Influence of Physical Parameters on Microwave Noise Characteristics of AlGaN/GaN/In0.1Ga0.9N/GaN Double-Heterojunction HEMTs

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Abstract—The noise characteristics of AlGaN/GaN/In0.1Ga0.9N/GaN DH-HEMT are calculated as a function of gate voltage as well as drain voltage. The Al percentage of barrier is changed. It is shown that the minimum noise figure decreases when the Al percentage of barrier increases. Also minimum Noise Figure (NF_{min}) is calculated for different physical parameters. It is shown that the minimum noise figure decreases when the distance between source-gate or gate-drain decrease, or when the gate length decreases.

I. INTRODUCTION

AlGaN/GaN HEMTs are the good candidates for high frequency, high output power and high temperature applications because of their physical properties of large energy gap, high saturation velocity and high carrier concentration [1-2]. GaAs and InP based HEMTs have low noise, but their breakdown voltage is low, and they need the protection circuit. GaN based HEMTs have high breakdown voltage and don’t need the protection circuit [3]. Large offset in the conduction band of AlGaN-GaN interface and also the polarization charge causes its carrier concentration become larger than other HEMTs with different materials. Larger Al's percentage in the barrier causes the larger conduction band offset and therefore, larger carrier concentration [4]. The efforts on the improvement of microwave noise have been carrying out in GaN HEMTs over last years [5-9]. Wu Lu et al. and Xu et al. studied the microwave noise figure of AlGaN/GaN HEMTs at different Al's percentage in barrier layer [4,10]. AlGaN/GaN HEMTs with 0.3 μm gate length had NF_{min} of 3.3 dB at 10 GHZ [14]. J.Liu et al. fabricated AlGaN/GaN/InGaN/GaN DH-HEMT where InGaN works as minor channel. Also InGaN causes high polarization charge, which makes a high barrier potential and prevents the carrier to go into the substrate. This transistor has shown higher conductance relative to normal AlGaN/GaN HEMTs and NF_{min} of this transistor with 1 μm gate length is measured about 4 dB for E-mode and 5 dB for D-mode at 10 GHZ [15-17].

In this paper, the effect of different structure parameters of this structure on its noise figure will be calculated. Section II presents the device layer structure and calculation of the polarization charge of different layer. Section III describes the DC characteristics of the device. Section IV explains the microwave noise characteristics. Finally, we conclude in section V.

II. DEVICE STRUCTURE

The Al_{0.3}Ga_{0.7}N/GaN/In_{0.1}Ga_{0.9}N/GaN DH-HEMT structure is shown in Fig. 1. It consists of 2 μm sapphire substrates, a 2.5 μm GaN undoped buffer layer, a 3 nm In_{0.1}Ga_{0.9}N undoped minor channel layer, a 6 nm GaN undoped major channel layer, a 3 nm Al_{0.3}Ga_{0.7}N undoped spacer layer, a 15 nm doped (1e18) carrier supplier layer and a 2 nm undoped cap layer. The devices have a source-gate spacing of L_{sg}=1 μm, gate-drain spacing of L_{gd}=1 μm, a 1 μm gate-length and a gate width of 1 μm [17]. The polarization charge density at the interface of Al_{0.3}Ga_{0.7}N/GaN, GaN/In_{0.1}Ga_{0.9}N and In_{0.1}Ga_{0.9}N/GaN is calculated. The polarization charge density is 1.39e13 cm^{-2}, 8.85e12 cm^{-2} and -8.85e12 cm^{-2} respectively [18].

III. DC PERFORMANCE

The DC characteristics are calculated using Silvaco software. Fig. 2(a) shows the I-V characteristics of Al_{0.3}Ga_{0.7}N/GaN/In_{0.1}Ga_{0.9}N/GaN DH-HEMT. The gate was
biased from 0 V to -5 V in steps of 1 V. The device exhibited high current drive capability. The device pinched off completely at $V_{gs}=-5$ V. The dc transfer characteristics at drain voltage of 7 V are shown in Fig. 2(b)-(d). The sub-threshold drain-current characteristics are plotted in logarithmic scale against gate bias in Fig. 2(c).

The noise characteristics of the device were calculated using Silvaco software. Fig. 3 shows the minimum noise figure as a function of frequency for DH-HEMT biased at $V_{ds}=6$ V and $V_{gs}=-0.2$ V. The device showed a minimum noise figure (NF$_{min}$) of 0.122 dB at 1 GHz and a NF$_{min}$ of 0.97 dB at 10 GHz.

