Analysis of Polarization Charge on III-V Compound Materials for HEMT Devices

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Abstract

The paper presents the polarization charge analysis on III-V compound materials for HEMT Devices. The mathematical model for polarization charge analysis is derived from the experimental outcomes from the laboratory. The electron density in the channel of HEMT devices and the current versus polarization charges are demonstrated based on the numerical analysis. According to the numerical results, the results could be proved to fabricate the real devices in practical applications. The numerical analyses could be carried out by using MATLAB language.

Keywords: Polarization Charge Analysis, III-V Compounds, HEMT Devices, Numerical Analysis, MATLAB Code

Introduction

While the most widespread application of III-V compound-based devices is in the fabrication of microwave power devices has attracted much attention because of large potential markets. The world market for transistors is divided between bipolar and field effect transistors, depending on application. For III-V compound-based devices applications there has been research into both Heterojunction Bipolar Transistors (HBTs) and High Electron Mobility Transistors (HEMTs). State-of-the-art III-V compound-based HBTs generally still offer poor performance and typically has current gains of ~10. One researcher has achieved promising results with III-V compound-based Double Heterojunction Bipolar Transistors (DHBT) having current gains greater than 2000 and breakdown voltages above 50V. However, the progress made in HBTs has been very slow owing mostly to the poor acceptor activation in the base layer. As a result, most research has focused on field effect transistors with both Metal Semiconductor Field Effect Transistors (MESFETs) and HEMTs receiving considerable attention [1-5].

The HEMT is a heterojunction device with superior performance to its homojunction counterpart, the MESFET. The principle of operation in a HEMT is very similar to Metal Insulator Semiconductor Field Effect Transistor (MISFET). However, instead of carrying current in a thick channel, a HEMT relies on the formation of a two dimensional electron gas at the heterojunction interface [6-9].

Model

A typical cross-sectional schematic of AlGaN/GaN HEMT device is shown in Figure 1. The device is usually grown on a semi-insulating substrate which has a high thermal stability and close lattice matching with GaN. A buffer layer is grown on top of the substrate to act as an isolation layer between the substrate and channel. Any lattice mismatching or

crystal defects from the substrate are minimized using this GaN buffer layer. The device usually uses a schottky gate contact and ohmic source and drain contact. The channel in a HEMT is formed at the heterojunction interface of the AlGaN barrier and GaN channel layer. The following section describes more about the operation of HEMT.

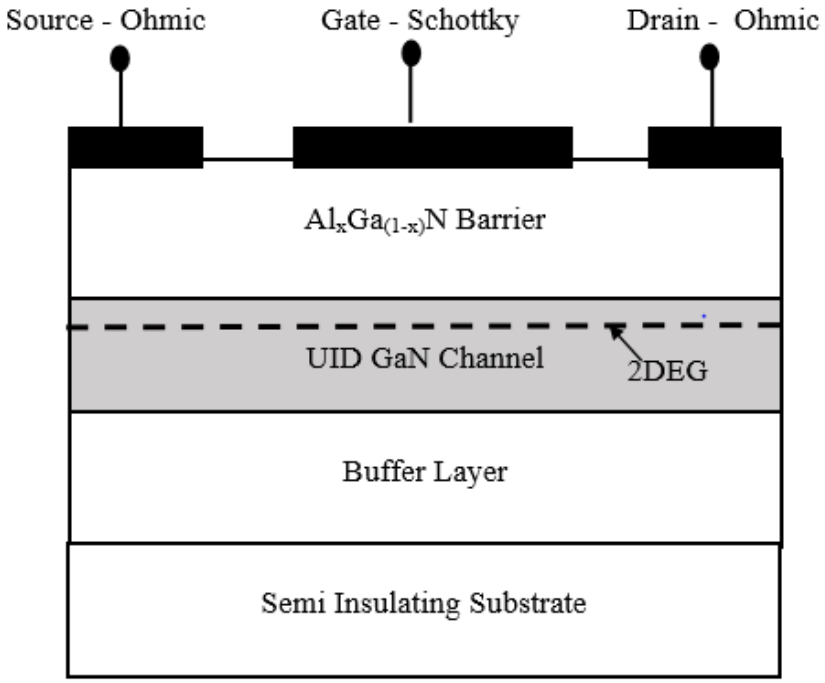

Figure.1. Layer structure of a typical $Al_xGa_{(1-x)}N$/GaN HEMT

In the most common HEMT structures, the wide bandgap barrier is doped n-type while the narrow bandgap channel remains undoped. As a result, electrons diffuse from the wide bandgap material into the narrow bandgap material to minimize their energy. This process continues until a balanced Fermi level is formed in the two materials and equilibrium is established. Because of the resulting electrostatics, a new triangular well forms on the narrow bandgap side of the heterojunction. Which we call it as two dimensional quantum well and the electrons confined inside the well is called Two Dimensional Electron Gas (2DEG).

