Impact of Buffer Mole Fraction on AlGaN/ GaN HEMT with Different Gate Voltage

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Abstract - *The effect of buffer mole fraction on AlGaN/GaN field plated High Electron Mobility Transistor (HEMT) with composite AlGaN/GaN buffer were investigated. The sandwich of AlGaN and GaN mainly depends on Al mole fraction as it defines the band gap and lattice constant of AlGaN. Increasing mole fraction will results in increased drain current. This can be explained by the fact that the increasing mole fraction leads to higher polarization. The analytical relation between 2DEG density and the barrier potential (at the AlN/GaN interface) and other parameters in the HEMT is summarizing by the equations (1 & 2). And with the help of silvaco software we simulate and show the output of I-V curve of drain current vs drain voltage and source current vs drain voltage.*

Key Words: **HEMT, AlGaN, GaN, 2DEG, Mole fraction**

1. INTRODUCTION

The HEMT structure, three metal contacts, source (S), gate (G), and drain (D) are made to the top AlGaN of thickness 25nm or GaN of thickness 1475nm barrier layer as shown in Fig.1. Both the source and drain terminals with doping concentration of $1x10^{18}$ cm^{-3} are Ohmic contacts they provide by the means of controlling the carriers in the direction parallel to the heterointerface. The source is typically high and dry while a positive bias is applied to the drain, thus forcing the electrons in the 2DEG to flow from source to drain. The applied voltage between the drain and source is called VDS, while the gate-source voltage is called VGS. The gate terminal is a metal-semiconductor rectifying contact (Schottky barrier contact).

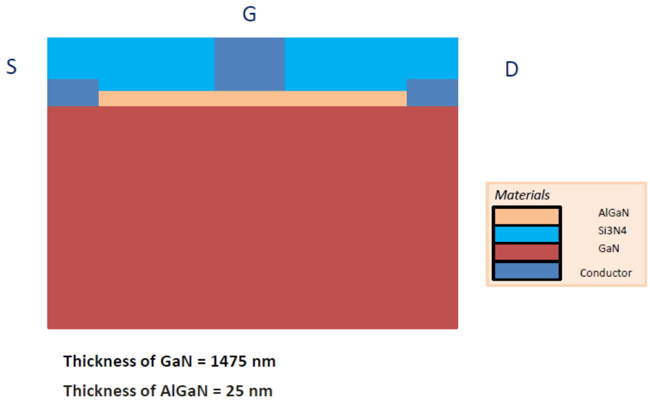


Fig-1: Top AlGaN/GaN HEMT structure.

1.1 Methodology

Gallium nitride (GaN) based HEMTs are used for high temperature and high power microwave applications due to its great energy band gap, high electron saturation velocity, and high 2-Dimensional Electron Gas (2DEG) Density at AlGaN/GaN heterointerface. Due to the large conduction band discontinuity between AlGaN and GaN high electron mobility and high electron saturation velocity have been established in the AlGaN/GaN system. These parameters are necessary for high frequency operations. The occurrence of piezoelectric and spontaneous polarization in GaN leads to a high carrier concentration which results in high current density at interface without any intentional doping. Moreover, GaN has wide band gap and high breakdown electric field. The advantage of high current density and high breakdown field allow this material to be an outstanding applicant for high power application. AlGaN/GaN HEMTs are usually grown on silicon carbide substrate (SiC). SiC is a good substrate because of its high thermal conductivity [1-2]. In this THESIS, the effect of buffer mole fraction with different Vg, Vd and Vs on AlGaN/GaN field plated High Electron Mobility Transistor (HEMT) with composite AlGaN/GaN buffer were investigate. The sandwich of AlGaN and GaN mainly depends on Al mole fraction as it defines the band gap and lattice constant of AlGaN. The Low Al composition delivers an increased breakdown voltage and decreased drain leakage current. So, the mole fraction of AlGaN buffers varied from 0.10 to 0.30. Increasing mole fraction will results in increased drain current. This can be explained by the fact that the increasing mole fraction leads to higher polarization

