Influence of Physical Parameters on Microwave Noise Characteristics of Al0.3Ga0.7N/Al0.05Ga0.95N/GaN Composite-Channel HEMTs

Robab Madadi, Rahim Faez, and Behrouz Behtoee

***Abstract*—The noise characteristics of $Al_{0.3}Ga_{0.7}N/Al_{0.05}Ga_{0.95}N/GaN$ CC-HEMT are calculated as a function of gate voltage as well as drain voltage. 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. Also the thickness of $Al_{0.3}Ga_{0.7}N$ is changed. It is shown that the noise figure decreases when the barrier thickness increases.**

***Index Terms*—AlGaN/GaN, composite-channel (CC) HEMTs, minimum noise figure (NF_{min})**

I. Introduction

AlGaN/GaN HEMTs are good candidate for high frequency, high power and high temperature applications because of their physical properties of large energy gap, high saturation velocity. High power potential of AlGaN/GaN HEMTs has been shown in [1]-[4]. GaAs and InP based HEMTs have low noise, but their breakdown voltage is low and they need protection circuit. GaN based HEMTs have high breakdown voltage and don't need protection circuit [5], [6]. Large offset in 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 percentage in the barrier causes larger conduction band offset and therefore larger carrier concentration [7]. AlGaN/GaN HEMTs have low noise. NFmin for AlGaN/GaN HEMT with 0.25 µm gate lengths is shown 1.06 dB at 10 GHZ [8], and 0.15 µm gate length transistor achived NF_{min} of 0.6 dB at 10 GHZ [9]. W.Lu et al. have shown for AlGaN/GaN HEMT with 0.12 gate length NF_{min} of 0.98 dB at 18 GHZ [10]. HEMT made by I.P, et al. measured NF_{min} of 1.5 dB at 26 GHZ for 0.2 µm gate length transistor [11].

Recently new structure based GaN have been made. Zhiqun Cheng, et al. have shown $Al_{0.3}Ga_{0.7}N/Al_{0.05}Ga_{0.95}N/GaN$ HEMT where GaN works as minor channel. This transistor has shown smaller conductance relative to normal AlGaN/GaN HEMTs but it is more linear [12].

In this paper the noise of this transistor will be calculated. It is organized as follows. Section II presents the device layer structure and calculation of the polarization charge, band gap and affinity of different layer. Section III presents the DC characteristics of the device. Section IV presents the microwave noise characteristics. Finally, we conclude in Section V.

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II. Device Structure

THE $Al_{0.3}Ga_{0.7}N/Al_{0.05}Ga_{0.95}N/GaN$ CC-HEMT structure is shown in [12]. It consists of 2 µm sapphire substrates, a 2.5 µm GaN undoped minor channel layer, a 6 nm $Al_{0.05}Ga_{0.95}N$ undoped major channel layer, a 3 nm $Al_{0.3}Ga_{0.7}N$ undoped spacer layer, a 21 nm doped(1e18) carrier supplier layer and a 2nm undoped cap layer. The devices have a source-gate spacing of L_{sg}=0.5 µm, gate-drain spacing of L_{gd}=1 µm, a 1 µm-gate-length and a gate width of 1 µm [12]. The band gap (Eg), affinity and electron mobility of layers of this device are shown in Table I. The polarization charge density at the interface of $Al_{0.3}Ga_{0.7}N/Al_{0.05}Ga_{0.95}N$ and $Al_{0.05}Ga_{0.95}N/GaN$ is calculated. The polarization charge density is 1.12e13 cm^{-2} and 1.93e12 cm^{-2} respectively [13].

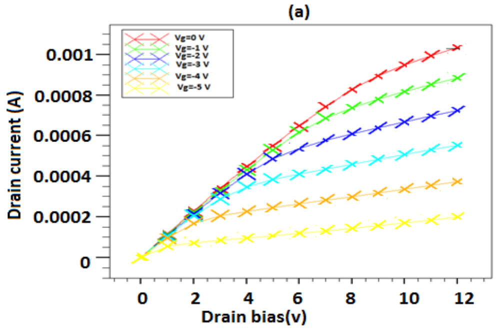
TABLE I: Band Gap (EG), Mobility (μ) and Affinity of Different Layers

HEMT layer	Band gap (ev)	µobility (cm^2/vs)	Affiny (ev)
$Al_{0.3}Ga_{0.7}N$	4.023	800	2.97
$Al_{0.05}Ga_{0.95}N$	3.508	950	3.35
GaN	3.42	1100	3.42

III. DC Performance

The DC characteristic is calculated using Silvaco software. Fig. 1(a) shows the I-V characteristics of $Al_{0.3}Ga_{0.7}N/Al_{0.05}Ga_{0.95}N/GaN$. The gate was biased from 0V to -5 V in steps of -1 V. The device exhibited high current drive capability. The dc transfer characteristics are shown in Fig. 1(b)-(c). The drain was biased at 6 V.

