] and that reducing the gate–source spacing ($L_{\rm gs}$) can increase drain current and transconductance[5]. Yet there have been no general comparisons between different source–drain spacings. On the other hand, reducing $L_{\rm sd}$ is believed to be difficult. The most important reason is that the conventional Ti/Al/Ti/Au ohmic contact has rough morphology and edges after annealing, which limits the reduction of the spacing. At present, most domestic AlGaN/GaN HEMTs have $L_{\rm sd}$ of over 4 μm.

According to our study, the ohmic contact edges can be improved by using Ti/Al/Ni/Au. Being a more effective diffusion barrier, nickel (Ni) can prevent the formation of an Al–Au alloy, which can scatter along the wafer surface and causes rough morphology and edges[6]. Moreover, the ohmic contact resistivity of Ti/Al/Ni/Au can reach 10^{-6} $\Omega\cdot$cm^2 which is equivalent to that of Ti/Al/Ti/Au.

Based on this study, we fabricated AlGaN/GaN HEMTs with $L_{\rm sd}$ of 2.4 μm. To the best of our knowledge, so far these are the smallest source–drain spacing devices implemented with a domestic wafer and process. We also compare their performance with that of 4 μm source–drain spacing devices on the same wafer. The 2.4 μm source–drain spacing devices exhibit better performance.

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 $\Omega/\Box$. Ohmic metal consisting of Ti/Al/Ni/Au was deposited by evaporation, followed by rapid thermal annealing at 870 °C for 50 s. The ohmic contact resistivity was 8.7×10^{-6} $\Omega\cdot$cm^2 measured by the 4-probe method. Passivation was done by using SiN film (120 nm) deposited by PECVD. The T-shape Ni/Au gate was formed by the combined processes of electron-beam lithography, dry-etch and evaporation. The completed gate length is 0.35 μm and the length of the gate head is 0.7 μm. The unit gate width is 75 μm. The gate–source spacing is 0.7 μm for the SD 2.4 μm devices, and is 1.5 μm for the SD 4 μm devices. Figure 1 shows a picture of an SD 2.4 μm device.

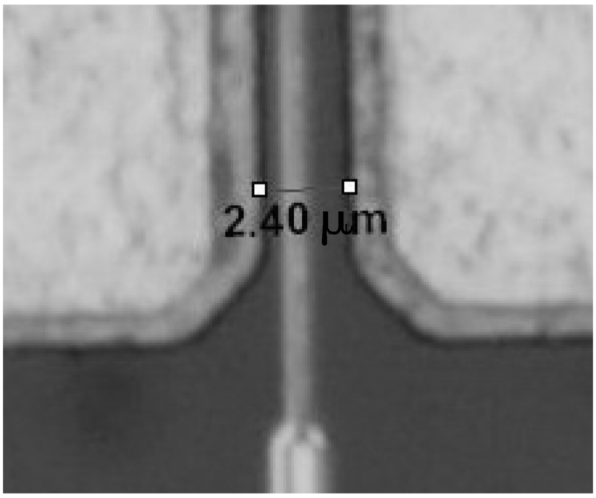

Fig. 1. An AlGaN/GaN HEMT with 2.4 μm source–drain spacing.

---

* Project supported by the National Natural Science Foundation of China (No. 60890191).

† Corresponding author. Email: wdf0155@sina.com

Received 30 July 2009, revised manuscript received 9 September 2009

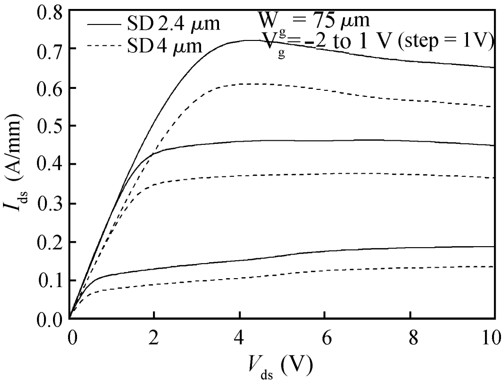

Fig. 2. Drain I–V characteristics of devices with SD 2.4 μm and SD 4 μm respectively.