The n-doped barrier in the device supplies electrons to the undoped channel, thus spatially separating the channel charge carriers from their ionized donors. In this manner, the heterostructure channel is capable of delivering high carrier concentration with high mobility as impurity scattering is minimized in the undoped channel. As an added advantage, surface scattering is also reduced by moving the current-carrying region below the barrier. To understand the principle of operation and techniques, the formation of 2DEG and different effects involved in the HEMT are explained in the following sections.

Method

The formula for the polarization charge is applicable to calculation. However, for current, the polarization charges have to be calculated it by another method.

$$eN_I(x)=C\left(V_{GS}-V_{FB}-\phi_s(x)\right)-\sqrt{2\varepsilon eN_A\phi_s(x)}$$

where N_I,C,V_{GS},V_{FB},$\Phi_s(x)$,ε, N_A are electron density in the channel, capacitance at the gate/channel/p-layer structure, gate-source voltage, flat band potential, conduction band minimum at the interface between the gate semi-insulator (AlInN) and p-GaN, electric permittivity and acceptor density of the p-GaN.

However, for the precise N_I (x), the Schrödinger-Poisson equation is better, as explained in the literature. The assumption of the account of two quantum levels may be appropriate. The first assumption is recommended to try for analysis. The current in the channel is expressed using $\varphi_s(x)$.

$$I=eN_I(x)\mu_n \frac{d\phi_s(x)}{dx}$$

Where μ_n is electron mobility.

Since the current is constant in the whole channel region, the integral of the above equation is J_L, where L is the channel length. Thus, the current J can be obtained.

This method is recommended in this case. $\varphi_s(x)$ is calculated by taking into account the polarization electric field, which varies place by place, since the InN mole fraction in AlInN varies spatially. Here it is recommended that the barrier layer into a certain number of region corresponding to grains with various InN mole fraction could be divided. This model allows obtaining polarization filed depending on the x direction along the channel. This distribution of $\varphi_s(x)$and resultant N_I (x) give us the current J.

The investigation of the V_{DS}-J characteristic and its dependence on V_G could be found. Particularly, the pinch off voltage is an important character. The comparison of the VDS-J characteristic curve by varying the grain size and fluctuation degree of the InN mole fraction has been analyzed.

Results and Discussions

Figure 1 shows the electron density in the channel of HEMT devices. In this result, the electron density in the channel of HEMT device increases according to the changes of the V_{GS} from -2V to 2V. The range of changes is started from -0.04 to 0.03 in reality for the electron density with respect to V_{GS}.

