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Gain Improvement of Enhancement-mode AlGaN/GaN HEMTs Using Dual-Gate Architectures

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1. Introduction

Wide bandgap AlGaN/GaN high electron mobility transistor (HEMT) has emerged as a promising candidate for RF/microwave power amplifiers (PAs) because of its high power handling capabilities. Previously, depletion-mode dual-gate (D-mode DG) AlGaN/GaN HEMTs, composed of two D-mode gates, were reported for use as broadband PAs because of higher output impedance and smaller feedback capacitance [1]. Compared to D-mode devices, enhancement-mode (E-mode) HEMTs allow the elimination of negative-polarity voltage supply, and therefore, reductions of circuit complexity and system cost. In this paper, E-mode DG AlGaN/GaN HEMTs, which consist of an E-mode gate and a D-mode gate, are demonstrated by using CF_4 plasma treatment technique [2], and comparison of RF and DC characteristics is made between E-mode dual-gate and single-gate (SG) devices. At 2.1 GHz, a 9-dB gain improvement has been achieved using E/D-mode dual-gate structure with only one positive polarity voltage supply.

2. Devices Fabrication and Characterization

The AlGaN/GaN HEMT structure used in this work is grown on (0001) sapphire substrate in an Aixtron AIX 2000 HT metal-organic chemical vapor deposition (MOCVD) system. The HEMT epitaxial structure is similar to that used in our previous work [2], with an AlGaN barrier thickness of 21 nm.

The E-mode DG AlGaN/GaN HEMT process flow is illustrated in Fig. 1. At first, the device mesa is formed using Cl_2/He plasma dry etching in a STS ICP-RIE (inductively coupled plasma reactive ion etching) system. Then the source/drain ohmic contacts are formed by e-beam deposition of Ti/Al/Ni/Au and rapid thermal annealing at 850ºC for 30 s, as shown in Fig. 1 (a). Secondly, the D-mode gate electrodes and interconnections are defined by e-beam evaporation of Ni/Au and lift-off [Fig. 1 (b)]. Next, E-mode gate electrodes are patterned by photolithography. Prior to deposition of Ni/Au, the gate regions are treated by CF_4 plasma in a STS RIE system, as shown in Fig. 1 (c). The RF power is 150 W, and the plasma bias is set to be 0 V. The CF_4 gas flow is controlled to be 150 sccm, and the treatment time is 150 s. This step performs the function of converting the treated region from D-mode to E-mode operation [2]. At last, the gate meal is deposited and the whole sample is annealed at 400ºC for 10 min to repair the plasma-induced damage in the AlGaN barrier and channel. The E-mode gate electrode is separated by 1 μm from the source, and the D-mode gate is 1μm away from the drain contact, with a 1.5-μm separation between two gates. All the gate electrodes have dimensions of 1 x 100 μm^2.

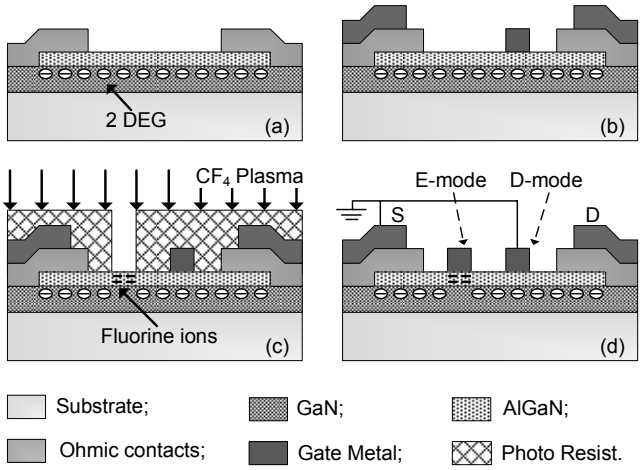

Fig. 1 Schematics showing the process flow of E-mode DG HEMTs: (a) mesa and ohmic contacts; (b) D-mode gate electrode; (c) E-mode gate definition and plasma treatment; (d) E-mode gate metal deposition and lift-off.

