Atlas Simulation of GaN-Based Super Heterojunction Field Effect Transistors Using the Polarization Junction Concept

Introduction

Wide-bandgap semiconductors such as SiC and GaN have attracted much attention because they are expected to break through the material limits of silicon. In particular, AlGaN/GaN HEMTs are generally promising candidates for switching power transistors due to their high electric field strength and the high current density in the transistor channel giving a low on-state resistance.

Field plate (FP) technologies are generally used in order to manage surface electric field distribution of GaN HEMTs. Recently, GaN Super Heterojunction Field Effect Transistors (Super HFETs) based on the polarization junction (PJ) concept have been demonstrated [1, 2]. This concept is based on the compensation of positive and negative polarization charges at heterointerfaces such as AlGaN/GaN to achieve similar effect to RESURF or Super Junction (SJ) in silicon devices.

In this article, we will demonstrate the Atlas device simulation of GaN Super HFETs in comparison with the experimental data based on [1, 2]. Convergence difficulties in this simulation generally arise from the formation of large polarization charges and the use of abrupt heterojunctions with a Schottky gate, as well as the existence of a p-GaN base region and a floating undoped-GaN region. Atlas's sophisticated physical models properly account for all physical mechanisms inherent in a GaN Super HFET structure, thereby ensuring well-converged solutions with consistent simulation results.

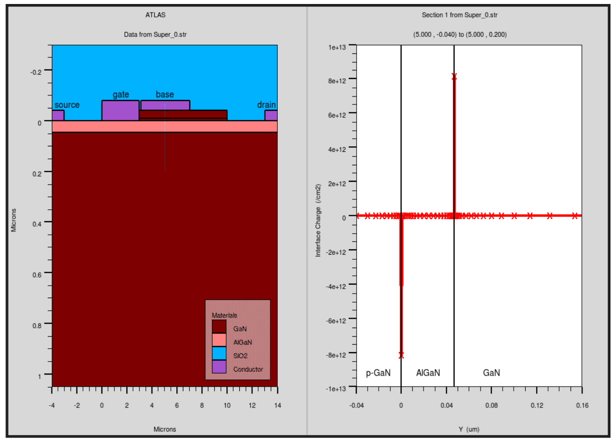

Figure 1. Cross sectional diagram of a GaN Super HFET (left) and interface charge density under the base electrode (right).

Device Structure and Physical Models

The Super HFET structure created by Atlas syntax is shown in Figure 1. The layer structure consists of an undoped double-hetero GaN/AlGaN/GaN structure with a p-GaN cap layer. The feature of the Super HFET structure is the presence of the 2-D hole gas (2DHG) induced by negative polarization charge at the upper GaN/AlGaN heterointerface as well as the 2-D electron gas (2DEG) at the lower AlGaN/GaN heterointerface. The computation of 2DEG and 2DHG due to polarization effect was performed automatically during the simulation with our built-in model [3]. The Super HFET has four electrodes: source, gate, base, and drain. The source and drain electrodes form ohmic contacts to the 2DEG by setting their work function identical to the electron affinity of the AlGaN layer. The gate forms a Schottky contact to the AlGaN layer. The base electrode makes an ohmic contact to the 2DHG through the top p-GaN layer and is electrically connected to the gate by specifying COMMON parameter on the CONTACT statement.

Atlas uses specific physical models and material parameters to take into account the mole fraction and doping of the AlGaN/GaN system [3]. We chose to model low field mobility using the ALBRCT model allowing the separate control of electrons and holes. We selected a nitride-specific high field mobility model by specifying GANSAT.N on the MODEL statement. In order to take into account the relatively deep ionization levels for acceptors in p-type GaN, we set the INCOMPLETE parameter on the MODEL statement [4]. In the simulation of high current operation, self heating effect may be important. We set the LAT.TEMP parameter on the MODEL statement to enable the heat flow simulation by the GIGA module. As for the breakdown simulation, an impact ionization model should be taken into account. We can use the tabular Selberherr model with the build-in parameters for GaN.

Performance of GaN device and convergence of its simulation can be significantly influenced by the presence of defects. We introduced bulk and interface traps by setting DOPING and INTTRAP statements in this Super HFET simulation. Threshold voltage and substrate leakage current are controlled by a concentration of acceptor and donor traps in the GaN buffer layer, respectively. Moreover, we put the interface traps to represent Fermi level pinning at the bottom of the GaN buffer. This assumption is properly valid because an actual GaN epitaxial layer has quite many defects around the interface with the substrate. It should be noticed that these traps play an important role in the convergence of the device simulation including a floating undoped-GaN buffer region.

Simulation Results and Discussions

Figure 2 shows the band diagram and the vertical carrier profile under base electrode calculated at zero bias condition. As reported in [2], the accumulation of 2DEG and 2DHG has been verified at the lower and upper heterointerfaces, respectively.

The simulation results of the Id-Vg and Id-Vd characteristics are shown in Figure 3 and Figure 4, respectively. Very good agreement between simulations and experiments were obtained by setting some parameters properly. For example, the donor trap density in the GaN buffer determines the substrate leakage current and the acceptor trap density in GaN buffer affects the threshold voltage and the maximum drain current. The ALPHA parameter on the THERMCONTACT statement has an impact on the negative differential resistance at high current operation as well as the maximum drain current.

