

### ABSTRACT

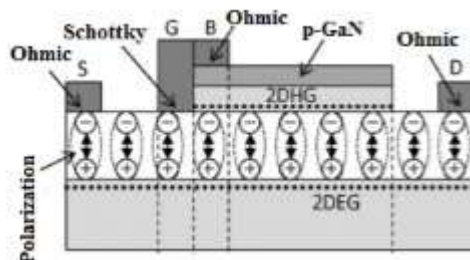
In GaN Based Super Heterojunction Field Effect Transistors a 2 Dimensional Hole Gas (DHG) is formed in addition to the 2 Dimensional Electron Gas. The positive and negative charges due to the polarization nullify each other resulting in a flat electric field which enhances the characteristic of the device. The device is a depletion mode device with a threshold of -3V. The  $I_{ON}/I_{OFF}$  of the device is  $10^6$ .

**KEYWORDS:** Polarization, Polarization Junction, 2 DHG, GaN.

### INTRODUCTION

As GaN is a wide band gap semiconductor ( $E_g=3.44\text{eV}$ ), therefore it has a capability to withstand high electric field before a breakdown can occur in the device. It also has an ability to form heterojunctions with semiconductors having wider band gap than GaN. Because of this, negative and positive charges accumulate at the interface due to the large polarization between the materials. This results in the formation of 2 D Hole Gas or 2D Electron Gas.

The device in this paper is a GaN/AlGaIn/GaN Heterostructure. Due to the negative polarisation at the GaN/AlGaIn heterointerface, a 2 Dimensional Hole Gas



**Fig.1: Structure of a Super HFET Based On GaN Using the Polarization Junction Concept. The interface polarization charges are shown. Source (S), Drain (D), gate (G), and Base form the four electrodes of the device.**

is formed along with the 2 Dimensional Electron Gas at the AlGaIn/GaN interface due to the positive polarization in the material. These two charges neutralize to result in a levelled electric field which improves the device characteristic such as the breakdown voltage.

### DEVICE STRUCTURE

The device is a GaN/AlGaIn/GaN heterostructure consisting of a  $1\mu\text{m}$  thick undoped GaN layer. The AlGaIn layer on top of GaN layer is 47 nm thick. The composition of Al in AlGaIn layer is 23% (mole fraction=0.23). A 10nm thick

undoped GaN layer is on top of the AlGaIn layer. The device consists of a 30nm thick p-GaN layer with magnesium doping of  $3 \times 10^{19}$ . There are four electrodes in this device, source, Drain, Gate and the Base.

The source and drain contact are ohmic whereas the gate electrode is schottky. The presence of a fourth electrode differentiates it from the conventional Heterojunction Field Effect Transistor (HFET). The base electrode is shorted with the gate electrode. The top p-GaN layer allows the base electrode to form ohmic contact with the 2D Hole Gas. The separation between the gate and drain is  $10 \mu\text{m}$ . The source-gate separation is  $3 \mu\text{m}$ . The gate length of the device is  $3 \mu\text{m}$ .

In the OFF state, the electric field obtained is flat. In the ON state, current flows from the drain towards the source. When the device is switching off, the 2DEG and 2DHG charges are discharged through the base and drain electrodes respectively.

### SIMULATION RESULTS

Fig.2 shows the  $I_d$ - $V_{gs}$  characteristic obtained of the device at  $V_{ds}=10\text{V}$  with  $L_{gd}=10 \mu\text{m}$ . The threshold voltage of the device is  $-3\text{V}$  as is apparent from the characteristic. Fig.3 shows the  $I_d$ - $V_{ds}$  characteristic of the device with  $L_{gd}=10 \mu\text{m}$ . The drain current is maximum at  $V_{gs}=+2\text{V}$  with the value equal to  $0.29\text{A/mm}$ .

The Super Heterojunction Field Effect Transistor Based on GaN is a depletion mode device. The device can be made enhancement by changing the AlGaIn barrier thickness, by using a field plate, or by employing a recessed gate structure. The main focus of all these method is to deplete the channel of the electron density thereby increasing the threshold voltage. Here in this paper AlGaIn thickness is varied to study the change in threshold voltage with it. The thickness is varied from  $47\text{nm}$  to  $25\text{nm}$  and the variation of threshold with thickness is tabulated in Table 1.

