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Extremely Low Noise Characteristics of 0.15 μm Power Metamorphic HEMT

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1. Introduction

Metamorphic high electron mobility transistors (MHEMTs) on GaAs substrate, comparable to InP HEMTs, provides the ability to tailor the lattice constant with wide ranges of indium content and large size as well as low cost. Thus, MHEMTs are being attractive to fabricate millimeter-wave monolithic integrated circuits (MIMICs) for high power and low noise applications [1].

In addition, as the one-chip transceiver consisting of a transmitter and a receiver can be readily applicable for system integration, the MHEMTs would be especially valuable when the epitaxial structures are adequately engineered so that the transceivers can be fabricated on a wafer. Here, we adopt the power MHEMT with a double-doped structure to realize the receiver MMIC on a wafer for the automotive radar system application.

Until now, there have been many reports on the power performances of MHEMTs for high power applications [2]. However, there have been few reports on the noise characteristic of power MHEMT structure.

In this paper, we report on the noise performance of 0.15 μm GaAs power MHEMTs with an In content of 53% in InGaAs channel and a wide head T-shape gate together with the DC and microwave characteristics.

2. Experiments

The GaAs-based power MHEMT epitaxial structure with a double delta-doped carrier-supplying layer was grown by using molecular beam epitaxy (MBE). The double delta-doped power MHEMT was grown on a graded buffer layer of a 4-inch GaAs wafer, followed by a 500 nm thick InAlAs buffer layer. The $In_{0.53}Ga_{0.47}As$ channel layer was 16 nm thick. The top and bottom Si-planar doping layers were separated from the channel layer by 3 nm thin $In_{0.52}Al_{0.48}As$ undoped spacer layers, followed by a 16 nm thick $In_{0.52}Al_{0.48}As$ undoped Schottky layer and a 20 nm thick $In_{0.53}Ga_{0.47}As$ cap layer doped with Si of 5×10^{18} cm^{-3} for obtaining low ohmic resistance.

The fabrication procedures of the 0.15 μm GaAs power MHEMT devices are as follows. After mesa isolation by wet chemical etching, AuGe/Ni/Au ohmic contacts were formed using RTA and the obtained ohmic contact resistance is below 1×10^{-6} Ωcm^2. The T-gate with a wide head were patterned by electron-beam lithography using the PMMA/P(MMA-MAA)/PMMA trilayer resists. Then, selective gate recess was performed using succinic acid to selectively etch the InGaAs cap layer over the InAlAs Schottky layer. The etch selectivity of InGaAs cap layer over InAlAs Schottky layer higher than 100 was obtained. Then, Ti/Pt/Au gate metal were deposited by using electron-beam evaporator and lifted-off with acetone, followed by the deposition of PECVD nitride to passivate the devices. The source-to-drain distance, gate-to-source spacing, and gate width are 3, 1, and 100 μm, respectively.

3. Results

Figure 1 shows a cross-sectional scanning electron microscopy (SEM) image of a silicone nitride passivated 0.15 μm power MHEMT with wide head T-shaped gate. The head width and gate length is about 1.2 μm and 0.15 μm, respectively. This T-shaped gate with a high aspect ratio (the ratio of gate head width to gate length) is the main reason of the low gate resistance.

Figure 2 shows the current-voltage (I-V) characteristics of 0.15 μm power MHEMT devices. The MHEMT devices exhibit complete pinch-off characteristics and a little kink effect. The drain saturation current measured at a source-to-drain voltage of 2 V and a source-to-gate voltage of 0 V is 40.4 mA.

Figure 3 shows the extrinsic transconductance (g_m) and drain current (I_{ds}) as a function of gate voltage (V_{gs}) at 1.5 V of the 0.15 μm power MHEMT devices. The measured threshold voltage (V_{th}) was -0.65 V. The typical maximum g_m measured is 828 mS/mm at V_{gs} = -0.13 V and V_{ds} = 1.5 V.

A considerably high breakdown voltage of -8.3 V was obtained for the power MHEMT devices with a high In mole fraction of 0.53 in the lattice-matched $In_{0.53}Ga_{0.47}As$ channel layer. In addition, the standard deviation of V_{th} and maximum g_m across a 4-inch wafer were -0.64±0.03 V and 810±25 mS/mm, respectively. These high breakdown voltage and small standard deviation are attributed to the highly selective wet gate recess process using succinic acid.

The measured current gain ($|h_{21}|$) and MSG/MAG as a function of frequency of the 0.15 μm power MHEMT devices are shown in Fig. 4. The obtained cut-off frequency (f_T) and the maximum frequency of oscillation (f_{max}) were 141 and 243 GHz, respectively.

Figure 8 shows the minimum noise figure (F_{min}) and associated gain (G_{as}) as a function of frequency at I_{ds}= 7.4 mA and V_{ds} = 1 V of the 0.15 μm power MHEMT devices. A F_{min} of 0.79 dB and a G_{as} of 10.56 dB are measured at 26 GHz. At 40 GHz, the measured F_{min} and G_{as} is 1.21 dB and 6.41 dB, respectively.