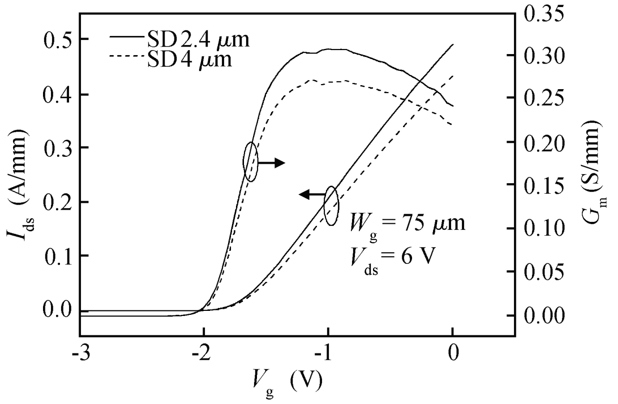

Fig. 3. Transconductance (g_m) and I_{ds}–V_g characteristics of devices with SD 2.4 μm and SD 4 μm respectively.

3. DC and small-signal characteristics

Figure 2 shows the drain I–V characteristics for devices with SD 2.4 μm and SD 4 μm respectively. Typically, the SD 4 μm devices exhibit a maximum drain current (I_{DSS}) of 608 mA/mm, and the knee voltage (V_k) is 2.80 V at V_g = 1 V. For the SD 2.4 μm devices, the drain current is 721 mA/mm and the V_k is 2.86 V. The drain current of the latter is 18% higher, yet the knee voltage is similar.

Figure 3 shows the transconductance (g_m) and I_{ds}–V_g characteristics of the two kinds of devices at V_{ds} = 6 V. The maximum g_m of the SD 2.4 μm device is 308 mS/mm, and the SD 4 μm one's is 272 mS/mm. The increased g_m of the former is due to the reduction of the gate–source spacing[3]. Figure 4 shows the breakdown characteristics of the two kinds of devices. If taking the breakdown condition as the drain current reaching 1 mA/mm, the breakdown voltages of the SD 2.4 μm and the SD 4 μm devices are 62 V and 100 V respectively. Considering that an operating voltage of 28 V is widely used in microwave systems, 62 V is enough for such applications.

Figure 5 shows the current gain (h_{21}) and MSG/MAG (maximum stable gain/maximum available gain) of the two kinds of devices. Both the devices have a gate width of 75 μm × 10. Table 1 shows a comparison of the small signal RF gains of the two devices.

It can be seen that the SD 2.4 μm device exhibits higher frequency and higher gain characteristics. Also, the SD 2.4 μm device has a higher turning frequency from MSG to MAG, which is helpful to increase the gain at high frequency. At 30 GHz, the maximum gain of the SD 2.4 μm device is 1.3 dB higher. This indicates that reducing the source–drain spacing is important for high frequency HEMTs.

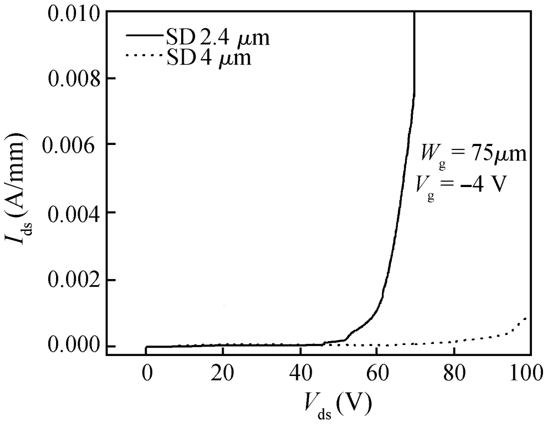

Fig. 4. Breakdown characteristics of devices with SD 2.4 μm and SD 4 μm respectively.

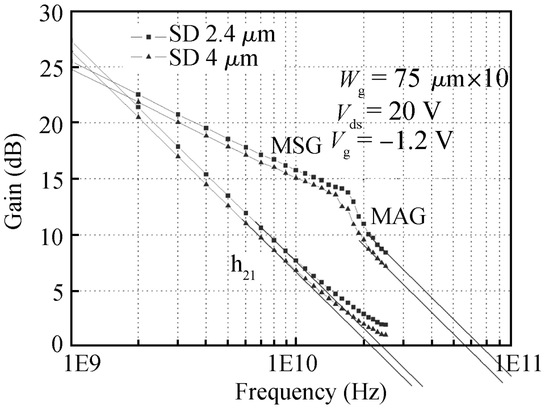

Fig. 5. Small-signal RF gains of devices with SD 2.4 μm and SD 4 μm respectively.