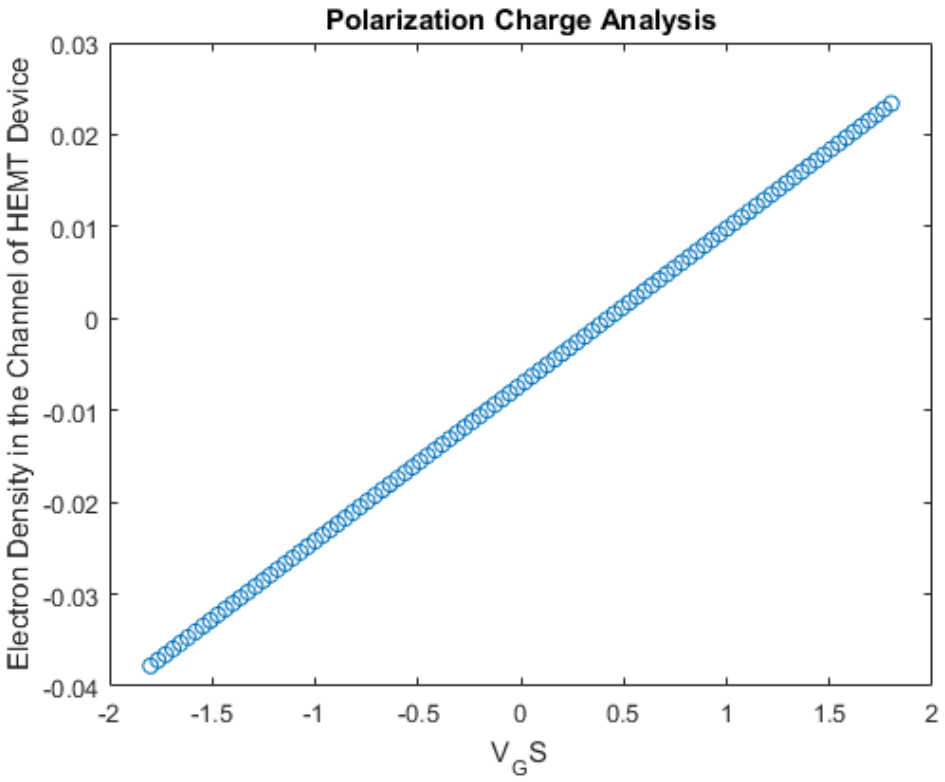

Figure.1. Electron Density in the Channel of HEMT Devices

Figure 2 illustrates the current versus polarization charges. The current changes could be found between the polarization charges of 0.01 to 0.02, 0.03 to 0.04, 0.05 to 0.06, 0.06 to 0.07 and 0.08 to 0.09 respectively. According to this response, the values of currents increases with the increase values of Polarization Charges from 0.01 to 0.09.

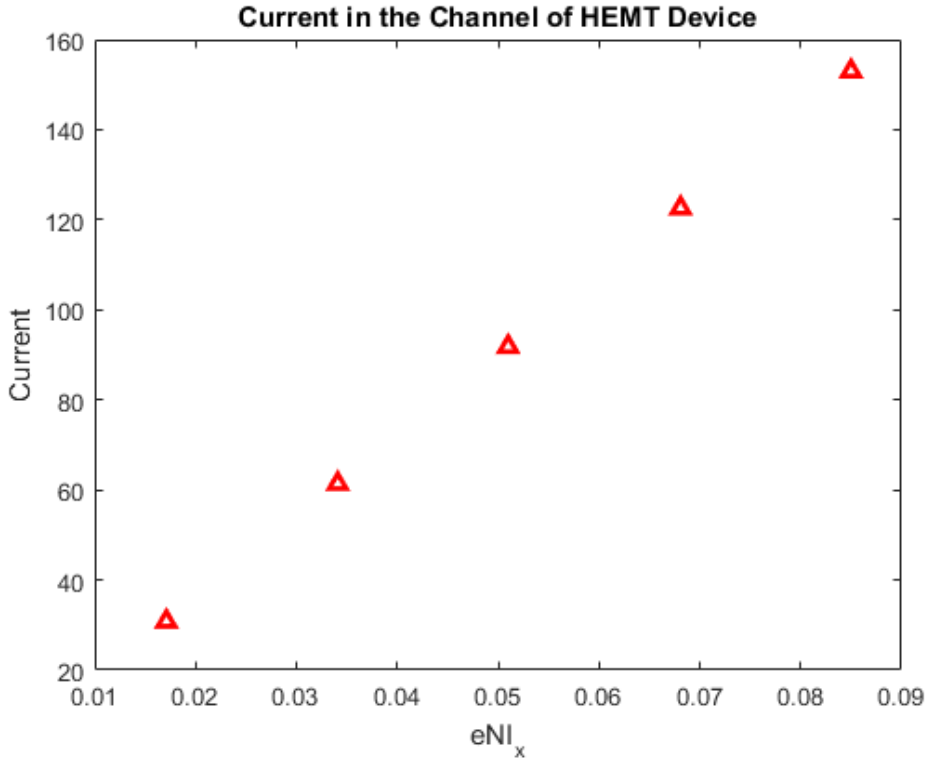

Figure.2. Current versus Polarization Charges

Conclusion

The electron density in the channel of HEMT devices and the current versus polarization charges were confirmed based on the experimental outcomes from the laboratory. In the previous part of the research work, the background theory of physical model of HEMT has been mentioned and the theoretical evaluation has been made. And then the numerical analyses have been proved to fabricate the real devices based on the confirmation results from the theoretical analysis. The present work can be extended by incorporating a spacer layer which would improve the device characteristics significantly.

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