Considering the power MHEMT structure with the In content of 53% in InGaAs channel, these noise characteristics of the MHEMT devices are excellent. As shown in Fig. 1, the wide head T-shaped gate exhibited a large cross-sectional area with the aspect ratio of about 8. This high aspect ratio provides a significant reduction of gate resistance. Thus, this low noise performance can be attributed to the drastic reduction of gate resistance by the T-shaped gate with a wide head [3] and the improved device performance [4]. As these 0.15 μm power MHEMT devices show decent noise performances, these can be applicable for the fabrication of the transceivers for millimeter-wave system applications.

4. Conclusion

The noise performance of the 0.15 μm power MHEMTs has been examined together with the DC and microwave characteristics. The 0.15 μm power MHEMT devices show a maximum g_m of 828 mS/mm, and a V_{th} of -0.65 V. In addition, the devices exhibited a high breakdown voltage of -8.3 V and small standard deviations across a 4-inch wafer. The f_{max} and f_T of oscillation are 141 GHz and 243 GHz, respectively. A very low F_{min} of 0.79 dB and an G_{as} of 10.56 dB are obtained at 26 GHz. This low noise characteristic is attributed to the drastic reduction of gate resistance by the T-shaped gate with a wide head and the improved device performance. This power MHEMT technology can be used to 77 GHz band applications.

References

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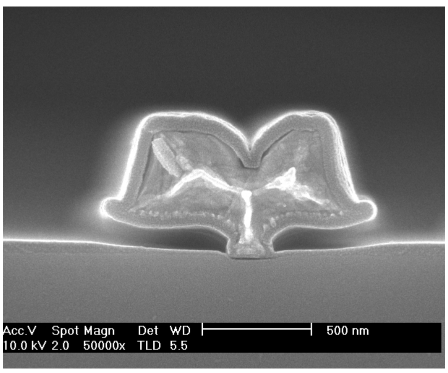

Fig. 1. A cross-sectional SEM image of a silicon nitride passivated 0.15 μm T-gate with wide head.

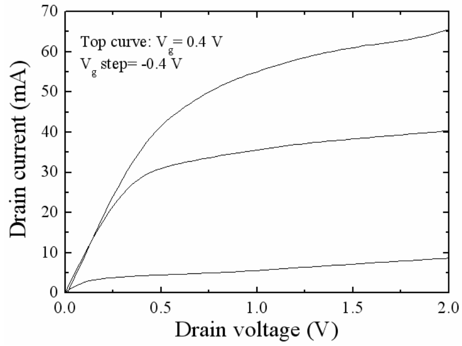

Fig. 2. I-V characteristic of a 0.15 μm power MHEMT.

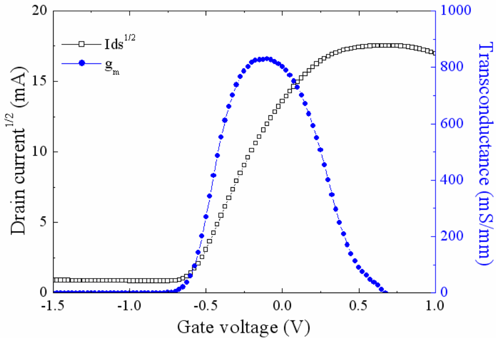

Fig. 3. I_{ds} and g_m characteristics of a 0.15 μm power MHEMT.

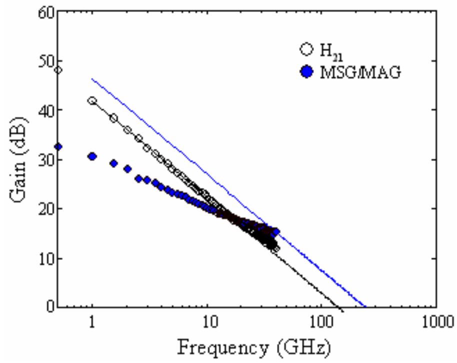

Fig. 4. Frequency dependence of the current gain ($|h_{21}|$) for a 0.15 μm power MHEMT.

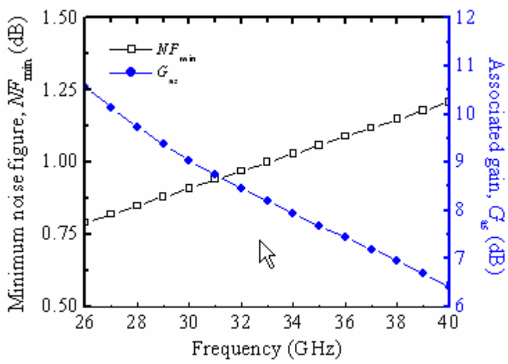

Fig. 5. Minimum noise figure and associated gain as a function of frequency at V_{ds}=1 V and I_{ds}= 7.4 mA of a 0.15 μm power MHEMT.