Table 1. Comparison of RF gains for devices with SD 2.4 μm and SD 4 μm respectively.

Parameter	SD 4 μm	SD 2.4 μm
f_T (GHz)	22	24
f_{max} (GHz)	57	67
MSG at 8 GHz (dB)	16.0	16.7
MAG at 30 GHz (dB)	5.7	7.0
Turning frequency from MSG to MAG (GHz)	15	17

By reducing the gate–source spacing and gate–drain spacing, the series resistances R_S and R_D are lowered. So the SD 2.4 μm devices exhibit better DC and small-signal characteristics as above. Also, because of the reduction of the gate–drain spacing, the breakdown voltage is lowered.

4. Power operation

Figure 5 shows the large-signal RF performance of the two kinds of devices with a gate width of 75 μm × 10. The devices

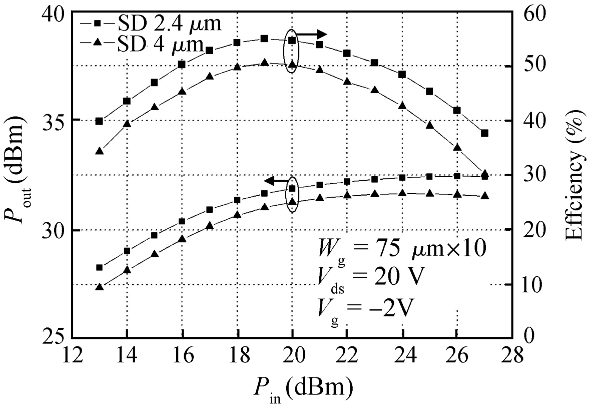

Fig. 6. Output power and PAE of devices with SD 2.4 μm and SD 4 μm respectively at 8 GHz.

operated in deep AB class at $V_{\rm ds} = 20$ V, and were measured on-wafer with a load–pull system at 8 GHz. The SD 2.4 μm device has a saturated output power of 32.4 dBm, which is 0.8 dB (20%) higher than that of the SD 4 μm device. Moreover, the gain and the PAE (power added efficiency) are also higher.

The higher output power of the SD 2.4 μm device is due to its higher $I_{\rm dss}$ and relatively low $V_{\rm k}$. Because the gate–source spacing and gate–drain spacing are reduced, the power consumed at the resistances $R_{\rm S}$ and $R_{\rm D}$ decreases, and the PAE increases.

5. Conclusion

We have successfully fabricated AlGaN/GaN HEMTs with 2.4 μm source–drain spacing. So far these are the smallest source–drain spacing devices which have been implemented with a domestic wafer and process. Compared with the 4 μm source–drain spacing devices, the former exhibit higher drain current, higher gain, and higher efficiency. In particular, the maximum frequency of oscillation is noticeably enhanced.

References

[1] Wu Y F, Moore M, Saxler A, et al. 40-W/mm double field-plated GaN HEMTs. IEEE 64th Device Research Conference, 2006: 151

[2] Wu Y F, Moore M, Saxler A, et al. 8-Watt GaN HEMTs at millimeter-wave frequencies. IEEE International Electron Devices Meeting, 2005

[3] Inoue T, Ando Y, Miyamoto H, et al. 30-GHz-band over 5-W power performance of short-channel AlGaN/GaN heterojunction FETs. IEEE Trans Microw Theory Tech, 2005, 53(1): 74

[4] Micovic M, Kurdoghlian A, Hashimoto P, et al. GaN HFET for W-band power applications. IEEE International Electron Devices Meeting, 2006

[5] Russo S, Carlo A D. Influence of the source–gate distance on the AlGaN/GaN HEMT performance. IEEE Trans Electron Devices, 2007, 54(5): 1071

[6] Mohammed F M, Wang L, Koo H J, et al. Anatomy-performance correlation in Ti-based contact metallizations on AlGaN/GaN heterostructures. J Appl Phys, 2007, 101: 033708