Polarization Charge Effects analysis on AlGaN/GaN HEMT

By

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Abstract

Due to the high breakdown voltage and higher temperature GaN HEMT has drawn attention for high power electronics. In this work we have investigated the polarization effect of GaN HEMT and compared the result without adding the polarization effect. The $I_d - V_d$ characteristics, electric field, threshold voltage and transconductance operations has been observed here. We simulated the device in ATLAS simulator in TCAD with adding the polarization effect and compared the result in the same device without adding the polarization effect.

The polarization effect in the GaN HEMT device induces Two Dimensional Electron Gas (2DEG) in the AlGaN/GaN interface which increases the electron concentration of the polarization effect enabled device by three times of magnitude comparing without adding polarization effect.

The $I_D - V_G$ characteristics curve also shows the polarization effect. Because of the effect a channel is created and drain current can be found where without adding the polarization effect no drain current can be found and the device doesn't work as a transistor.

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Authorization page

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Chapter 1

Introduction

Power electronics is the application of solid-state electronics for the control and conversion of electric power which has a wide variety of applications from a country's basic infrastructure such as automobiles, computers, power plants, solar farms etc. The main component of power electronic devices are power transistors or diodes. Power system depends on the converters to step down or step up electric voltages. For the power converters the main component is the switch that is made of power diodes. The characteristics of an ideal switch is to pass any amount of current with no voltage drop and no current passing when they are open. For devices, low on resistance and high breakdown voltages are required to provide high power and low loss operation and low on-resistance and high breakdown voltage are two main figures of merits of power devices.

The limitations of Si made power devices are limited critical field and higher resistance. The limitations have made the devices and circuits very heavy, bulky and inappropriate for future applications. Because of the wide bandgap, high critical field and high electron mobility GaN High Electron Mobility Transistor has got its attention.

1.1 Background

A High-electron-mobility transistor (HEMT), is a field-effect transistor organized with different band gaps of a junction between two materials. HEMT can operate at high frequency and are used for products such as cell phones, satellite television receivers, voltage converters and radar equipment.

Invention of HEMT structure was a product of an exploration with various purposes and also several factors work behind this invention. In the late 70s, the molecular beam epitaxy growth technique and modulation doping was invented together to see the characteristics of quantum well structures. By Takashi Mimura, HEMT structure was first demonstrated. Ray Dingle and Horst Störmer also played an important role in the invention of the HEMT in America. The patent of this device was approved by the help of Daniel Delagebeaudeuf and Trong Linh Nuyen from Thomson-CSF (France) [1].

Beginning of the last decade GaN deposition in HEMT were developed. The first AlGaN/GaN HEMT was imposed by Khan et al. in 1992 with a carrier density of 10^{11} cm^{-2} and a mobility of 400-800 cm^2/Vs. GaN is a wide band gap material which brings the advantages of higher breakdown voltages and higher operational temperature. Due to the large lattice mismatch a strain in the AlGaN layer is induced, which generates a piezoelectric field.

1.2 Literature Review

For the last few years the gallium nitride (GaN) have received much attention because of the wide use in the high power high frequency devices. Due to the unique material properties, high electric field breakdown due to wide band gap are giving GaN its incredible potential in the high frequency area as well as in the microwave, automative and aerospace industry [2].

The reason behind the wide energy gap is the low intrinsic carrier concentration and resistance to ionization. Because of the low dielectric constant the wide bandgap semiconductors like GaN has reduced capacitance loading [3]. The wide band gap property of GaN is very helpful for high temperature conditions because the high power applications mostly depends on the extraction of heat due to the dissipated energy [4]. Large bandgap semiconductors also bring less noise which makes them suitable for the making of high sensitive detectors in UV range as the conduction band permits for a high saturation velocity, flat field and flat parasitic [5]. AlGaN/GaN HEMT provided a current density of 850mA/mm and transconductance of 93mS/mm [6]. The reason behind the high electric field, high transconductance or the high electron concentration is because of the polarization effect. The polarization dependent analysis has been done and because of the high electron concentration the GaN HEMT is good for high power application [7]. The formation of two dimensional electron gas in the GaN HEMT device has effect on the device charge density. The sheet channel density of AlGaN/GaN heterostructure depends on aluminum mole fraction and layer thickness. The stress induced charge because of the spontaneous polarization is an essential component of the overall polarization charge and cannot be ignored when computing the sheet channel density [8]. By optimizing field plate technique, the high breakdown voltage and of 600V and high on-state resistance of $3.3\text{m}\Omega\text{cm}^2$ was achieved which was because of the high critical field of GaN material and the high mobility in 2DEG channel [9].

Normally the GaN HEMT are used as a depletion mode device but using the fluoride based plasma treatment the threshold voltage of the device has been -4V to 0.9 V which acts as an enhancement mode device [10]. The induced polarization charges play an important role in the electrical and optical properties of the device and also provide a source of 2DEG in the AlGaN/GaN heterostructures. The controlling of the source of the electrons are important for the performance of the device. Some advantages of using GaN HEMT has been described in table 1.1.

Table 1.1: Advantages of GaN HEMT [11].

Need	Enabling Features
High power per unit width	Wide bandgap, High field
High voltage operation	High breakdown field
High linearity	HEMT Topology
High Frequency	High electron velocity
High Efficiency	High operating voltage

Here, first column represents the requirements of any power devices and second column represents the characteristics of enabling features to fulfill the needs. For example, high power per unit width introduces smaller devices that are easier to fabricate and they have high impedance. High voltage operation decrease or eliminates the need for voltage conversion so that in the commercial systems GaN devices can operate at the same voltage.

GaN HEMT can operate at high frequency as well as possess high breakdown strength and high electron velocity in saturation. GaN shows piezoelectric polarization which upholds accumulation of enormous carriers at AlGaN/GaN interface. In these types of HEMTs, device performance depends on the types of material layer, layer thickness, and doping concentration of AlGaN layer providing flexibility in the design process.

1.3 Objective

The objective of this work is to observe different properties of GaN HEMT including polarization effect and without polarization effect using SILVCO ATLAS.

We have exhibited their basic operation, drain current vs. drain voltage characteristics, drain current vs. gate voltage characteristics, electric field effect, transconductance and electron concentration effect on our created device for both the polarization effect and without polarization effect.

1.4 Thesis Outline

This report contains five chapters. Chapter’s brief description is summarized below

Chapter 1 contains the background and objective behind this particular work which includes the necessity of GaN HEMT and the increasing demand of the device because of its widely use in the radio frequency, power electronics and aircraft application.

Chapter 2 focuses on the GaN HEMT device, its operation and fundamental issues.

Chapter 3 introduces about the software Silvaco Atlas which was used for design and simulation of the device. Mainly the models and methods which are used for the simulation is discussed in the chapter.

Chapter 4 includes our investigation results and explanation for different situation under both cases with and without polarization respectively.

Chapter 5 contains the summary of the work and also the extension part of this work for future.

Chapter 2

Introduction to Gallium Nitride HEMT

The GaN HEMT is a three terminal device where gate is utilized to control the current flow. The GaN material is used here as the channel layer. The advantage of using the AlGaN/GaN HEMT is that the formation of two dimensional electron gases due to the polarization effect. Due to this 2DEG the device has high electric field and drain current. In this chapter we are going to discuss about the device that has been used in this work and also about the formation of 2DEG and the spontaneous and piezoelectric effect.

2.1 GaN Material

Some necessary properties of Gallium Nitride material are exhibited in the table 2.1.