(a)



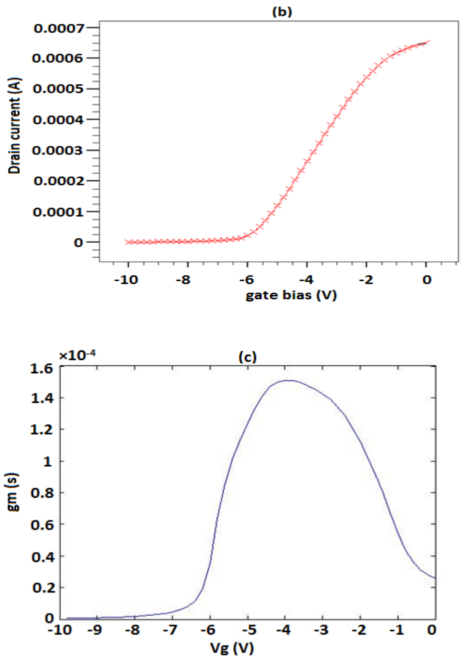
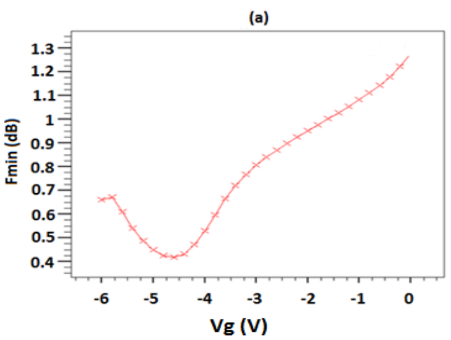


Fig. 1. (a) I_D-V_{DS} for different gate voltage, (b) I_D-V_{GS} for V_{DS}=6V, (c) g_m-V_{GS} at V_{DS}=6V

IV. Microwave Noise Characteristics

The noise characteristics of the device were calculated using Silvaco software. Calculation shows a minimum noise figure (F_{min}=NF_{min}) of 0.122 dB at 1 GHz and an NF_{min} of 1.22 dB at 10 GHz for CC-HEMT biased at V_{ds}=6 V and V_{gs}=-3 V. The dependences of the noise performance on gate bias and drain bias were also calculated. Fig. 2 (a) shows the dependence of the F_{min} on the gate bias at 2GHz with the drain voltage at 2 V. This figure has two sections, the gate voltage less than -4.5 volts where the transistor is in its saturation region. In this case with increase of gate voltage the number of carriers in the channel increases and, as Fig. 2(c) shows, the channel conductance increases and therefore the noise decreases. The second region in the figure is for gate voltages above -4.5 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. 2 (b) shows F_{min} versus gate voltage at 2GHz with the drain bias voltage at 8V. In this case the transistor is in its saturation region for almost the whole range of the gate voltages. Therefore with increase of the gate voltage the conductance increases (Fig. 2(d)) and as a result the noise decreases.