2. POLARIZATION CHARGE

One of the key properties of GaN HEMTs is the presence of polarization charge at the interfaces. The occurrence of the polarization charge affects 2DEG density and is necessary for the operation of AlGaN/AlN/GaN HEMTs. GaN and AlN are highly polar in nature. In closeness, these layers logically will display polarization-induced fields [3-5]. These fields are classified into spontaneous polarization and piezoelectric polarization. Spontaneous polarization refers to the built in polarization field present in an unstrained crystal. This field exists because the crystal lack inversion symmetry and the bond between the two atoms are not purely covalent. This results in a displacement of the electron cloud towards one of the atoms in the bond. Thus, along the direction in which the crystal lack inversion symmetry, the asymmetric electron cloud lead to a net positive charge on one face of the crystal and net negative charge on the other. Piezoelectric polarization is the polarization field that results from the distortion of the crystal lattice. Due to the differences in lattice constants of AlN, GaN, and AlGaN, growing AlGaN on GaN leads to compressive strain in AlGaN [3-5]. This strain results in a charge sheet at the two faces of the crystal. As an example, figure 11 shows the combined piezoelectric (Pp) and spontaneous (Ps) electric fields in a structure with an AlxGa1-xN layer grown on GaN. The polarization field increases with the Al substance in the AlGaN. Thus, HEMT structures with AlN on GaN have very large polarization fields [6].
The analytical relation between 2DEG density and the barrier potential (at the AlN/GaN interface) and other parameters in the HEMT is summarized by the following equations [7].

$$\varphi_B = (-q\, n_s\, t_1 + q\,(\sigma_{AlGaN} - n_s) t_2 - q\, n_s\, d_o) / (\varepsilon\varepsilon_0) \qquad \_\_(1)$$

$$n_s = (\sigma_{AlGaN}\, t_2 + \sigma_{AlN}\, t_3 - (\epsilon\epsilon_0\, \varphi_B) / q) / t_1 + t_2 + t_3 + d_o) \qquad \_(2)$$