The DC characteristics of the E-mode DG HEMTs are plotted in Fig. 2, with the D-mode gate grounded as shown in the inset of Fig. 2 (b). It can be seen that the DG devices exhibit a peak current density of ~ 314 mA/mm; the peak transconductance (g_m) is about 145 mS/mm. Defining threshold voltage (V_{th}) as the gate bias intercept of the linear extrapolation of drain current at the point of peak g_m, the V_{th} of E-mode DG HEMT is determined to be 0.3 V [Fig. 2 (b)]. As a comparison, the discrete E-mode and D-mode SG AlGaN/GaN HEMTs are also fabricated on the same substrate with the same gate dimensions. The transfer characteristics of SG devices are shown in Fig. 3. The peak current density for SG D-mode and E-mode HEMTs are about 520 and 328 mA/mm respectively; the peak transconductances are 160 and 146 mS/mm. It can be concluded that E-mode DG HEMTs have comparable DC characteristics with the E-mode SG devices. The E-mode DG and SG HEMTs exhibit a smaller g_m compared to the D-mode devices due to the incomplete recovery of the plasma-induced damage [2].

On-wafer small-signal RF characteristics of E-mode SG and DG AlGaN/GaN HEMTs are measured from 0.1 to

39.1 GHz. The current gain (h21) and maximum stable/maximum available gain (MSG/MAG) of both types of devices are derived from the measured S-parameters as a function of frequency, as shown in Fig. 4. At V_{DS} = 10 V and V_{GS} = 1 V, E-mode DG HEMTs reveal a similar current gain cutoff frequency (f_T) of 13.7 GHz with the SG devices. Comparing the MSG/MAG, E-mode DG HEMTs exhibit about a 9-dB gain improvement at 2.1 GHz than the SG devices, with an increase in the power gain cutoff frequency (f_{max}) from 30.9 and 31.9 GHz.

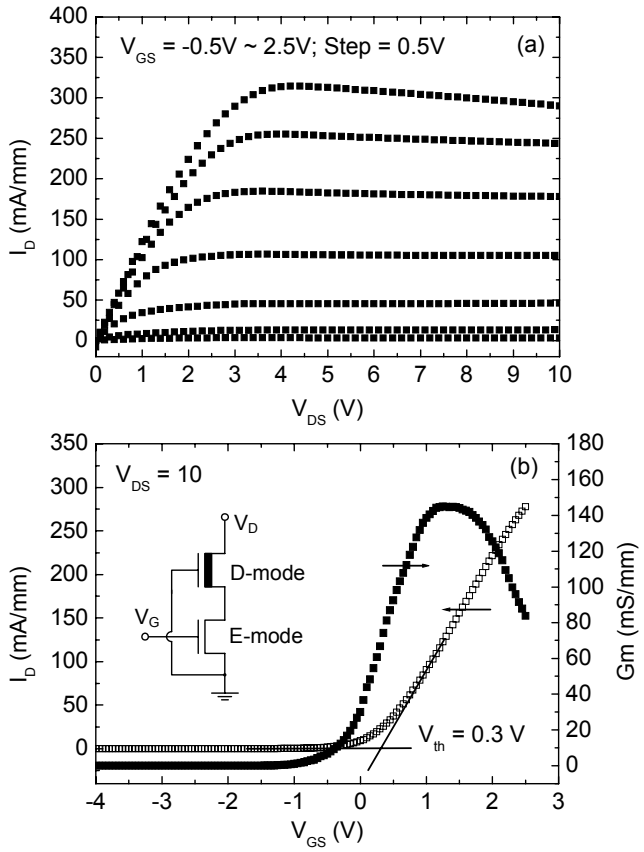

Fig. 2 DC characteristics of E-mode DG HEMTs: (a) output curves and (b) transfer characteristics.