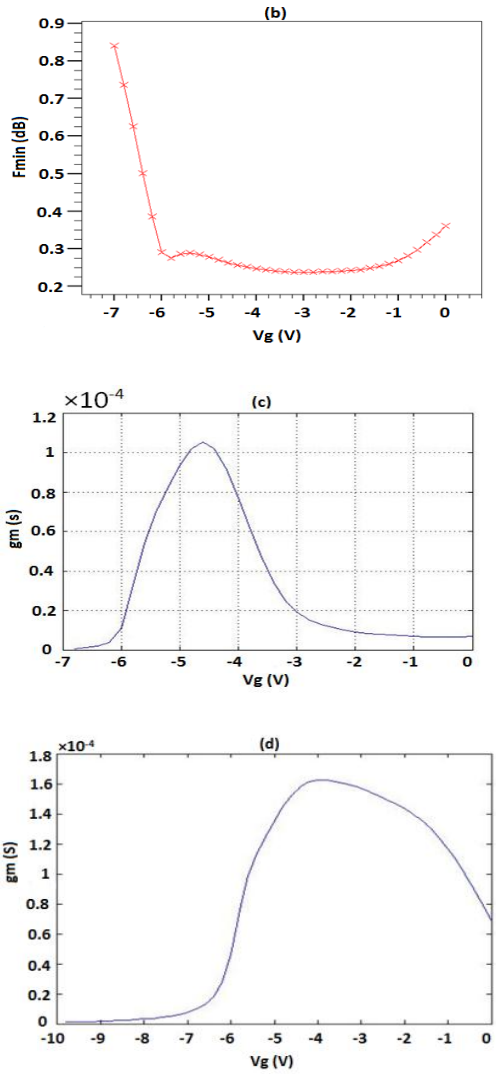
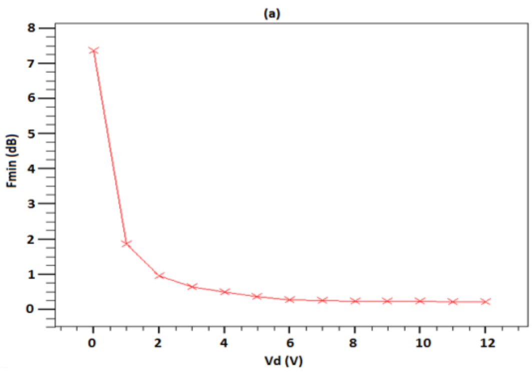


Fig. 2. (a) F_{min}-V_{GS} for V_{DS}=2 V (b) F_{min}-V_{GS} for V_{DS}=8 V (c) g_m-v_g at V_{ds}=2 V, (d) gm-v_g at V_{ds}=8 V

Fig. 3(a) shows the dependence of NF_{min} on the drain voltage at 2GHz and V_{gs}=-2. This figure also shows two regions. The region before V_{DS}=6 volts where the transistor is in its triode region. In this case with increase of the drain voltage the noise decreases. As Fig. 3(b) shows with 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 6 volt where the transistor is in its saturation region. In this case with increase of the drain voltage the noise is almost constant.



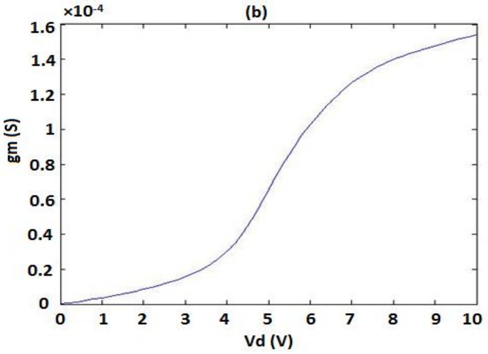
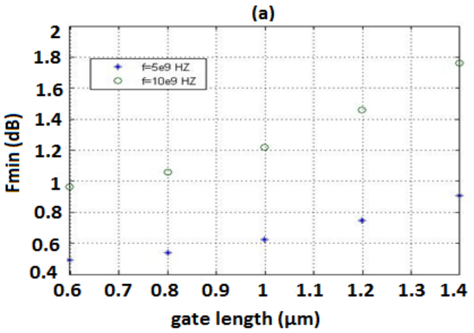


Fig. 3. (a) F_{min}-V_{DS} for V_{gs}=-2 V and (b) g_m-V_{ds} at V_{gs}=-2 V

Now the effect of physical parameters on noise will be discused. Fig. 4 (a) shows the F_{min} for five different gate-length at V_{ds}=6 V and V_{gs}=-3 V. With increase of the gate-length the channel length becomes larger and its conductance decreases (Fig. 4(b)). Therefore the device with the largest gate-length (1.4 µm) has the largest F_{min}.



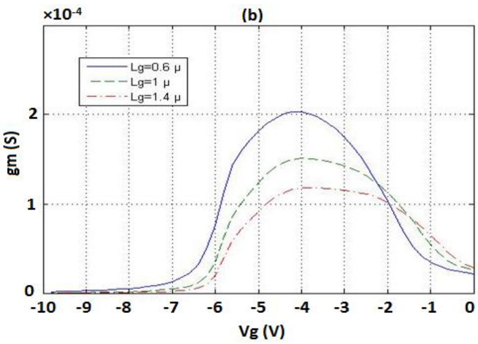
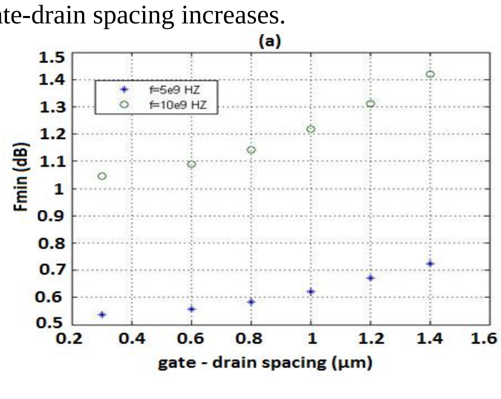


