Influence of Aluminum Concentration of Barrier on Noise Characteristics of $Al_{0.3}Ga_{0.7}N/Al_{0.05}Ga_{0.95}N/GaN$ HEMTs

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Abstract

The noise characteristics of Composite-Channel $AL_{0.3}Ga_{0.7}N/Al_{0.05}Ga_{0.95}N/GaN$ HEMT is calculated as a function of gate voltage as well as drain voltage. The noise curve versus drain voltage shows two regions. The first region is related to the triode region of the transistor where the noise decreases with increase of the drain voltage. The second region is related to the saturation region of the transistor where the noise is almost constant. The noise curve versus gate voltage also shows two regions. The first region is related to the saturation region of the transistor where the noise decreases with increase of the gate voltage. The second region is related to the triode region where the noise increases with increase of the gate voltage. Also minimum Noise Figure (NF_{min}) is calculated for different Aluminum mole fraction of barrier.It is shown that the minimum Noise Figure (NF_{min}) decreases when the Aluminum mole fraction increases.

Key words -ALGaN,GaN,Microwave noise,Minimum Noise Figure(NF_{min}),Composite- Channel HEMT.

1. 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 showen 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. NF_{min} 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. Has 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 [13] but it is more linear.

In this paper the noise of this transistor will be calculated. It is organized as follows. Section II presents the device layer structur and calculation of the polarization charg, 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.

2. Device Structur

The $AL_{0.3}Ga_{0.7}N/Al_{0.05}Ga_{0.95}N/GaN$ CC-HEMT structur, is shown in Fig.1. 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 gatewidth of 1 μm [13].

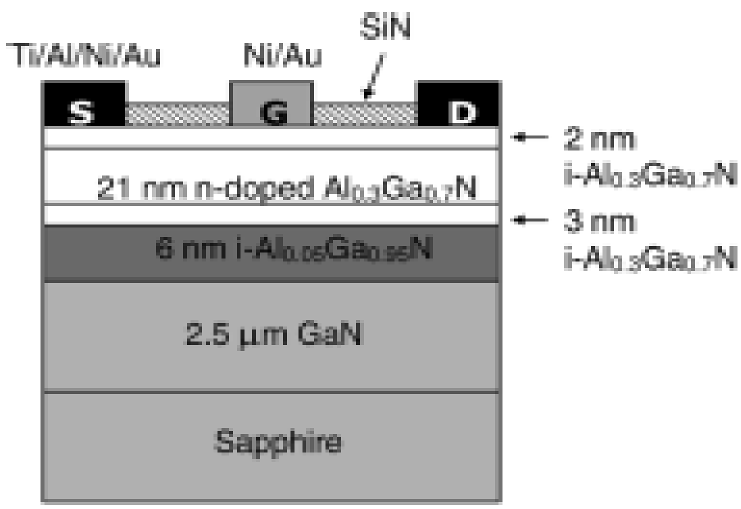

Fig1: Structur of simulated device**.**

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 [12].

	Eg(ev)	μ(cm^2/vs)	Affinity(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

TABLE1. Band gap (Eg), mobility (μ) and affinity of different layers.

3. DC Performance

The DC characteristic is calculated using Silvaco software. Fig. 2(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. 2(b)-(d). The drain was biased at 8 V. The sub-threshold drain-current characteristics are plotted in logarithmic scale against gate bias in Fig. 2(c). The drain was biased at 8 V for this calculation.