Table 2.1: Electronic, Thermal Parameters of Gallium Nitride [12].

Bandgap	3.44eV
Lattice Constant	3.189Å (a), 5.185Å (c)
Breakdown Field	3.3×10^{6}V/cm
Electron Mobility	$\mu_{n} =$ 1000 $cm^{2}V^{-1}S^{-1}$
Thermal Conductivity	1.5W/cm-K

2.2 The GaN HEMT Structure

The GaN HEMT is a three terminal device that utilizes the gate to control the current flow. The structure shown in figure 2.1 has been selected for this work. It has gate, drain and source length of 1µm, drain to gate distance of 2µm and gate to source distance of 3µm. The GaN HEMT structure used in this work consists of;

Barrier Layer: The barrier layer is the most critical layer in the structure. The material that has been used in this layer has wider bandgap than the channel layer. In this case $Al_xGa_{1-x}N$ has been used and the bandgap depends on the aluminium mole fraction. The mole fraction that has been used in the device is 0.30 and the bandgap is 3.97eV. The layer has the width of 23nm.

Channel Layer: The material of this layer has lower bandgap than the barrier layer. High resistivity GaN layer of 2.5µm has been used here to ensure proper drain-source current saturation and low loss at high frequencies.

Substrate: 1µm of Gallium Nitride substrate has been used here.

Three metal contacts, source (S), gate (G) and drain (D) are made to the top AlGaN barrier layer. Both the drain and source terminals are Ohmic. The source is typically grounded and bias is applied to the drain which force the electrons in the 2DEG to flow.

The gate terminal is a metal-semiconductor rectifying contact (Schottky barrier contact). High workfunction materials are used as Schottky contact. Ni has been used as a Schottky contact here which has the workfunction of 5.04eV. The gate bias required to pinch-off the channel is called the threshold voltage (V_T). If the threshold voltage is negative then it is called the depletion mode HEMT. If the required threshold voltage is positive then the HEMT is called an enhancement mode device. Conventionally the AlGaN/GaN HEMT's are the depletion mode transistors.

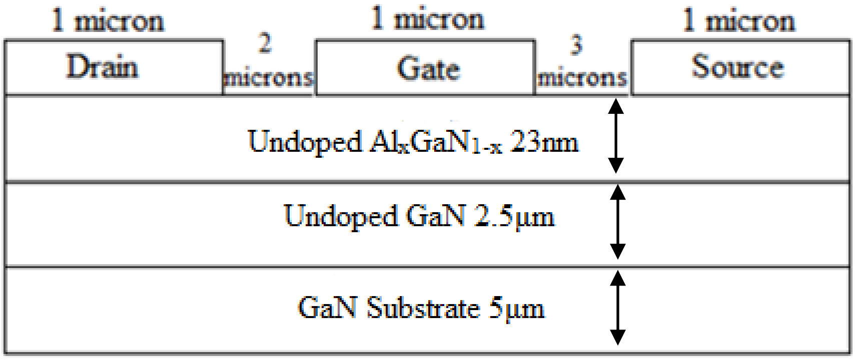

Figure 2.1: Structure of AlGaN/GaN HEMT.

2.3 Polarization and Formation of Two Dimensional Electron Gas (2DEG)

2.3.1 Formation of Two Dimensional Electron Gas (2DEG)

The formation of 2DEG in the AlGaN/GaN interface occurs due to the polarization effect. There can be seen two types of polarization effects which are the piezoelectric polarization and the spontaneous polarization. This section will describe about the formation of 2DEG due to the polarization effect.

The AlGaN layer grown on a GaN buffer induces positive polarization charges in the interface of the AlGaN/GaN and the negative charges in the AlGaN layer. Because of the polarization charge an electric field is formed in the AlGaN layer. The electric field induced in the device will force few conductive electrons to be moved and the band diagram remains unchanged. But the 2DEG is not because of this conducting electron.

The formation of 2DEG at the AlGaN/GaN interface can be well explained by assuming the existence of donor states on the AlGaN surface. If the AlGaN layer is under the same tensile strain as grown on GaN layer then the electrons are stimulated into the conductive band and move due to the polarization force induced electric field. When the contact with the GaN layer is made the electrons will flow into the GaN side because of the drop of the Fermi level which can be seen in the figure below.

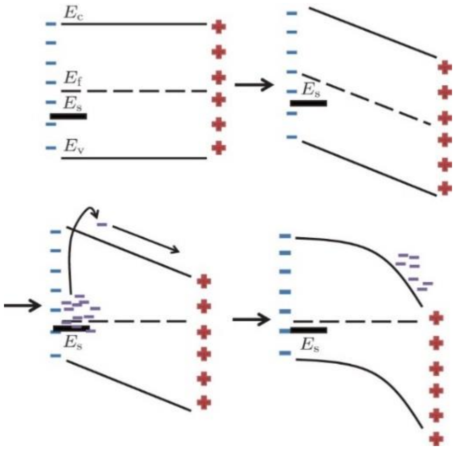

Figure 2.2: Energy band of undoped AlGaN where electrons are stimulated into the conductive band [13].

The electrons will accumulate at the interface of the AlGaN/GaN which will form 2DEG as shown in figure 2. The electron gas and the ionized surface donor states will also generate an electric field which will reduce the polarization effect [13].

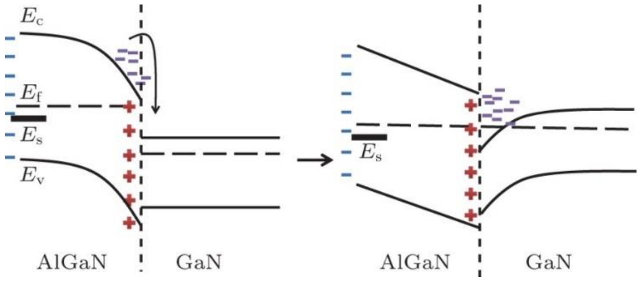

Figure 2.3: Energy band of AlGaN/GaN heterostructure where electron accumulates at the interface [13].

2.3.2 Spontaneous Polarization

The high carrier concentration in the GaN HEMT is due to two types of polarization induced in the device. They are spontaneous and piezoelectric polarization.

The spontaneous polarization occurred even there is no strain present in the device. This forms due to the lack of symmetry during develop of the wurtzite group along the [0001] axis or c-direction. The polarization charge effects vary according to the form of the structure [14].

2.3.3 Piezoelectric Polarization

The piezoelectric polarization can be calculated by the equation [15];

$$P_{PE} = e_{33}\varepsilon_z + e_{31}(\varepsilon_x + \varepsilon_y) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.1)}$$

Where $\epsilon_z = (c-c_0)/c_0$ is the strain along the c-axis, and the in-pane strain $\epsilon_x = \epsilon_y = (a-a_0)/a_0$ is assumed to be isotropic.

The total piezoelectric polarization in the direction of the c-axis can be calculated by the equation;

$$P_{PE} = (\frac{a-a_0}{a_0})(e_{31} - e_{33}\left(\frac{C_{13}}{C33}\right)) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.2)}$$

Where C_{11} and C_{33} are the elastic constants.

2.4 GaN HEMT Operation Theory

The operating parameters for the GaN HEMT would be the drain current, the threshold voltage, the transconductance etc.

