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Study of High Performance of Gan-Based HEMT Having Two Channel Layers of Gan/Inalgan

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Abstract: *In this paper, the impact of GaN-based High Electron Mobility Transistor (HEMT) is reported. The device is having two channel layers of GaN (Gallium Nitride) and InAlGaN (Indium Aluminium Gallium Nitride). The device is simulated by the TCAD, Silvaco Software in 2D format. The results so obtained have proved the high performance on the parameters like electric potential, concentration of electron, break-down voltage and transconductance (g_m). The simulated device and obtained results are compared with the structure of AlGaN/GaN HEMT. The major benefit of the simulated device is the reduced leakage current. The mole fraction of Aluminium in InAlGaN has been optimized to create the best performing device.*

Keywords: *Mole Fraction, GaN/AlGaN, Breakdown Voltage, High Electron Mobility Transistor (HEMT*)

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I. Introduction

In today's world, Gallium Nitride (GaN) is considered as an outstanding material for high frequency and high power devices due to its superior properties. GaN is a binary III/V direct band-gap semiconductor commonly used in LED's since 1990's [1]. But due to its properties like wide band-gap of 3.4ev, high breakdown electric field, high electron saturation velocity and high density carriers in the form of two dimensional electron gas with high mobility, it is being widely used in microwave engineering applications and optoelectronics[2]-[9]. The physical properties of GaN include its robust and hard structure, mechanically stable wide band-gap semiconductor materials with high heat capacity and thermal conductivity. In its pure form, it can be doped on Silicon Carbide or Sapphire. Wide band-gap semiconductor power devices offer great performance improvements and can work in harsh environments where silicon power devices cannot function. One of the main advantages of III-nitride materials such as gallium nitride is the ability to form a heterojunction with a ternary alloy made from another III-nitride semiconductor material such as aluminium gallium nitride. The high electric breakdown field of GaN is a result of the wide band-gap of 3.44 eV at room temperature of the material and enables the application of high supply voltages on GaN-based devices, which is one of the two requirements for high power device performance. Therefore, these material properties clearly indicate why GaN is a serious candidate for next generation microwave high power and high temperature applications. In recent years, GaN-based high electron mobility transistor (HEMT) has attracted considerable attentions and shown excellent performance in high power and high frequency microwave applications because of wide band-gap, superior carrier saturation velocity, large breakdown field strength and strong spontaneous and piezoelectric polarization. Due to the its unique characteristic and excellent performance in high power operations, AlGaN/GaN HEMTs are emerging as the promising candidates for next generation radio frequency power amplifiers. HEMTs are heterojunctions. This means that the semiconductors used have dissimilar band gaps. For instance, silicon has a band gap of 1.1 electron volts (eV), while germanium has a band gap of 0.67 eV. When a heterojunction is formed, the conduction band and valence band throughout the material must bend in order to form a continuous level. So, HEMTs' exceptional carrier mobility and switching speed come from the following conditions. The wide band element is doped with donor atoms; thus it has excess electrons in its conduction band. These electrons will diffuse to the adjacent narrow band material's conduction band due to the availability of states with lower energy. The movement of electrons will cause a change in potential and thus an electric field between the materials. The electric field will push electrons back to the wide band element's conduction band. The diffusion process continues until electron diffusion and electron drift balance each other, creating a junction at equilibrium similar to a p-n junction. Note that the undoped narrow band gap material now has excess majority charge carriers. The fact that the charge carriers are majority carriers yields high switching speeds, and the fact that the low band gap semiconductor is undoped means that there are no donor atoms to cause scattering and thus yields high mobility [10].

An important aspect of HEMTs is that the band discontinuities across the conduction and valence bands can be modified separately. This allows the type of carriers in and out of the device to be controlled. As HEMTs require electrons to be the main carriers, a graded doping can be applied in one of the materials making the conduction band discontinuity smaller, and keeping the valence band discontinuity the same. This diffusion of carriers leads to the accumulation of electrons along the boundary of the two regions inside the narrow band gap material. The accumulation of electrons leads to a very high current in these devices. The accumulated electrons are also known as 2DEG or two-dimensional electron gas. Advantages of HEMTs are that they have high gain, this makes them useful as amplifiers; high switching speeds, which are achieved because the main charge carriers in MODFETs are majority carriers, and minority carriers are not significantly involved; and extremely low noise values because the current variation in these devices is low compared to other FETs [11]-[12].

