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Non-Recessed-Gate Enhancement-Mode AlGaN/GaN HEMTs with High RF Performance

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1. Introduction

AlGaN/GaN high electron mobility transistors (HEMTs) are devices that can operate at high power, at high speed and in a high temperature environment. Recently, several reports on high performance AlGaN/GaN HEMTs have been published [1-3]. Such high performance was achieved with depletion-mode (D-mode) HEMTs where the threshold voltages have typically been -4 ~ -8 V. Enhancement-mode (E-mode) HEMTs are strongly required because of circuit simplicity and low power dissipation. Thus far, E-mode HEMTs have been fabricated by using recessed-gate structures for AlGaAs/GaAs [4] and AlGaN/GaN [5,6] material systems. However, process damage induced during the fabrication of recessed-gates is a serious problem. In this paper, we report on the fabrication and performance of non-recessed-gate E-mode AlGaN/GaN HEMTs.

2. Fabrication Process

AlGaN/GaN HEMT epitaxial layers were grown on (0001) sapphire substrates through metal organic chemical vapor deposition (MOCVD). The layers were a 2-μm GaN, which was the bottom layer, and a 10-nm $Al_{0.25}Ga_{0.75}N$. The $Al_{0.25}Ga_{0.75}N$ barrier layer was not doped. Hall measurements of this structure revealed a two-dimensional electron gas (2DEG) sheet density of 6.8×10^{12} cm^{-2} and a 2DEG mobility of 840 cm^2/Vs at room temperature.

Source and drain ohmic contacts with a source-drain spacing L_{sd} of 2 μm were formed using alloyed Ti/Al at 750°C. The specific contact resistance was about 2.0×10^{-6} Ω cm^2. T-shaped Mo/Pt/Au Schottky gates with widths W_g of 50 × 2 μm were fabricated with electron beam (EB) lithography and a standard lift-off technique. A SiO_2/SiN double-layer film was used as the mask material. A T-shaped gate pattern was directly written through 50-keV EB exposure after coating with a triple-layer EB resist consisting of ZEP/PMGI/ZEP. The bottom of the T-shaped gate pattern was then replicated on the SiN film by reactive ion etching (RIE) with CF_4 gas. The SiO_2 film was wet-chemically etched. A series of etching processes enabled us to minimize the process-induced damage. Finally, the Mo/Pt/Au gate metal was evaporated and lifted off. A schematic cross-section of the fabricated HEMT is shown in Fig. 1.

3. Device Performance

We measured the on-wafer DC and RF characteristics at room temperature. Figure 2 shows the current-voltage (*I-V*) characteristics of a 120-nm-gate HEMT. It was almost normally-off at a gate-source voltage V_{gs} of 0 V, indicating E-mode device operation. The maximum transconductance g_m was 295 mS/mm at a drain-source voltage V_{ds} of 3 V.

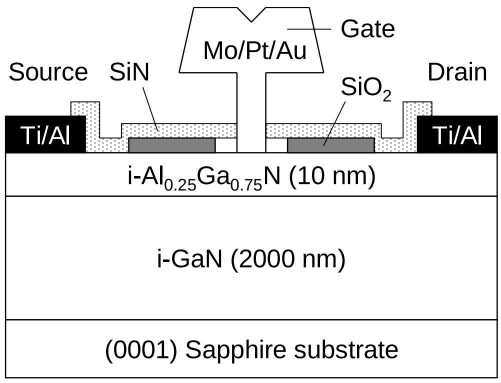

Fig. 1 Schematic cross-section of fabricated AlGaN/GaN HEMT.

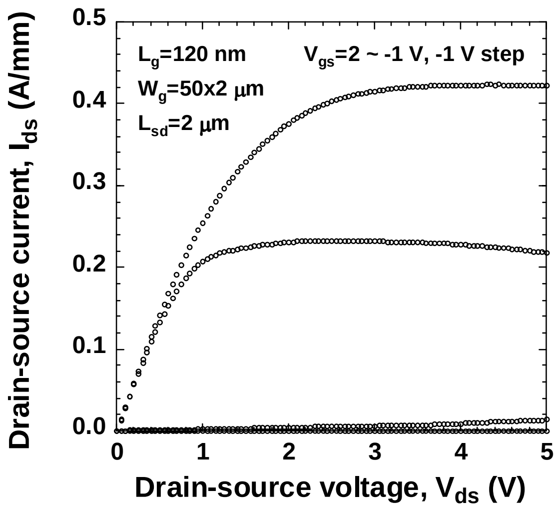

Fig. 2 Current-voltage characteristics of 120-nm-gate HEMT. Gate-source voltage V_{gs} is decreased from 2 V (top) to -1 V (bottom) in -1 V steps.