The current flowing between the drain and source contacts can be written as

$$I_D = qn_s v_{eff} W_G \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.3)}$$

Where v_{eff} is the effective velocity, n_s is the 2DEG charge density and W_G is the gate width. The n_s can be written as

$$n_s = \frac{\varepsilon_{AlGaN}}{q(d_{AlGaN}+\Delta d)}(V_g - V_t) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.4)}$$

Where, ε_{AlGaN} is the dielectric permeability, d_{AlGaN} is the thickness of the wide bandgap semiconductor, Δd is the effective thickness of the 2DEG, V_G is the gate bias [14].

The threshold voltage is another important parameter as it is a measurement of when the HEMT will be conducting where,

$$V_{th} = \emptyset_{eff}^{b} - \Delta E_c - \frac{qN_s d_{AlGaN}^2}{2.\varepsilon_{AlGaN}} - \sigma\frac{d_{AlGaN}}{\varepsilon_{AlGaN}} \ldots\ldots\ldots\ldots\ldots\ldots \text{(2.5)}$$

Where, $\emptyset_{eff}^{b} = metal - semiconductor\ Schottky\ Barrier\ Height$

$\sigma =$Overall net polarization charge at the barrier

d = AlGaN barrier layer thickness

$\varepsilon =$ Dielectric constant of AlGaN

Chapter 3

Modelling and Simulation

In this chapter we have discussed about the models and methods that has been used to simulate the semiconductor and to get the results. Atlas TCAD simulator has been used for this purpose. The Atlas has some basic models to simulate any semiconductor. For the simulation of GaN HEMT device, polarization charge effect and the strain effect is necessary which has been included in the code.

3.1 AlGaN/GaN HEMT Silvaco Model

The model presented in this work has been generated by Silvaco Atlas, where the device was designed using the DECKBUILD and was solved through the Atlas. The device was analyzed by TONYPLOT tool.

3.1.1 Silvaco Semiconductor Modelling Equations

To solve the device there are several fundamental semiconductor equations which are used on almost any semiconductor devices to solve the electric field, electrostatic potentials and the carrier densities. These equations have been derived using the Poisson’s equation which is

$$div(\varepsilon \Delta \varphi) = -\rho \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

$$-\rho = q(n - p - N_D^+ + N_A^-) - Q_T \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

Where, φ is the electrostatic potential, ε is the local permittivity, ρ is the local space charge density, n and p are the electron and hole concentration, N_D^+ and N_A^- are the ionized donor and acceptor impurity concentrations, and Q_T is the charge due to traps and defects.

The carrier continuity equations for electrons and holes are

$$\frac{\partial_n}{\partial_t} = \frac{1}{q}\, divJ_n + G_n - R_n \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.3)$$

$$\frac{\partial_p}{\partial_t} = -\frac{1}{q}\, divJ_p + G_p - R_p \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.4)$$

Where n and p are the electron and hole concentration, J_n and J_p are the electron and hole current densities. G_n and G_p are the generation rates for electron and holes and R_n and R_p are the recombination rate for the electron and holes. The continuity equations give the general framework for device simulation.

Polarization effect is one of the most challenging aspects of modelling AlGaN/GaN heterostructures. The surface donor like traps are the source of electrons in the channel and the polarization effects in AlGaN/GaN structures force the electrons in the channel.

The ‘Polarization’ parameter enables the two polarization effect in the device and it simulate polarization in wurtzite materials and include spontaneous and piezoelectric polarization. The polarization model works by enabling positive and negative charges at the top of the AlGaN layer and at the interface of the AlGaN/GaN.

The Shockley-Read-Hall model has been used for fixing the minority carrier lifetimes which is needed to be used in most of the simulations of the ATLAS. Phonon transitions occur in the presence of a trap within the forbidden gap of the semiconductor. The theory of this was established by Shockley-Read and then by Hall. The model is followed as

$$R_{SRH} = \frac{pn - n_{ie}^{2}}{TAUP0\left[n + n_{ie}\exp\left(\frac{ETRAP}{kT_L}\right)\right] + TAUN0\left[p + n_{ie}\exp\left(\frac{-ETRAP}{kT_L}\right)\right]} \ldots\ldots\ldots\ldots (3.5)$$

Where, ETRAP is the difference between the trap energy level and the intrinsic Fermi level, T_L is the lattice temperature in degrees Kelvin and TAUN0 and TAUP0 are the electron and hole lifetimes.

For the mobility model the Albrecht Model (albrct) has been used. It has been used to model low field mobility to control over electrons. The model is described as

$$\frac{1}{\mu(N,T_L)} = \frac{AN.ALBRCT.N}{NON.ALBRCT}\left(\frac{T_L}{TON.ALBRCT}\right)^{-3/2} \ln\left[1 + 3\left(\frac{T_L}{TON.ALBRCT}\right)^{2}\left(\frac{N}{NON.ALBRCT}\right)^{-\frac{2}{3}}\right] + \left[BN.ALBRCT \times \left(\frac{T_L}{TON.ALBRCT}\right)^{\frac{3}{2}}\right] + \frac{CN.ALBRCT}{\exp\left(T1N.\frac{ALBRCT}{T_L}\right) - 1} \ldots\ldots\ldots\ldots (3.6)$$

Where, where μ(N,T) is the mobility as a function of doping and lattice temperature, N is the total doping concentration, and T_L is the lattice temperature. AN.ALBRCT, BN.ALBRCT, CN.ALBRCT, N0N.ALBRCT, T0N.ALBRCT and T1N.ALBRCT are user specifiable parameters on the mobility statement [16].

Chapter 4

Polarization effect analysis of AlGaN/GaN HEMT

In this chapter we have discussed about the results we have got from the GaN HEMT device with the polarization charge effect and also without the polarization charge effect. We have observed changes in the operations of GaN HEMT due to the polarization effect and we compared the result by removing the polarization effect in the device which we have shown in figure 2.1.

4.1 Polarization charge effect on Electric Field

Due to the polarization effect two dimensional electron gas is formed in the interface of the AlGaN/GaN structure. Negative charge is formed in the upper layer of the AlGaN material and positive charge is formed in the interface of the AlGaN/GaN layer. Due to the polarization, an electric field is induced even though there is no voltage applied. Because of this induced polarization charge the electric field is high compared with no polarization charge effect in the device.