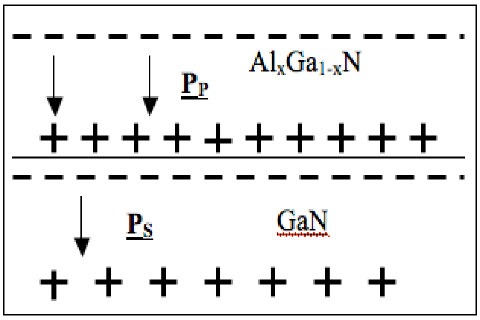


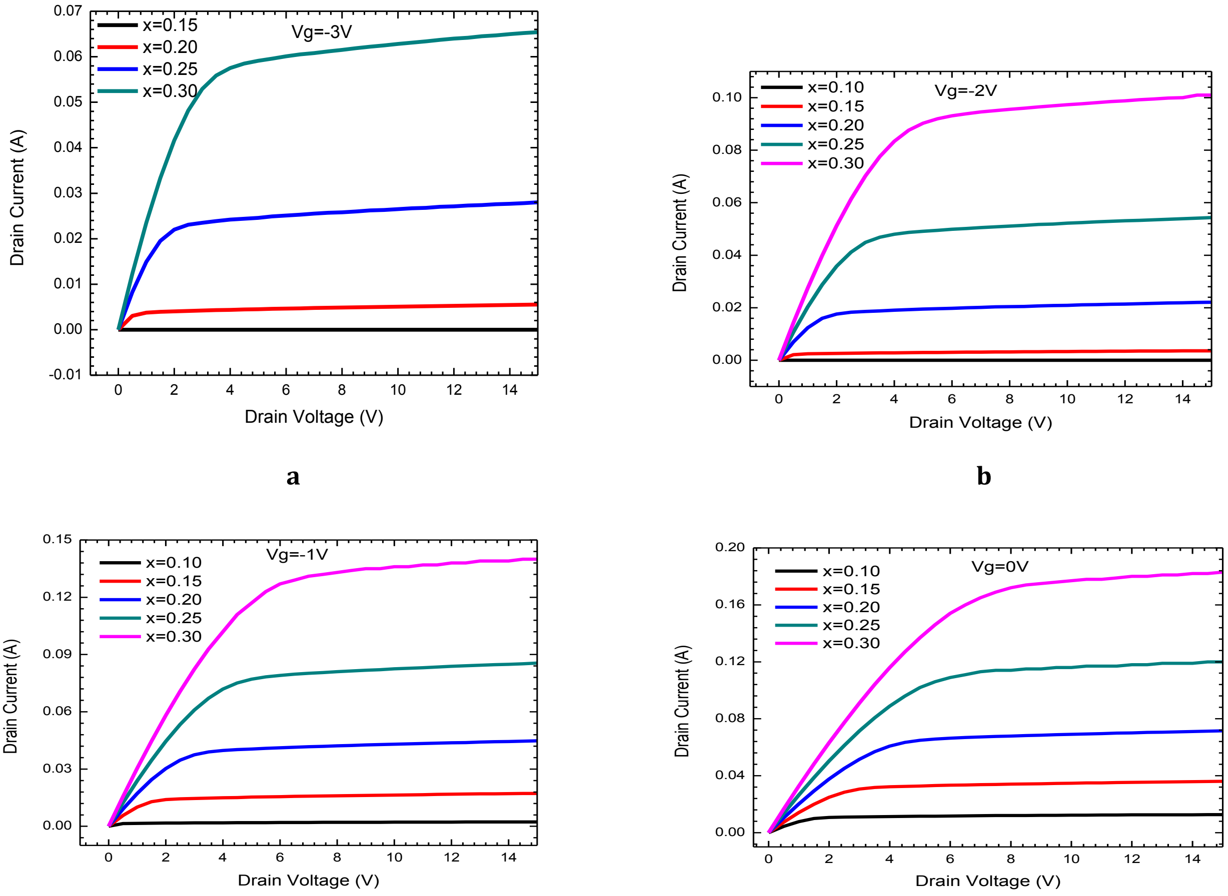
Fig-2: combined piezoelectric and spontaneous fields for AlGaN grown on GaN

Here n_s is the 2DEG density in the channel, σ_{AlGaN} is the net polarization charge density of the AlGaN, σ_{AlN} is the net polarization charge density of the AlN, *t*1 is the thickness of the AlGaN cap layer, *t*2 is the thickness of the AlGaN layer, *t*3 is the thickness of the AlN layer, *d*0 is the distance between the centroid of the 2DEG and the top UID-AlGaN/AlGaN interface, and *φB* is the surface potential. The lack of any doping term in (1) and (2) indicates that the 2DEG density in AlGaN/AlN/GaN HEMTs is mainly due to the polarization charge.

3. PLOTS

3.1 Drain Current vs Drain Voltage

Fig-3 (a,b,c,d) shows the transfer characteristics of AlGaN/GaN HEMTs with variation Al mole fractions of AlGaN buffer, measured at different gate voltage (Vg).Increasing mole fraction will results in increased drain current.



a b

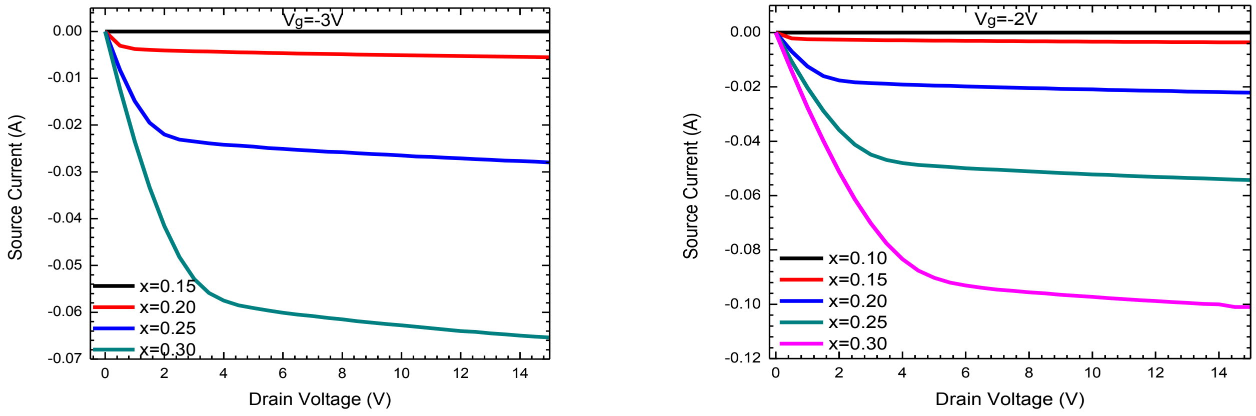
c d

Fig-3 (a-d): Tranconduction I-V characteristic between Drain current vs Drain voltage with different Vg.