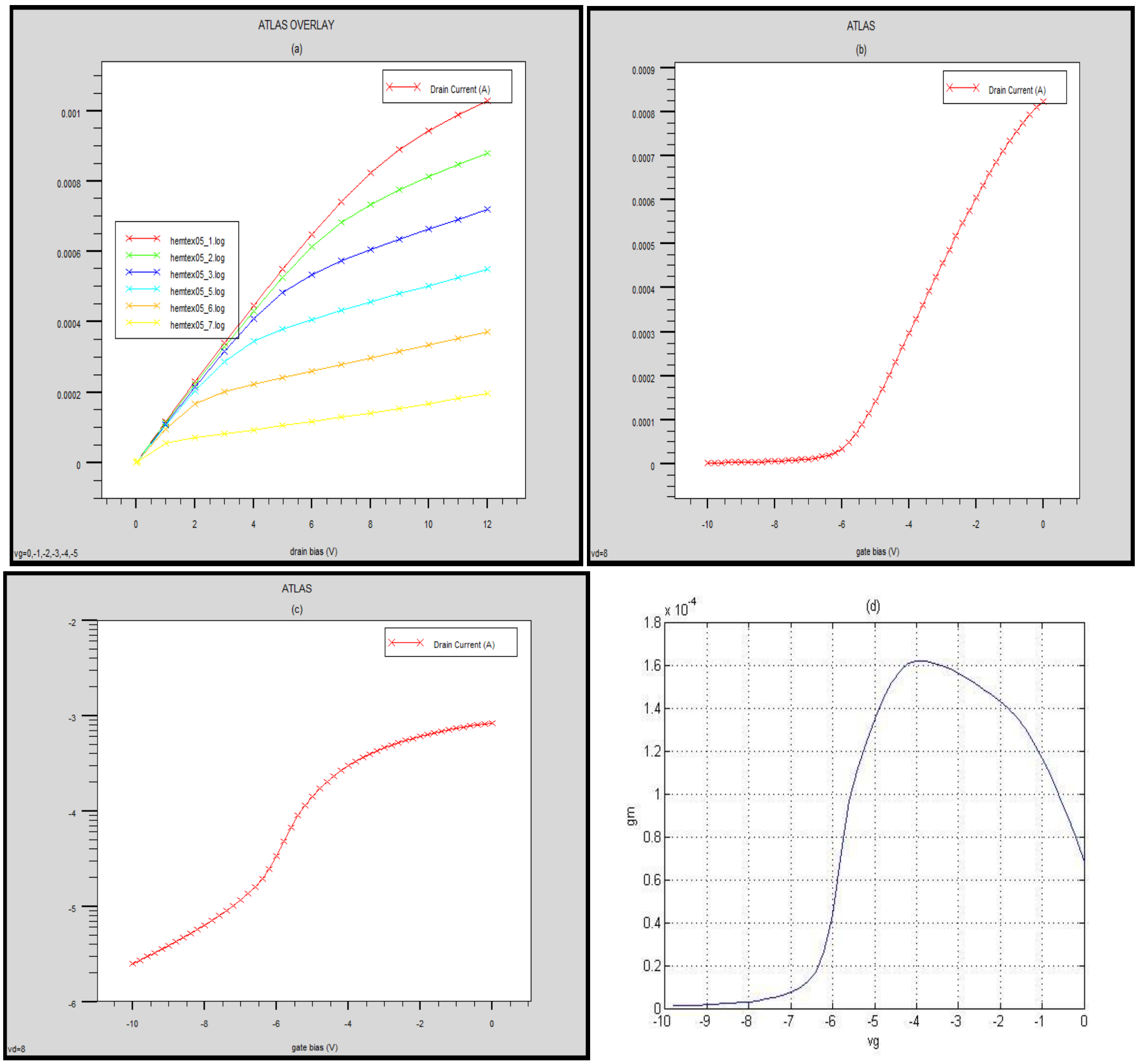

Fig2: (a) I_D-V_{DS} for different gate voltage, (b) I_D-V_{GS} for V_{DS}=8 V, (c) I_D-V_{GS} in logarithmic scale at V_{DS}=8 V, (d) g_m-V_{GS} at V_{DS}=8 V.

4. Microwave Noise Characteristics

The noise characteristic of the device was calculated using Silvaco software. Fig.3 shows minimum noise figure as a function of frequency for CC-HEMT biased at V_{ds}=8 V and V_{gs}=-3 V. The device showed a minimum noise figure (NF_{min}) of 0.12 dB at 1 GHz and an NF_{min} of 1.16 dB at 10 GHz.