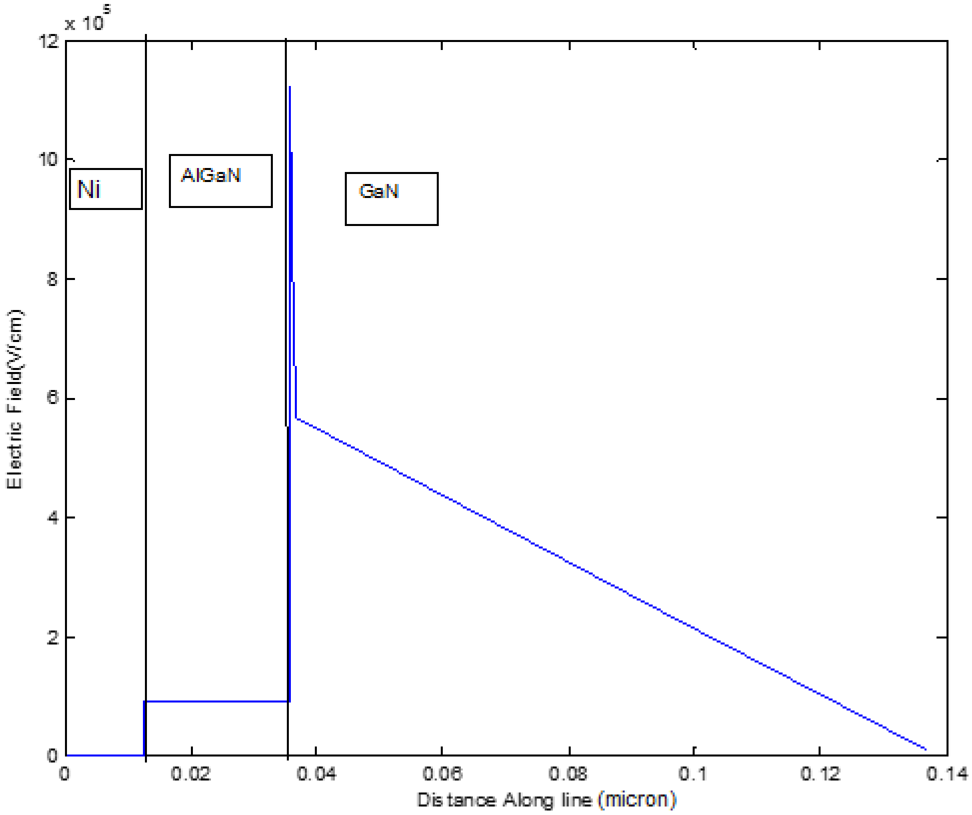

Figure 4.1: Electric Field for gate voltage 1V with polarization charge.

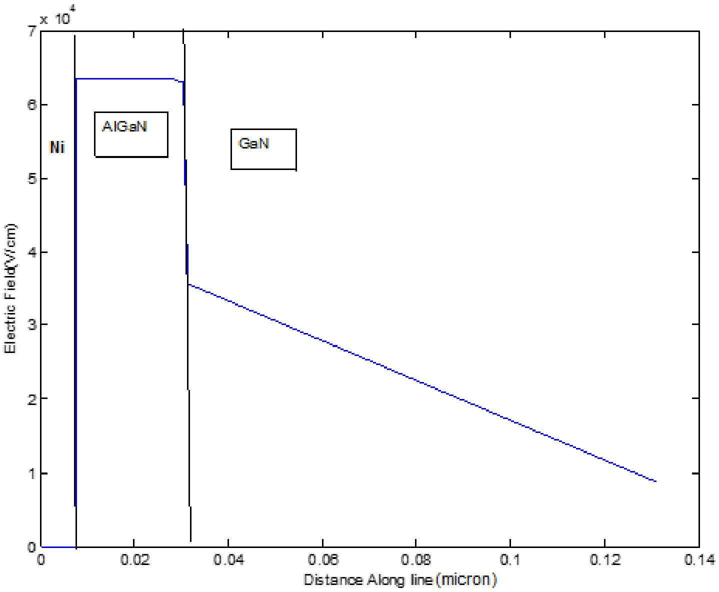

Figure 4.2: Electric Field for gate voltage 1V without polarization charge.

From figure (4.1) we can see that due to the presence of polarization charge in the device there has been increased in the electric field. When 1V is given in the gate the electric field is in the range of 1.7×10^6 V/cm and as there has already been positive charges in the interface of the AlGaN and GaN and negative charges in the top of the AlGaN layer, it increases the electric field. From figure (4.2) we can see that without the polarization effect due to the 1V in the gate the electric field is lower than figure (4.1) where with polarization charge the electric field in around 11×10^5 V/cm and without the polarization charge the electric field is around 6.5×10^4V/cm.

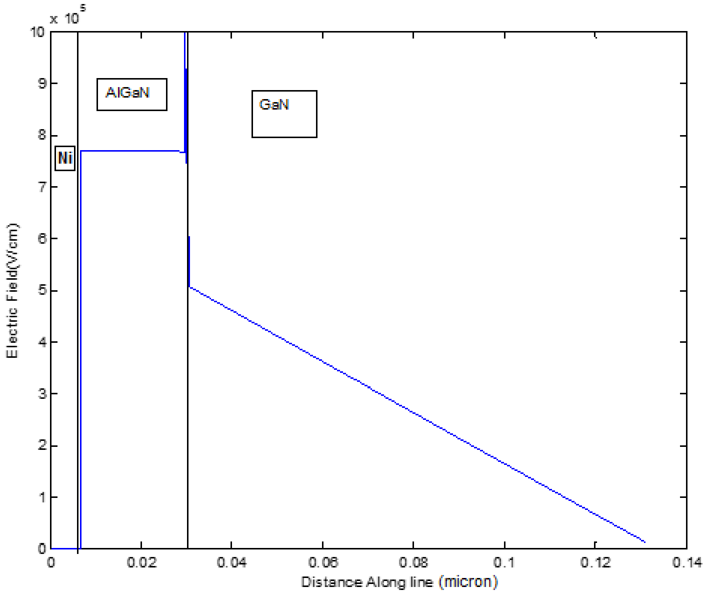

Figure 4.3: Electric Field for gate voltage -1V with polarization charge.

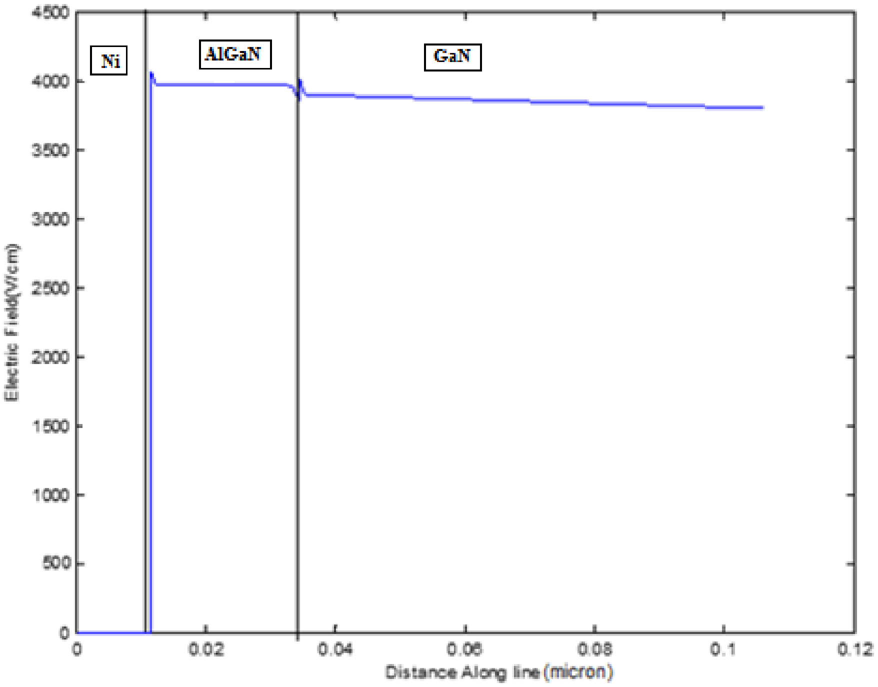

Figure 4.4: Electric Field for gate voltage -1V without polarization charge.

From figure (4.3) and figure (4.4) we can also observe the effect of polarization charges. In figure (4.3) where the polarization charge is present, we can see that the electric field is higher in the interface of the AlGaN/GaN which is 10×10^5 V/cm. For the same -1V in the gate, without the polarization charge, in figure (4.4) the electric field is less than figure (4.3) which is around 4000V/cm.

4.2 Effect on Electron Concentration

The 2DEG due to the polarization effect is formed in the GaN side of AlGaN-GaN interface. In the figure (4.5) we can see that due to the polarization effect the electron concentration in the interface is greater than without introducing the polarization effect in the device in figure (4.6) where 1V was given in the gate. From figure (4.5) and (4.6) the electron concentration in the polarization effect enable device is around $10^{20}/cm^3$ where without the polarization effect we can see the electron concentration in the interface is around $10^{17}/cm^3$.