This maximum g_m is comparable to that of D-mode HEMTs. It is well known that the deposition of SiO_2 on the AlGaN layer causes pronounced current collapse in AlGaN/GaN HEMTs [7]. However, very little current collapse occurred with the maximum V_{ds} of 5 V in our HEMTs. Figure 3 shows the V_{gs} dependence of the gate-source current I_{gs} for the same HEMT. As we can clearly see from Fig. 3, this HEMT has very high breakdown voltage. The turn-on voltage was 1.6 V at 1 mA/mm forward gate current.

The S-parameters were measured in a frequency range from 0.25 to 50 GHz in 0.25-GHz steps with an HP8510C vector network analyzer and on-wafer probes. Figure 4 shows the frequency dependence of current gain $|h_{21}|^2$ and Mason's unilateral power gain U_g for a 120-nm-gate HEMT under a V_{ds} of 3 V and a V_{gs} of 0.4 V. Note that the parasitic capacitance due to the probing pads was subtracted from the measured S-parameters. We obtained a cutoff frequency f_T of 55 GHz by extrapolating the $|h_{21}|^2$ with a -20 dB/decade using a least-squares fit. On the other hand, we obtained a maximum oscillation frequency f_{max} of 94 GHz from U_g. Thus, this 120-nm-gate E-mode HEMT also had high RF performance.

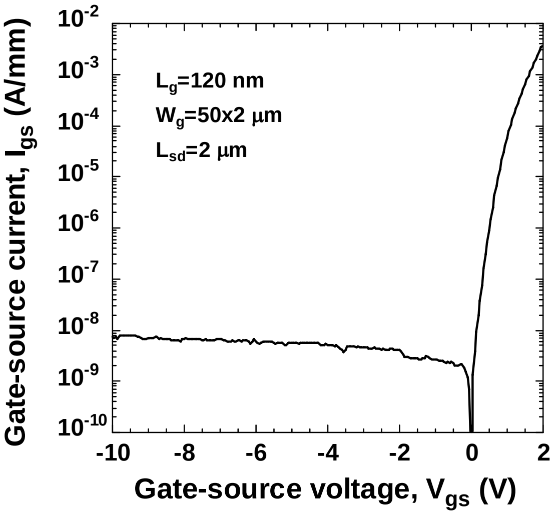

Fig. 3 Gate-source voltage V_{gs} dependence of gate-source current I_{gs} for 120-nm-gate HEMT.

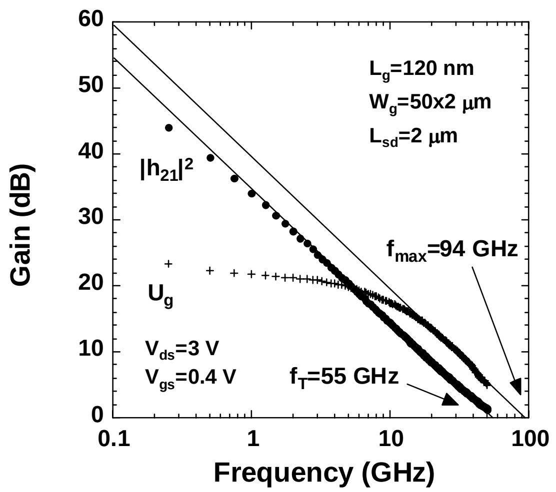

Fig. 4 Frequency dependence of current gain $|h_{21}|^2$ and Mason's unilateral power gain U_g in 120-nm-gate HEMT. Drain-source voltage V_{ds} was 3 V and gate-source voltage V_{gs} was 0.4 V.

4. Summary

In summary, we fabricated non-recessed-gate E-mode AlGaN/GaN HEMTs with a gate length of 120 nm that were almost normally-off at V_{gs}=0 V. The maximum g_m was 295 mS/mm. We also measured the S-parameters up to 50 GHz and obtained an f_T of 55 GHz and an f_{max} of 94 GHz for a 120-nm-gate HEMT, indicating that this E-mode HEMT also had high RF performance.

Acknowledgements

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