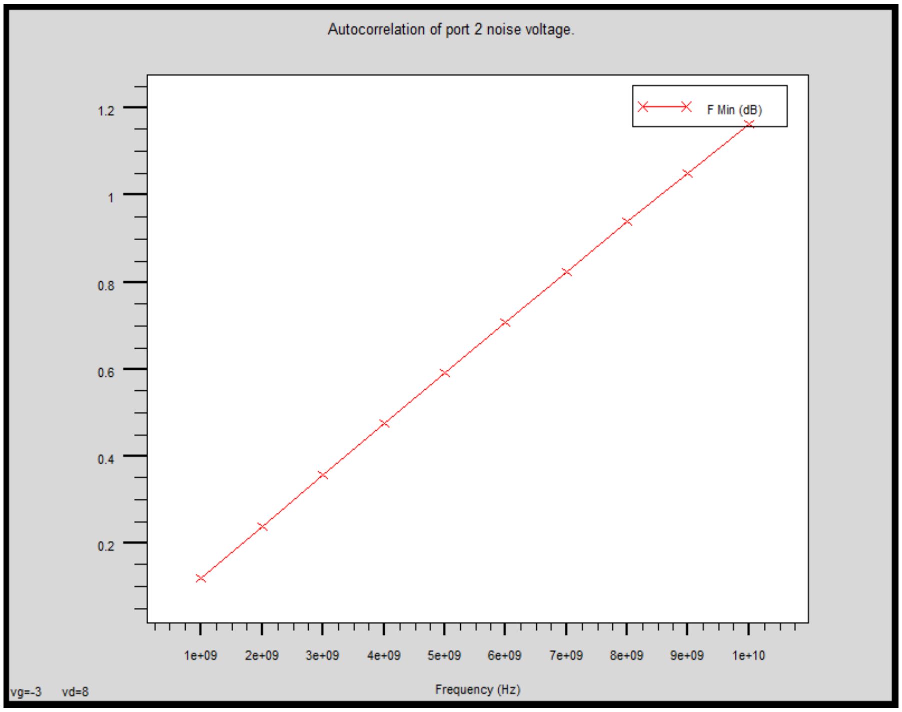

Fig3: .NF_{min}-F for V_{DS}=8 V and V_{GS}=-3 V.

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 3 V. This figure has two sections, the gate voltage less than -4 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 a result, the channel conductance increases and therefore the noise decreases. The second region in the figure is for gate voltages above -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(b) shows NF_{min} versus gate voltage at 2GHz with the drain bias voltage at 8 V. In this case the transistor is in its saturation region for the almost whole range of the gate voltages. Therefore with increase of the gate voltage the noise decreases.

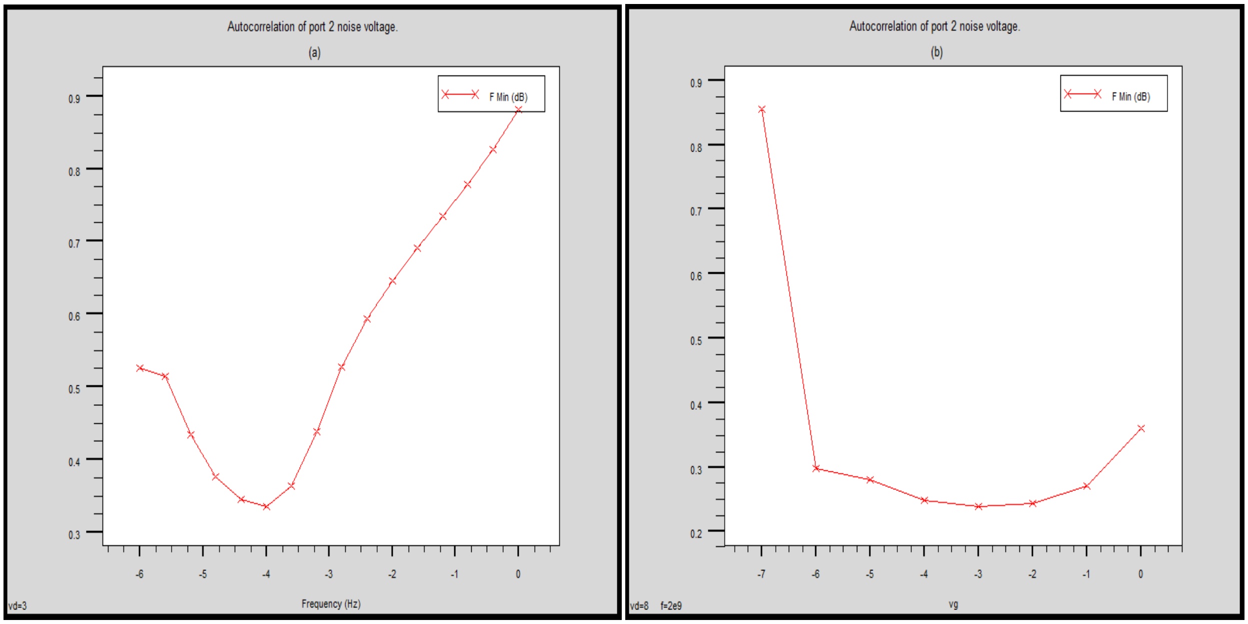

Fig4: (a) NF_{min}-V_{GS} at V_{DS}=3 V f=2 GHZ and NF_{min}-V_{GS} at V_{DS}=8 V and f=2 GHZ

Fig. 5 shows the dependence of NF_{min} on the drain voltage at 2GHz and V_{gs}=-3. This figure also shows two regions. The region before V_{DS}=4 volts where the transistor is in its triode region. In this case with increase of the drain voltage the noise decreases. Actually 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 4 volt where the transistor is in its saturation region. In this case with increase of the drain voltage the noise is almost constant.