Fig. 4. (a) F_{min}-*Lg* and (b) *gm-vg* at V_{DS}=6V

The gate-source and gate-drain spacing also affect the noise performance because they affect the access resistance. Therefore the channel conductance decreases (Fig. 5(b)), which contributes to the overall noise figure of these devices. Fig. 5(a) shows the NF_{min} for six different gate-drain spacing at V_{ds}=6V and V_{gs}=-3. It shows that the NF_{min} increases when the gate-drain spacing increases.



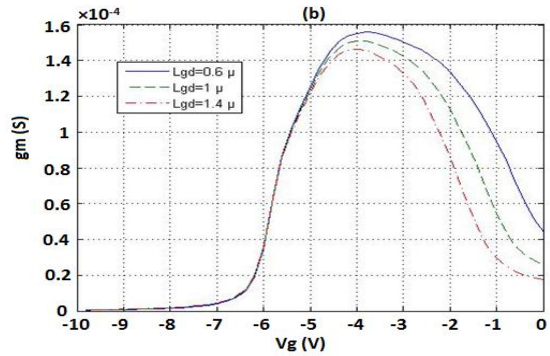
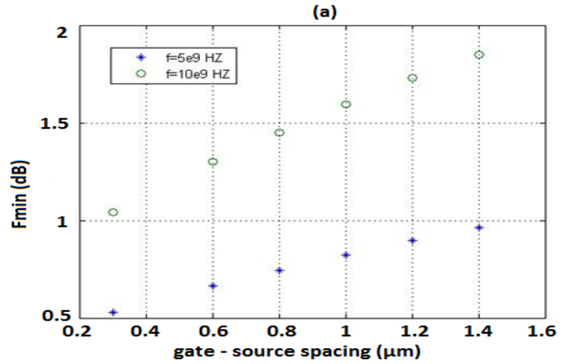


Fig. 5. (a) F_{min}-*Lgd* and (b) *gm-vg* at V_{DS}=6V

Fig. 6(a) shows the F_{min} for different values of gate-source spacing at V_{ds}=6 V and V_{gs}=-3 V. It shows that the F_{min} increases when the gate-source spacing increases.



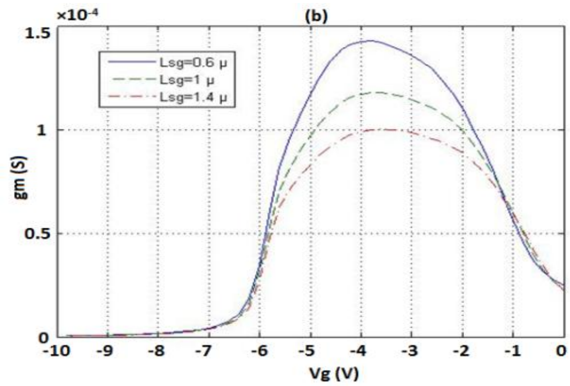


Fig. 6. (a) F_{min}-*Lgs* and (b) *gm-vg* at V_{DS}=6V

We also calculated the NF_{min} behavior with respect to thickness of $Al_{0.3}Ga_{0.7}N$. Fig. 7 shows the NF_{min} for three different values of thickness of $Al_{0.3}Ga_{0.7}N$ at V_{ds}=6V and V_{gs}=-3 V. It shows that the noise figure decreases when the barrier thickness increases.

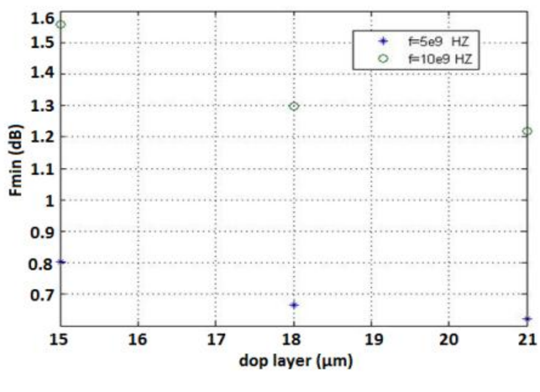


Fig. 7. F_{min} - thickness of dop layer $Al_{0.3}Ga_{0.7}N$.

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 and provides guidelines for optimization in physical design.

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