Figure 5 shows the breakdown characteristics and the impact generation rate distribution calculated by using slow transient simulation [3]. An increase of the gate current (including the base current) is observed near breakdown and the value is of the same order as the drain current. In addition, it should be noticed that impact ionization occurs near the drain-side edge of p-GaN region. These results indicate that breakdown voltage is dominated by the hole current into the base electrode through the p-GaN layer.

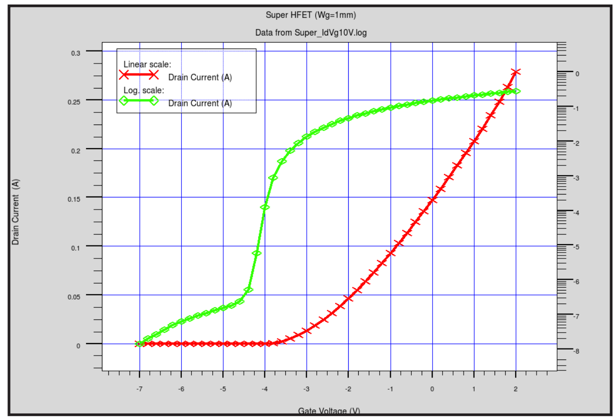

Figure 3. Simulated Id-Vg characteristics of the GaN Super HFET.

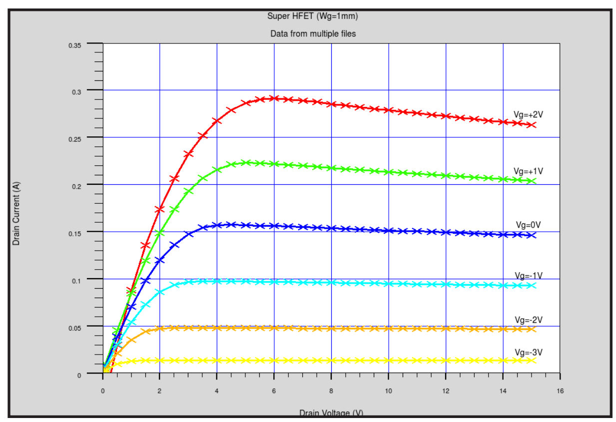

Figure 4. Simulated Id-Vd characteristics of the GaN Super HFET.

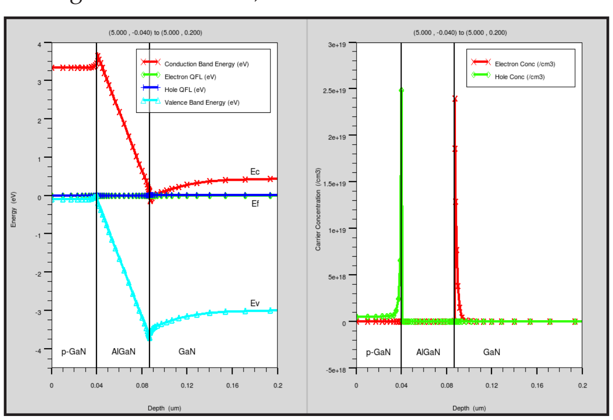

Figure 2. Band diagram (left) and vertical carrier profile (right) under the base electrode.

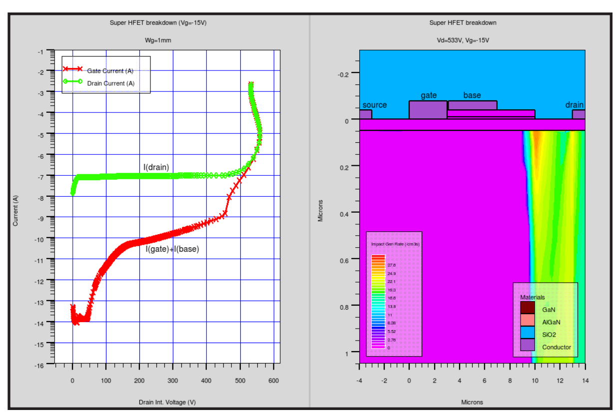

Figure 5. Breakdown characteristics (left) and impact generation rate distribution in the GaN Super HFET (right).

Conclusion

We have successfully demonstrated Atlas device simulation of a GaN-based Super HFET using the polarization junction concept. This device has many factors of convergence difficulty such as large polarization charges and abrupt heterojunctions as well as the existence of a p-GaN base region and a floating undoped-GaN buffer region. Owing to its sophisticated physical models, Atlas has proved to be capable of ensuring well-converged solutions with the device characteristics consistent with reference [1]. It allows users to speed up the product design process and shorten the development period.

References

[1] A. Nakajima, Y. Sumida, M. H. Dhyani, H. Kawai, and E. M. S. Narayanan, “GaN-based super heterojunction field effect transistors using the polarization junction concept,” IEEE Electron Device Lett., vol. 32, no. 4, p.p. 542-544, Apr. 2011.

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[3] “State of the art 2D and 3D process and device simulation of GaN-based devices,” Simulation Standard, July, August, September 2013.

[4] *Atlas User’s Manual.*