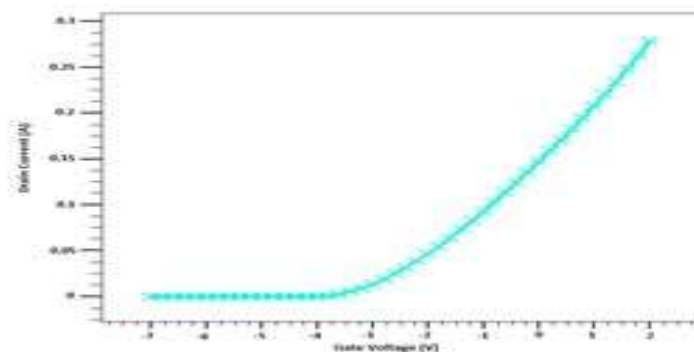


Fig.2:  $I_d$ - $V_{gs}$  characteristic of Super HFET

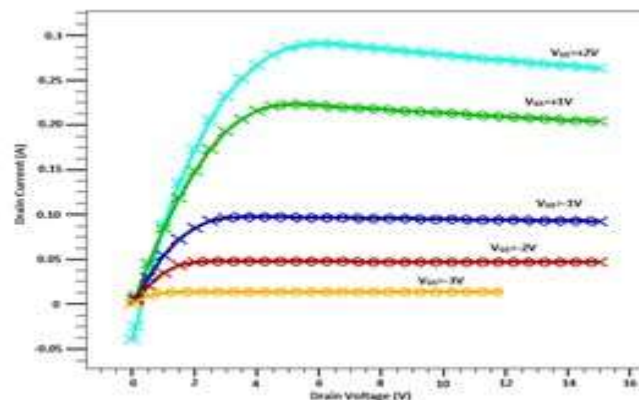
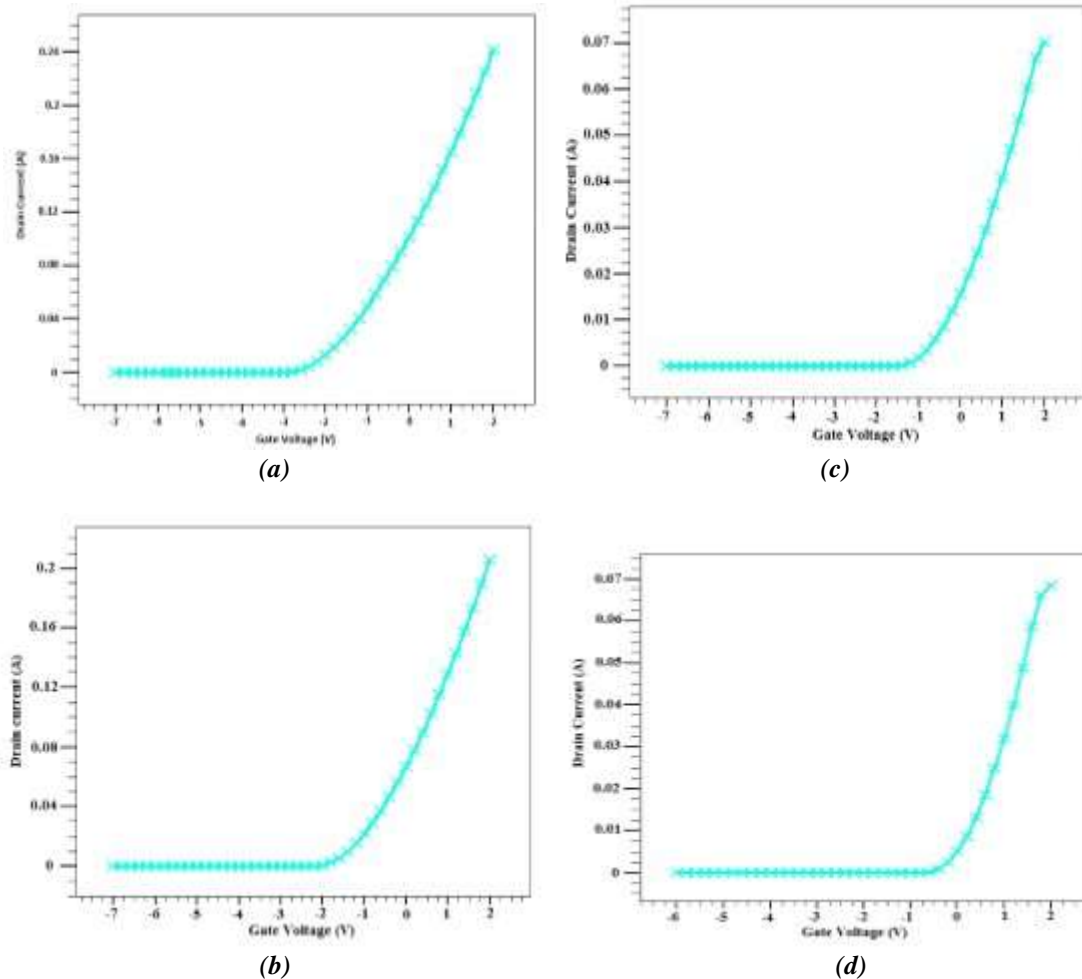


Fig.3:  $I_d$ - $V_{ds}$  characteristic of Super HFET

When the thickness of the AlGa<sub>N</sub> layer is reduced, the electron concentration along the entire channel between the source and drain decreases. This results in a positive shift of the threshold voltage. However, this also has an effect of reduced drain current which is not desirable for high voltage power devices. A normally-off or enhancement mode devices are suitable for power electronics applications. A threshold voltage of -0.66V is obtained with AlGa<sub>N</sub> layer thickness of 25nm.



**Fig.4: Variation of threshold voltage with AlGa<sub>N</sub> barrier thickness (a)40nm (b)35nm (c)30nm (d)25nm**

Fig.4 shows the variation of threshold voltage with reduced AlGa<sub>N</sub> barrier thickness. A positive shift in the threshold voltage is observed. However, the drain current is seen to be reducing with decrease in the thickness.

Various other techniques can be employed to further enhance the device.

**Table 1: Varying AlGaIn thickness of Super HFET**

AlGaIn thickness(nm)	Threshold Voltage (V)
47	-3
40	-2.66
35	-2
30	-1
25	-0.66

was presented. The device had a threshold voltage of -3V. The maximum drain current was 0.29A/mm at  $V_{gs}=+2V$ . The threshold voltage of the device was positively shifted by varying the AlGaIn barrier thickness.

GaN-Based devices have shown to be the most feasible devices for high power applications. Researches are still going on into the realisation of enhancement mode devices for power electronics applications.

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