In this paper, the potential impact of GaN-based HEMT with two channel layers of GaN/InAlGaN is studied using a two dimensional device simulator. The unique features of the HEMT with two channel layers of GaN/ InAlGaN are explored and compared with those of AlGaN/GaN and AlGaN/InGaN HEMTs in terms of the drain current, electrical potential, breakdown voltage and transconductance (gm). In the next section, the proposed structure dimensions and the physical models used in the 2-D simulation are described in detail. In the third section, we explain how the presence of the two channel layers of GaN/InAlGaN will enhance performance of GaN-based HEMT. Also, in this section, the effect of these layers on the electrical potential, electron concentration, breakdown voltage and transconductance are studied and compared with that in structure of AlGaN/GaN HEMT in details.

Device Design

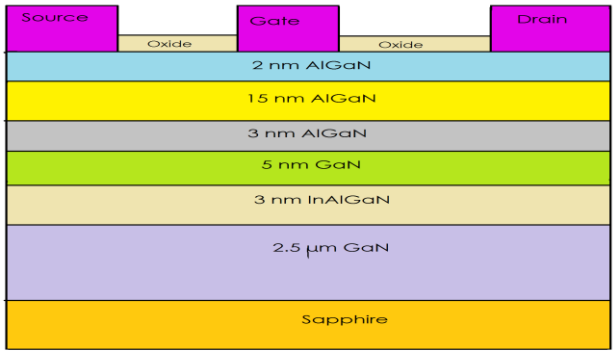

Fig 1: GaN HEMT having GaN/InAlGaN as channels

The figure 1 shows the GaN based HEMT having two layers of channel regions, i.e-AlGaN/GaN and AlGaN/InAlGaN. The device is simulated using the Silvaco software. The dimensions of the structures are as follows: gate length of 1 µm, gate-drain spacing of 1 µm, gate-source spacing of 1 µm. Barrier layer and two channel thicknesses of GaN/InAlGaN are 3 nm, 5 nm and 3 mm, respectively. The spacer layer is an n-type heavily doped Al0.3Ga0.7N thickness of 3 nm. Also, the p-layer in the barrier is a p-type heavily doped Al0.3Ga0.7N with doping concentration of 2e18. The work function of gate is 5.1 eV for the gate schottky contact. The devices are simulated using two dimensional SILVACO software [13]. The several models are activated in order to achieve more realistic results in simulations that including the SRH, Conmob, Fldmob and Fermi Dirac models for Shockley-Read-Hall recombination, standard concentration dependent mobility, parallel electric field-dependent mobility and statistics [14]-[15].

II. Result And Discussion

After the device is simulated, the next thing we achieved is optimizing the mole fraction of aluminium in the InAlGaN to create the best performing device. The table below shows the different structure parameters of InAlGaN layer with various mole fraction including polarization charge, bandgap, conduction band and critical electric field.

Material	Polarization Charge	Band Gap(ev)	Conduction Band(ev)	Ecrit(Mv/cm)
$In_{0.1}GaN$	1.22E26	3.025	-0.245	1.725
$In_{0.1}Al_{0.3}GaN$	8.10E25	3.31	-0.074	2.04
$In_{0.1}Al_{0.3}GaN$	7.25E25	3.384	-0.039	2.015
$In_{0.15}Al_{0.2}GaN$	1.12E26	3.26	-0.098	2.06