From figure (4.7) and (4.8) when -1V was given in the gate the polarization effect can be seen more clearly. Because of the presence of the polarization charge the electron concentration is $10^{20}/cm^3$ where because of the absence of the polarization charge the value is only $10^1/cm^3$.

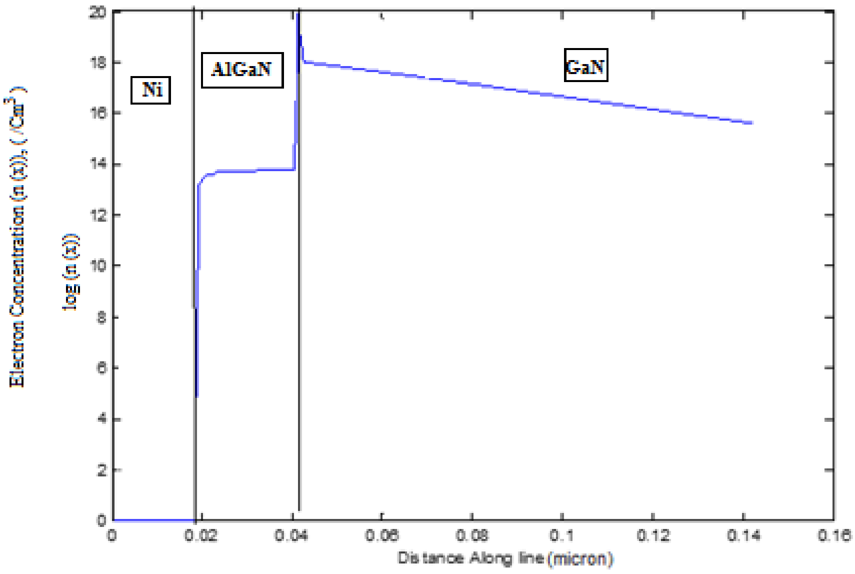

Figure 4.5: Electron Concentration for gate voltage 1V with polarization charge.

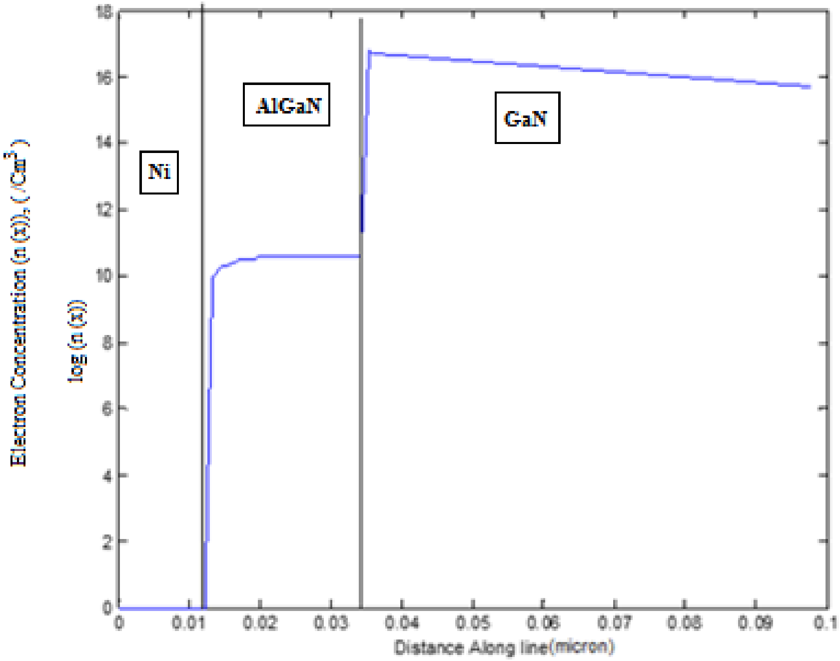

Figure 4.6: Electron Concentration for gate voltage 1V without polarization charge.

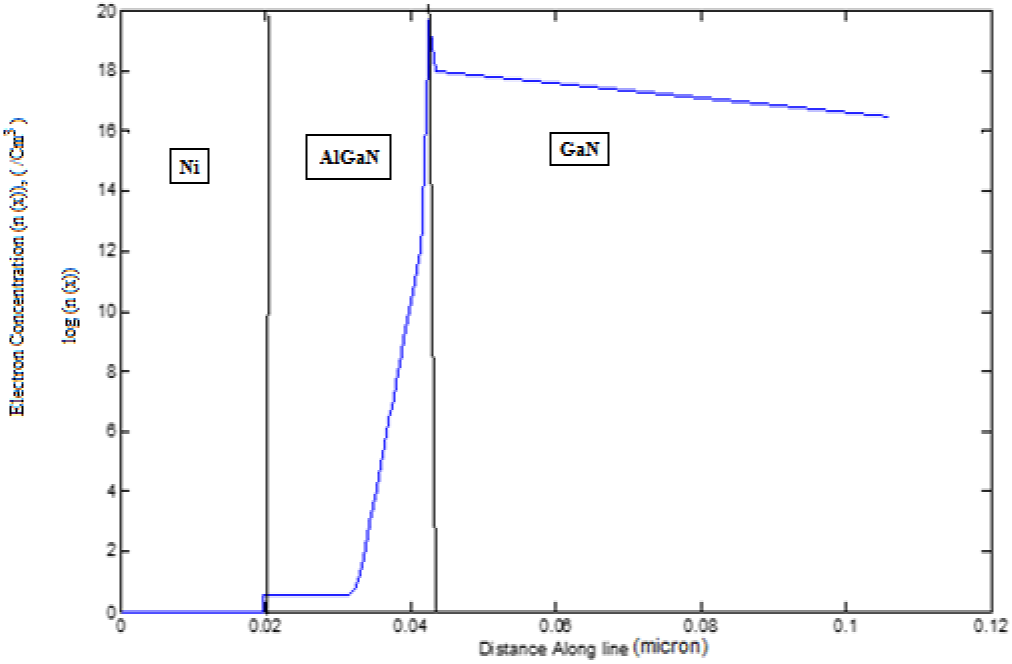

Figure 4.7: Electron Concentration for gate voltage -1V with polarization charge.