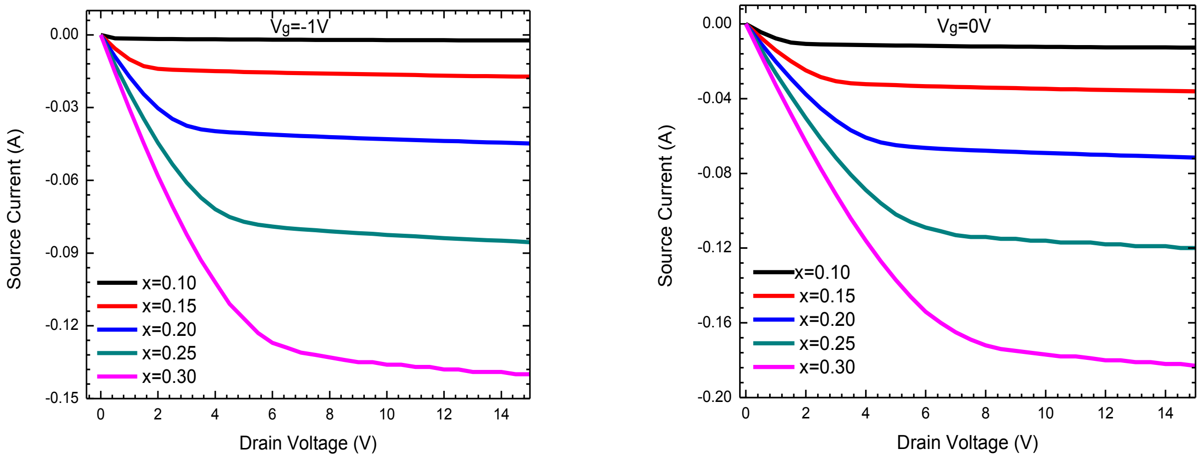
By this plot we can say that for different value of gate voltage the Al mole fraction x=0.30 give best output current following the curve between drain current vs drain voltage.

3.2 Source Current vs Drain voltage

Here, we take different gate voltage applied with variation of Al mole fraction to plots source current vs drain voltage.



a b



c d

Fig-4 (a-d): Tranconduction I-V characteristic between source current vs Drain voltage with different Vg.

By this plot we can say that for different values of gate voltage the drain voltage gradually increases at highest resistance at Al mole fraction x=0.30 following the curve between source current vs drain voltage. As a result, the conduction band at the heterojunction raises leads to increase in electron confinement. Increase in electron confinement reduces the scattering of electron from 2DEG into the GaN buffer. This leads to reduced short channel effect which results in high output resistance Rds.

4. CONCLUSION

In this work we obtained the polarization charge of a **Al** mole fraction in Equ.(1 & 2) increase the drain current with different gate voltage by plotting drain current vs drain voltage. **Al** mole fraction controls the conduction band edge discontinuity at the heterojunction and therefore the confinement of electron GaN channel is high. This leads to increased 2DEG, drain current, transconductance and frequency. Also, we see that when we plot a graph between source current vs drain voltage with different gate voltage the drain voltage gradually increases and source current decreases it is due to the variation of Al mole fraction of AlGaN buffer. And we obtain that the effective **Al** mole fraction at X= 0.30 which give the highest curve of increasing drain current and drain voltage which is shown in Fig.3(a,b,c.d) and Fig.4(a,b,c,d) simulated by silvaco software.

So, finally we can conclude that the variation of buffer mole fraction of the AlGaN affected the output I-V characteristic of AlGaN/GaN HEMT. **Al** mole fraction is the main reason for better output characteristic in AlGaN/GaN HEMT device.

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