The dependences of the noise performance on gate bias and drain bias were also calculated. Fig. 4(a) shows the dependence of the NF$_{min}$ on the gate bias at 2 GHz with the drain voltage at 2.2 V. This figure has two sections, the gate voltage less than -3.4 volts where the transistor is in its saturation region. In this case, with the increase of gate voltage, the number of carriers in the channel increases as
Fig. 4(b) shows, the channel conductance increases and therefore the noise decreases. The second region in Fig. 4(a) is for gate voltages above -3.4 volts where the transistor is in its triode region. In this case with increase of the gate voltage the channel conductance decreases and therefore the noise increases. Fig. 4(c) shows $NF_{\text{min}}$ versus gate voltage at 2 GHz with the drain bias voltage at 7 V. In this case the transistor is in its saturation region for the whole range of the gate voltages. Therefore, with the increase of the gate voltage the conductance increases (Fig. 4(d)) and as a result the noise decreases.

IV. MICROWAVE NOISE CHARACTERISTICS

Fig. 5(a) shows the dependence of $NF_{\text{min}}$ on the drain voltage at 2 GHz and $V_{GS}=-2$ V. This figure also shows two regions. The region before $V_{DS}=4.5$ volts where the transistor is in its triode region. In this case, with the increase of the drain voltage, the noise decreases. As Fig. 5(b) shows with the increase of the drain voltage the channel conductance increases and as a result the noise decreases. The second region in this figure is for drain voltages above 4.5 volts where the transistor is in its saturation region. In this case with the
Figure 5. (a) $NF_{\min}$-V$_{DS}$ for $V_{gs}=-2$ V and $f=2$ GHz, (b) $g_m$-V$_{ds}$ at $V_{gs}=-2$ V.

Figure 6. (a) $NF_{\min}$-L$_g$ and (b) $g_m$-V$_g$ at $V_{DS}=6$V.

Figure 7. (a) $NF_{\min}$-L$_{gd}$ and (b) $g_m$-V$_g$ at $V_{DS}=6$V.
increase of the drain voltage the noise is almost constant.

Now the effect of physical parameters on noise will be discussed. Fig. 6 (a) shows the NF$_{\text{min}}$ for six different gate-length at $V_{ds}=6$ V and $V_{gs}=-0.2$ V. With the increase of the gate-length the channel length becomes larger and its conductance decreases (Fig. 6(b)) and NF$_{\text{min}}$ increases. Therefore, the device with the largest gate-length (1.4 µm) has the largest NF$_{\text{min}}$.

The gate-drain and gate-source spacing also affect the noise performance, because they affect the access resistance. Therefore, the channel conductance decreases (Fig. 7(b) and Fig. 8(b)), that contributes to the overall noise figure of these devices. Fig. 7(a) shows the NF$_{\text{min}}$ for six different gate-drain spacing at $V_{ds}=6$ V and $V_{gs}=-0.2$ V. It shows that the NF$_{\text{min}}$ increases when the gate-drain spacing increases.

Fig. 8(a) shows the NF$_{\text{min}}$ for different values of gate-source spacing at $V_{ds}=6$ V and $V_{gs}=-0.2$ V. It shows that the NF$_{\text{min}}$ increases when the gate-source spacing increases.

We also calculated the NF$_{\text{min}}$ behavior with respect to barrier aluminum percentage. Fig. 9 shows this effect on NF$_{\text{min}}$ at $V_{ds}=6$ V and $V_{gs}=-0.2$ V. With the increase of the barrier aluminum percentage, the number of carriers in the channel increases (at a fixed gate voltage). Therefore, as figure shows, the noise figure decreases when the aluminum percentage increases.

V. CONCLUSION

Detailed microwave noise characterization was carried out on DH-HEMT. The dependence of the noise characteristics on the device geometric parameters is also calculated. The calculated noise at 10 GHz changes from 0.43 dB at gate length 0.3 µm to 1.49 dB at gate length 1.4 µm, 0.87 dB at gate-drain spacing 0.3 µm to 1.05 dB at gate-drain spacing 1.4 µm, 0.55 dB at gate-source spacing 0.3 µm to 1.17 dB at gate-source spacing 1.4 µm and 1.92 dB at Al 15 percentage to 0.97 dB at Al 30 percentage, which provide guidelines for optimization in physical design.

REFERENCES


[14] Zhiqun Cheng, Jie Liu, Yongzhen Zhou, Yong Cai, Kevin J. Chen and Kei May Lau, “Broadband microwave noise characteristics of high-linearity Composite-Channel Al0.3Ga0.7N/A10.05Ga0.95N/GaN HEMTs,” IEEE electron device letters, vol.26, pp. 521-523, 2005.