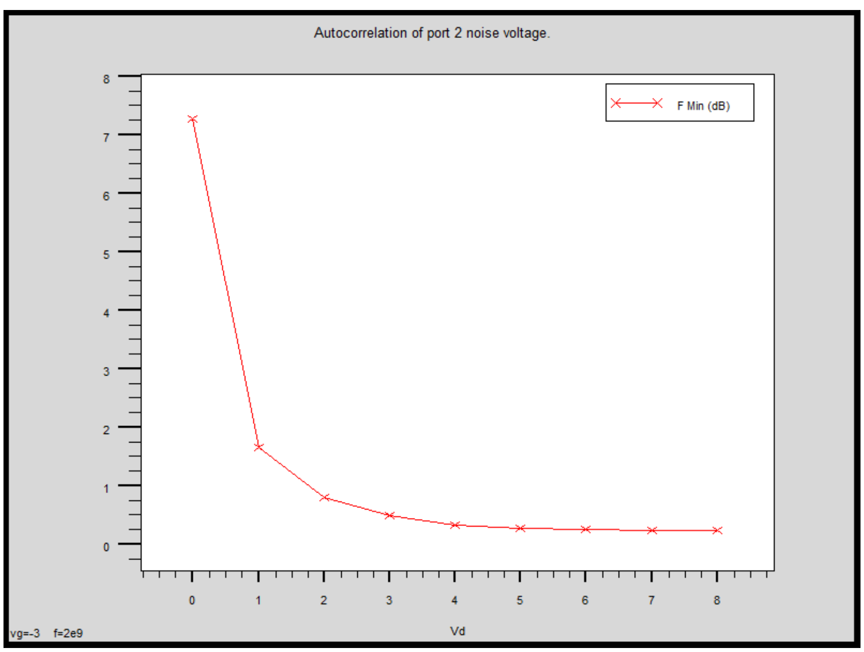

Fig5: NFmin-V_{DS} for V_{gs}=-3 V and F=2 GHz

We also calculated the NF_{min} behavior with respect to barrier aluminum percentage. Fig. 6(a) shows this effect of aluminum percentage on NF_{min} at V_{ds}=8 V and V_{gs} =-3 V. With increase of the barrier aluminum percentage the number of carriers in the channel increases. Therefore the channel conductance increases (Fig. 6(b)) (at a fixed gate voltage). Therefore, as figure shows, the noise figure decreases when the aluminum percentage increases.

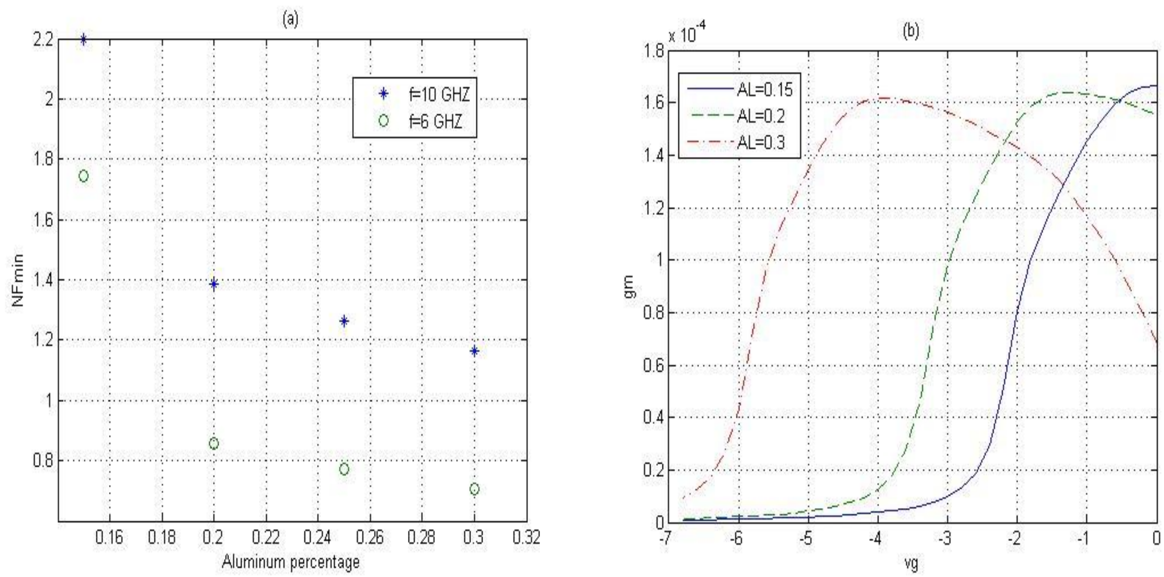

Fig.6: (a) NF_{min}-Aluminum Percentage and (b) gm-vg at Vds=8 V

5. CONCLUSION

Detailed microwave noise characterization was carried out on CC-HEMT. The dependence of the noise characteristics on barrier aluminum percentage is also calculated and shows the noise figure decreases when the aluminum percentage increases.

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