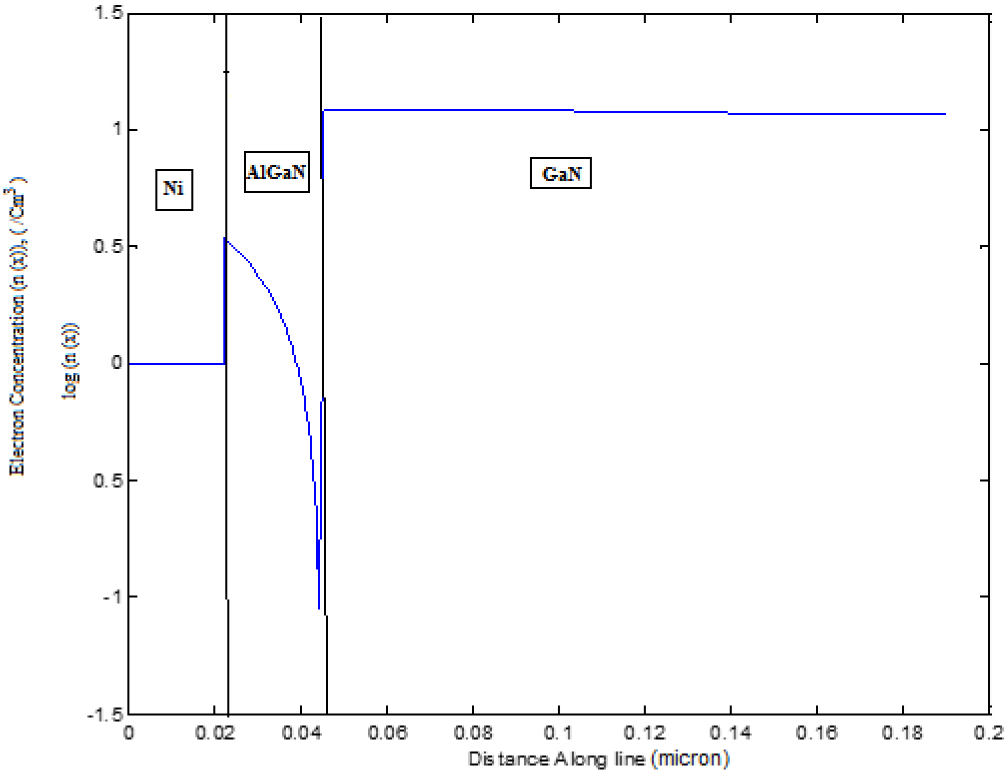

Figure 4.8: Electron Concentration for gate voltage -1V without polarization charge.

4.3 Effect on Threshold Voltage

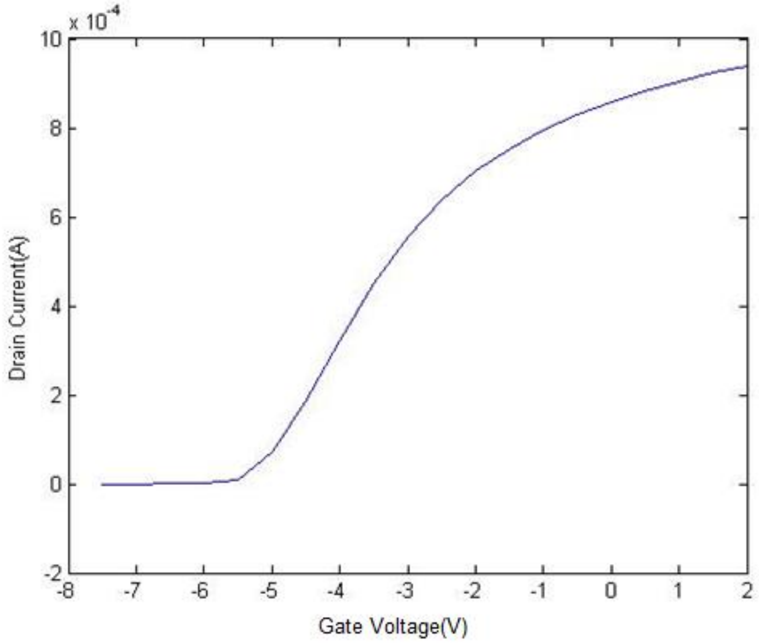

Figure 4.9: Threshold voltage calculation with adding the polarization charge.

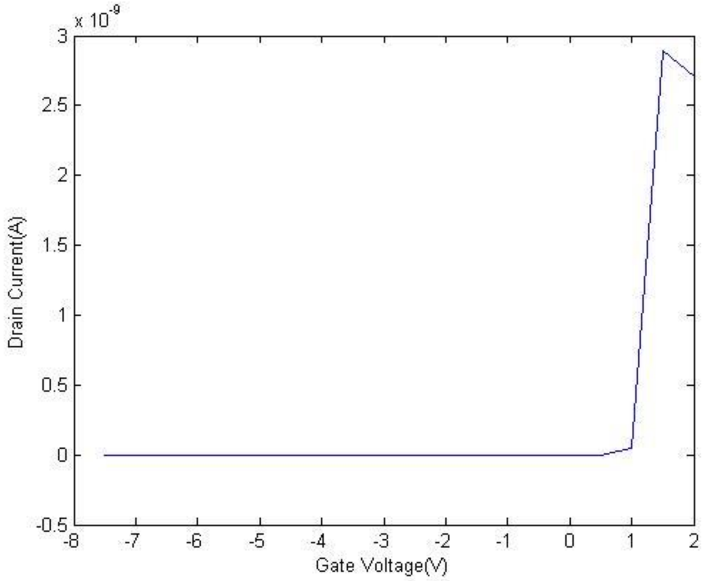

Figure 4.10: Threshold voltage calculation without adding the polarization charge.

Threshold voltage is the minimum gate to source voltage that is required to create a channel between the drain and source channels. By taking into account the effects of polarization charge we can calculate the threshold voltage.

By using the extract method of the Silvaco we get the threshold voltage of both the with polarization charge and without the polarization charge,

From figure (4.9) with adding polarization charge effect, the threshold voltage is -5.17V.

From figure (4.10) without adding polarization charge effect in the device, the threshold voltage is 0.99V.

In Silvaco Atlas the extraction of threshold voltage is done by calculating the maximum slope of the I_d/V_g curve and after that finding the intercept with the X axis and then subtracting half of the applied drain bias.

4.4 Effect on I_d – V_d characteristics

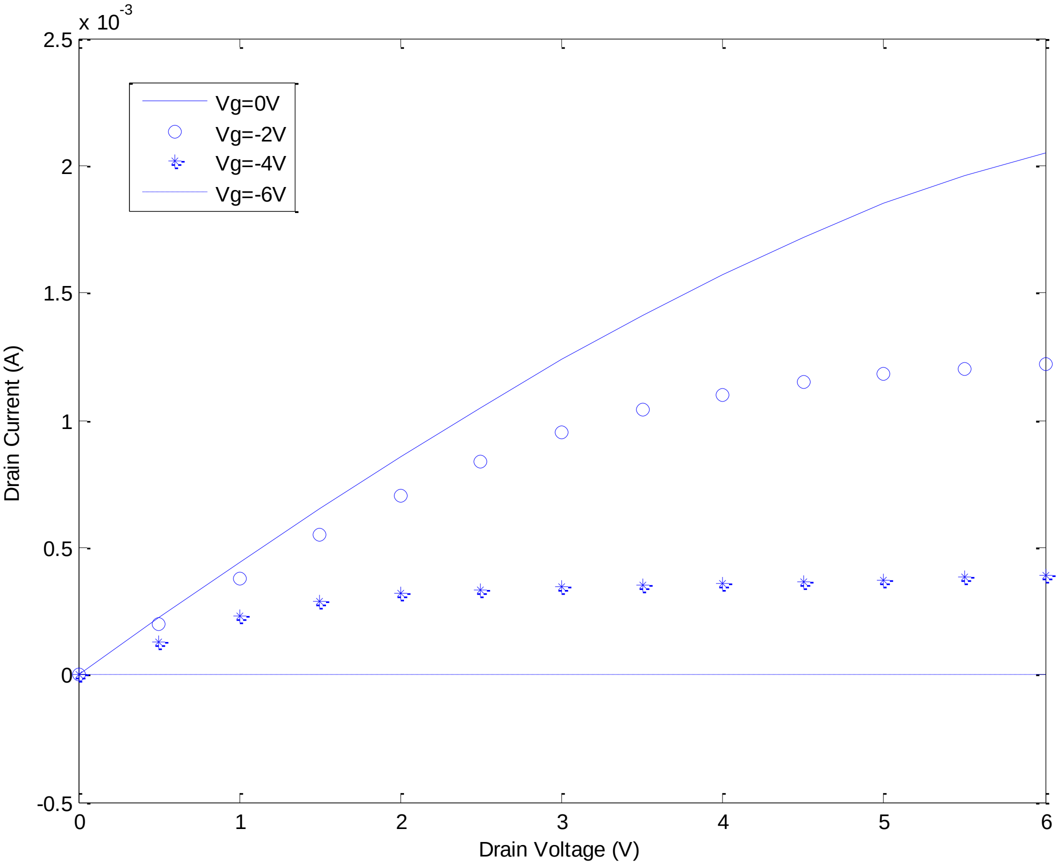

Figure 4.11: Output Characteristics with polarization charge.