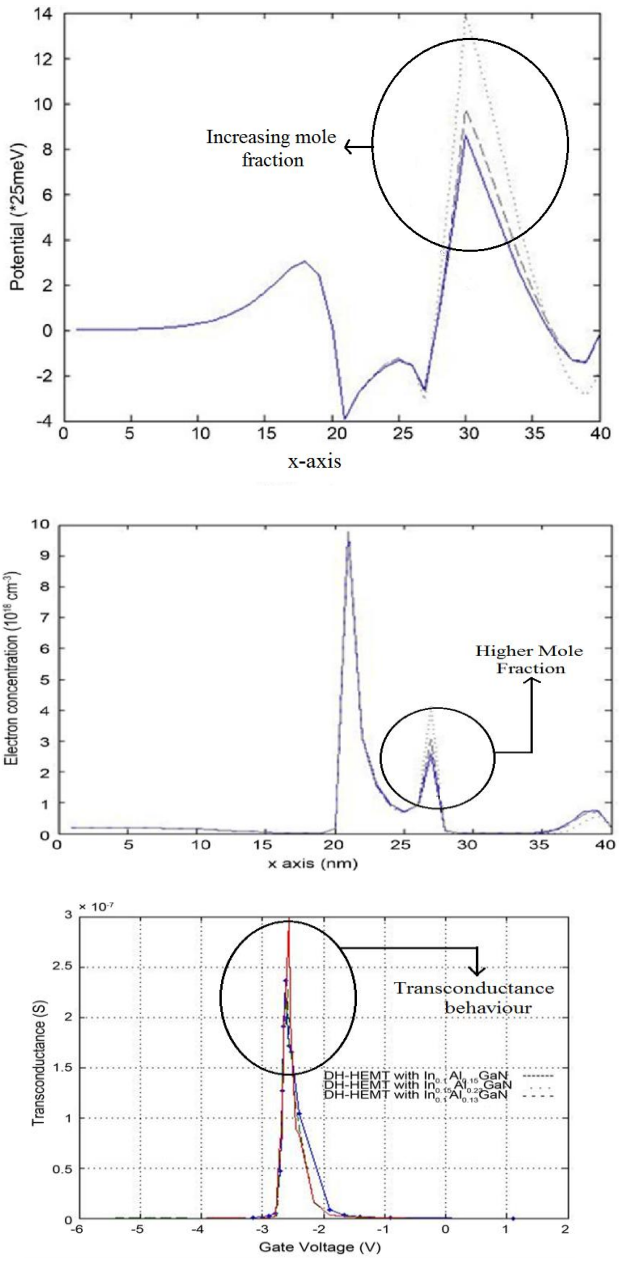

Fig 2 (a) Potential calibrated to 25mV showing increasing mole fraction,
(b) Electron concentration of the device showing mole fraction,
(c) Transconductance behavior with applied Gate voltage.

Table-1: Materials with their properties

It is seen that the InAlGaN is having better properties in terms of bandgap energy, Polarization charge, Conduction band energy and Electric field strength. This is the reason for the high performance of HEMT having Indium Aluminium Gallium Nitride as channel. However, the GaN as channel is also an additional benefit.

As seen, the polarization charge increases with lower mole fraction of aluminium that causes higher electron consternation. However, the higher mole fraction of aluminium causes higher critical electric field. Therefore, the best of mole fraction of aluminium is value that has the most polarization charge and the critical electric field greater than critical electric field of GaN.

Figure 2(a) and Figure 2(b) show the potential and electron concentration in the channel below at gate voltage of zero, respectively. The concentration is normalized to $N_0 = 1\times10^{18}$ cm^{-3}. Also, the energy axis in this figure is normalized to 25 meV. As can be seen from these figures, the structure with $In_{0.15}Al_{0.2}GaN$ layer has higher potential barrier and electron concentration than the other two structures. Therefore, structure with $In_{0.15}Al_{0.2}GaN$ layer has higher transconductance as can be shown in Figure 2(c).

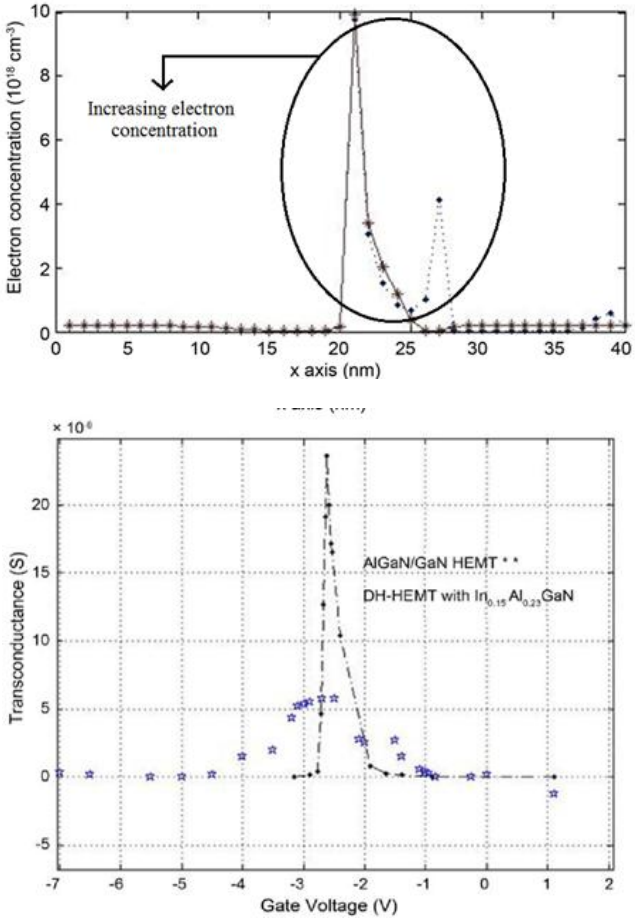

Fig 3 (a): Increasing concentration of electrons with respect to x-axis,
(b) Transconductance of AlGaN/GaN HEMT against Gate voltage.

III. Conclusion

To improve the electrical potential, electron concentration, breakdown voltage and transconductance, we have proposed a novel GaN-based HEMT that has two channel layers of GaN/InAlGaN. This new structure increases electron concentration, breakdown voltage and transconductance; and reduces the leakage current. The breakdown voltage of 130 V is obtained for the GaN/InAlGaN compared with 90 V of the conventional HEMT. Also, the mole fraction of aluminium in the InAlGaN has been optimized to create the best performing device.

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