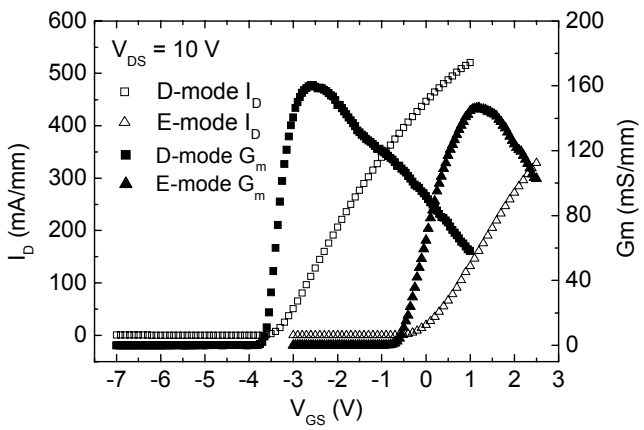

Fig. 3 Transfer curves of E-mode and D-mode SG HEMTs.

The MSG/MAG improvement of E-mode DG HEMTs can be attributed to the higher output impedance and smaller feedback capacitance [1, 3]. The output impedance (R_{DS}) comparison between E-mode DG and SG HEMTs, extracted from the measured S-parameters, is shown in Fig. 5. It can be seen that the R_{DS} has been improved remarkably by using dual-gate structure. On the other hand, DG HEMTs, compared to SG devices, substantially reduce signal feedback (S_{12}) by ~ 8 dB at 2.1 GHz because of good isolation between input and output by the D-mode gate, leading to increased device power gain further.

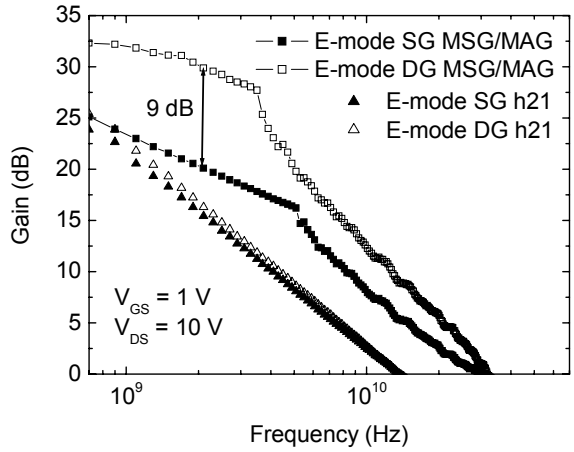

Fig. 4 Frequency dependence of short-circuit current gain (h21) and maximum stable/maximum available gain (MSG/MAG) for E-mode DG and SG AlGaN/GaN HEMTs.

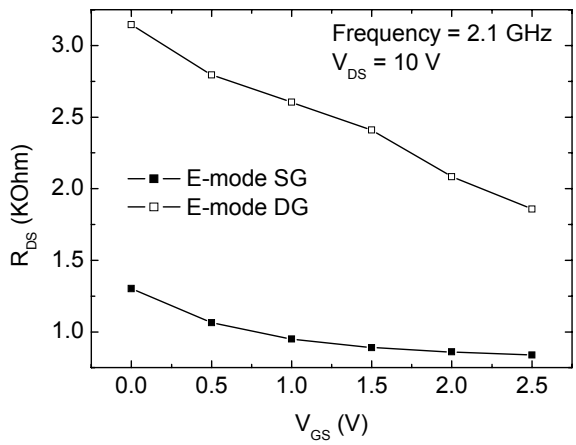

Fig. 5 Output impedance at the drain end of E-mode SG and DG HEMTs, which is extracted from measured S-parameters.

3. Conclusions

E-mode DG AlGaN/GaN HEMTs are fabricated by using CF_4 plasma treatment technique. A 9-dB gain improvement has been achieved at 2.1 GHz by using dual-gate structure, compared to E-mode SG devices.

References

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[2] Y. Cai et al., IEEE Electron Device Lett. **56** (2005) 435.
[3] T. Tanimoto et al., Tran. Electron Devices. **45** (1998) 1176.