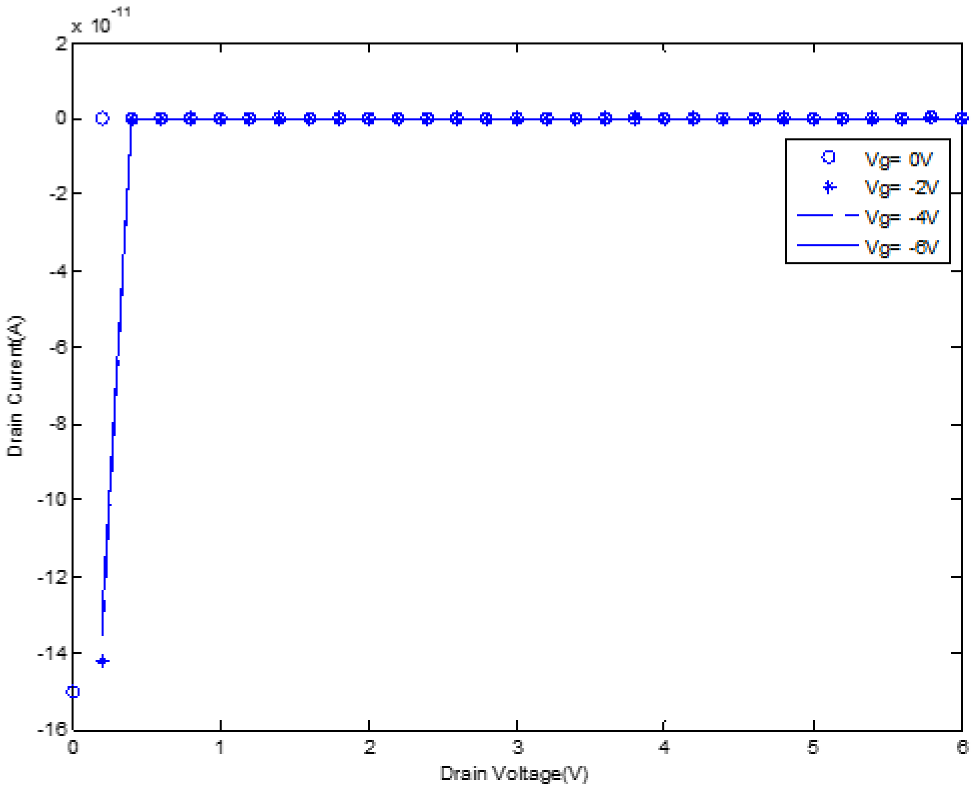

Figure 4.12: Output Characteristics without polarization charge.

In figure (4.11) and figure (4.12) the family of curves for drain voltage vs. drain current has been shown. In the first figure when the gate voltage is -6V there is no drain current which is clearly can be explained from the threshold voltage curve figure (4.9) where the threshold voltage was measured with the polarization charge was -5.17V. So there is no current for -6V. Now if we compare the figure with (4.12) we can see that without the polarization effect there has been no channel created in the device as no drain current is flown. We can again explain this using the threshold voltage curve figure (4.10) where the threshold voltage was measured 0.99V. So there is no drain current.

4.5 Effect on Transconductance

The transconductance is dependent on V_G as when the gate voltage is near the threshold voltage, the electrons in the 2DEG are pushed away from the heterointerface which decrease the value of distance from the 2DEG to heterointerface and it increases the transconductance [17].

The transconductance was calculated using the Edit/Functions menu in tonyplot which allows to specify and plot functions of the terminal characteristics in the graph function text fields. The transconductance was calculated by differentiating drain current with respect to gate voltage.

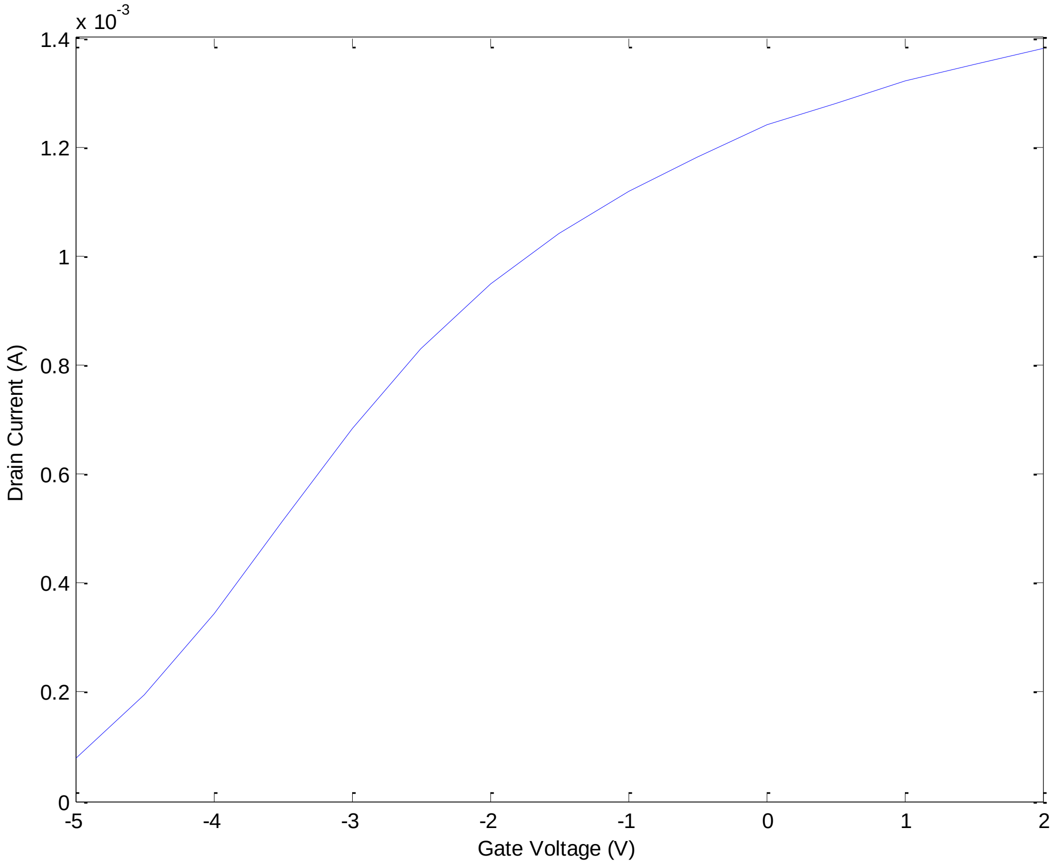

Figure 4.13: I_d – V_g curve for drain voltage 3V with polarization charge.

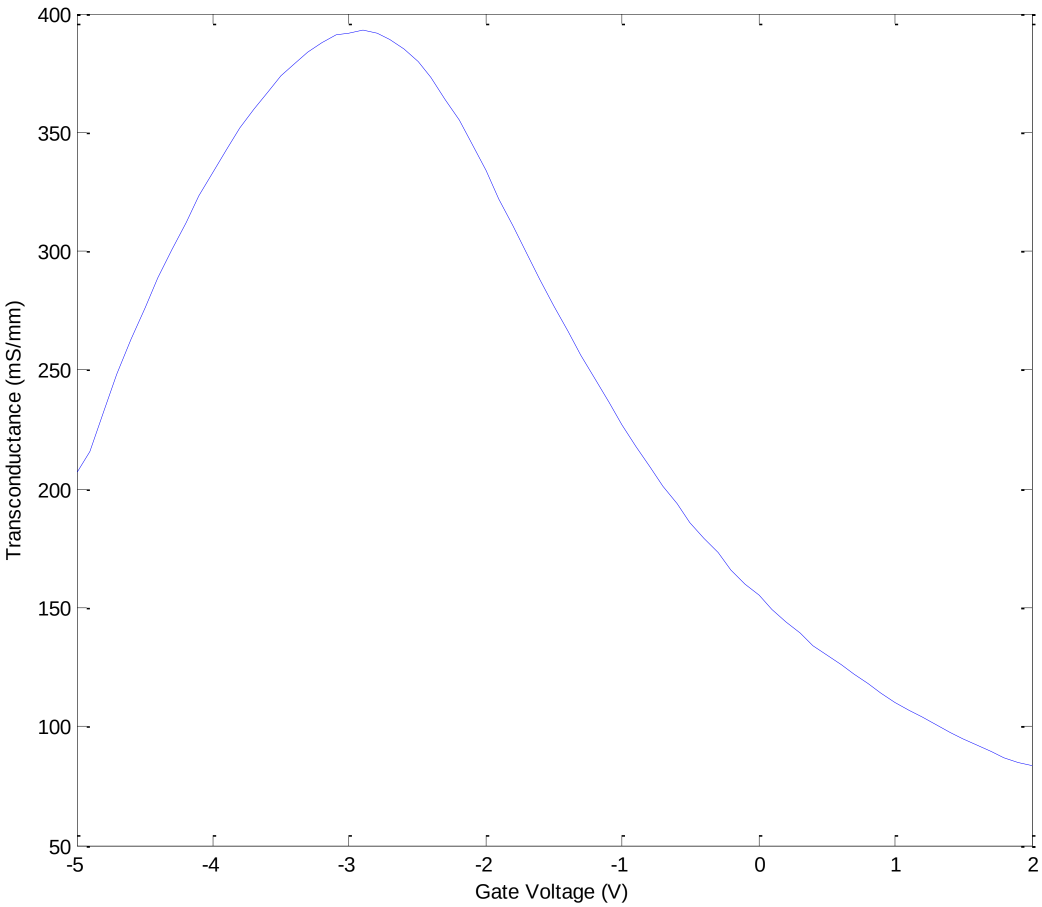

Figure 4.14: Transconductance vs V_g curve for drain voltage 4V with polarization charge.

From the above figure (4.14) we have tried to show the effect of polarization charges on the transconductance for the different gate voltages. The figure (4.13) shows the drain current vs gate voltage and (4.14) shows the transconductance vs. gate voltage, where the drain voltage is 3V. From the figure (4.14) we can see that transconductance decreases with increase in gate voltage. Variation of gate voltage modulates the 2DEG layer and parasite channel is formed within the AlGaN layer. When the gate voltage is increased the modulation of 2-D channel will be reduced due to the parasitic channel screens the 2DEG layer from the gate voltage. Consequently, transconductance falls off under increasing voltage when free carrier concentration increases to form a parasitic channel.

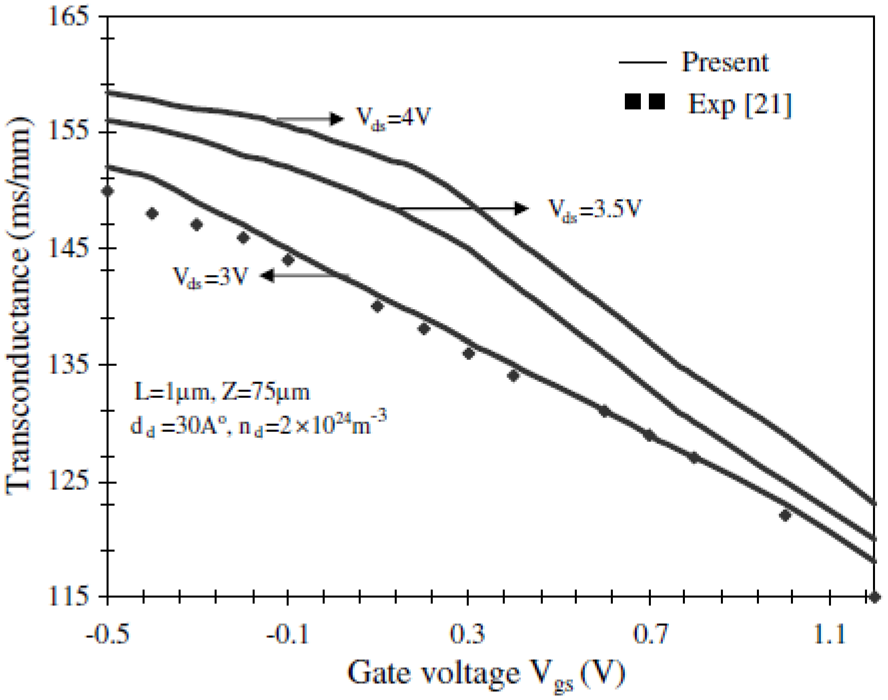

Figure 4.15: Transconductance vs. V_g curve [7].

We also compared the values of the transconductance with the result of the similar device in the published papers [7], [18], where we can see that the values of the transconductance in the paper and the values of our simulation is similar. For the value of 0.3 gate voltage we got the transconductance of 150 mS/mm in figure 4.14 and in the published paper the value for the transconductance is 155 mS/mm which we can see from figure 4.15.

Chapter 5

Conclusion

5.1 Summary

The main objective of our work is to find out the polarization effect on GaN HEMT. We observed the effect of polarization for different HEMT operation like electric filed, electron concentration, threshold voltage, I_D – V_D characteristics and transconductance.

We introduced polarization effect in the SILVACO ATLAS on the device and observed different characteristics. We then compared them without adding the polarization effect on the device. We observed a numbers of differences in the device characteristics due to the polarization effect.

We observed that due to the polarization effect on the GaN HEMT device the electric field is increased due to the polarization charges in the AlGaN/GaN interface. The threshold voltage is decreased. When the polarization charge is added the GaN HEMT works as a Depletion mode HEMT where the threshold voltage is negative and without the polarization effect the HEMT is an enhancement mode HEMT. For the I_D – V_D characteristics we observed that the drain current is increased due to the polarization effect.

5.2 Future Works

In this work we have only observed the polarization effect on the GaN HEMT device. There has also been effect of changing other parameters in the device which can bring a significant change in the result of the characteristics of the device. One of the important parameters of the device is the alloy composition of AlGaN where if the value of the composition is changed then the device characteristics change are observed. The substrate that is used in this device can be changed using other materials and the change in the substrate materials has effect on the device. The gate that has been used here is the schottky gate which can be replaced by a MOS gate.

In future, we will try to observe the change in different characteristics of GaN HEMT due to the change of alloy composition and the substrate material. The change of characteristics due to the change of Schottky gate by a MOS gate will also be studied in the future.

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