Modeling of Electron Transport in GaN-Based Materials and Devices

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Abstract. Material models which incorporate the basic characteristics of the underlying physics in a given semiconductor material are the core of device modeling. We employ a Monte Carlo (MC) technique to investigate stationary electron transport in GaN and AlGaN [1]. We obtain a set of model parameters which gives agreement with experimental data available for different physical conditions (doping, temperature, electric field, etc.). Such a calibrated set of models and model parameters delivers valuable data for low-field mobility, velocity saturation, energy relaxation times, etc. We use these data as a basis for the development of analytical models for the numerical simulation of GaN-based electron devices. As a particular example we analyze an AlGaN/GaN HEMT with l_g=300 nm from IAF using the two-dimensional device simulator Minimos-NT [2]. We study the impact of different models and efects (polarization charge, thermionic field emission, self-heating effects).

Keywords: Modeling, GaN, HEMT
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INTRODUCTION

AlGaN/GaN based high electron mobility transistors (HEMTs) have been subject of extensive investigations in the last years. Their performance makes them suitable for power amplifiers in infrastructure base station applications. In order to fully develop the potential of the device, an accurate simulation model is needed.

SIMULATION RESULTS

We employ a single-particle MC technique to investigate stationary electron transport in GaN. Our model includes the three lowest valleys of the conduction band. Several stochastic mechanisms such as acoustic phonon, polar optical phonon, inter-valley phonon, ionized impurity scattering, and piezoelectric scattering are considered [1]. Fig. 1 compares experimental [3, 4, 5, 6, 7] and MC simulation data for the low-field electron mobility in GaN as a function of the free carrier concentration. The figure also includes an analytical model fitted to our MC simulation results. This model is incorporated in the two-dimensional device simulator MINIMOS-NT [2]. For device simulation, we consider electron energy relaxation times which depend on electron energy and lattice temperature. Fig. 2 compares our analytical model to MC simulation data for GaN.

Fig. 3 gives an example of a typical fully planar GaN/AlGaN structure. All layers are non-intentionally doped except the δ-doping which is introduced to provide additional carriers.

The crucial factor building the channel in HEMTs is the polarization charges at the AlGaN/GaN heterointerfaces. The positive charge at the channel/spacer interface is compensated by a negative surface charge at the barrier/cap interface. An optimum value of 1.1×10^{13} cm^{-2} is found. As can be seen in Fig. 4 (the electron concentration for V_{DS}=7 V, V_{GS}=0 V is shown) the device is a normally on transistor. Another unknown is penetration depth of the drain/source metal contacts which may build an alloy with the AlGaN supply layer. We assume a metal diffusion to the δ-doping in our simulations.

We further assess the impact of thermionic emission and field emission (tunneling) effects which critically determine the current transport across the heterojunctions. An optimal tunnel length of 7.5 nm is found.

Since the longitudinal electric field in the channel reaches peak values of above 500 kV/cm, a hydrodynamic approach is used to properly model the electron transport and energy relaxation. We further account for self-heating (SH) effects using a global temperature model. Fig. 5 shows simulated and measured data for the transfer curves. Fig. 6 compares measured and simulated output characteristics.

CONCLUSION

We incorporate a new material model in our two-dimensional device simulator. Our results allow not only to get a good agreement between simulation and measured electrical data of AlGaN/GaN HEMTs, but to gain understanding and insight in the effects taking place in the devices.

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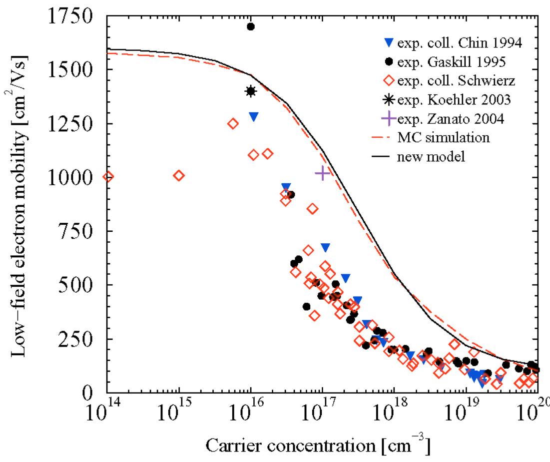

FIGURE 1. Mobility vs. concentration (Monte Carlo results and models used in the device simulator

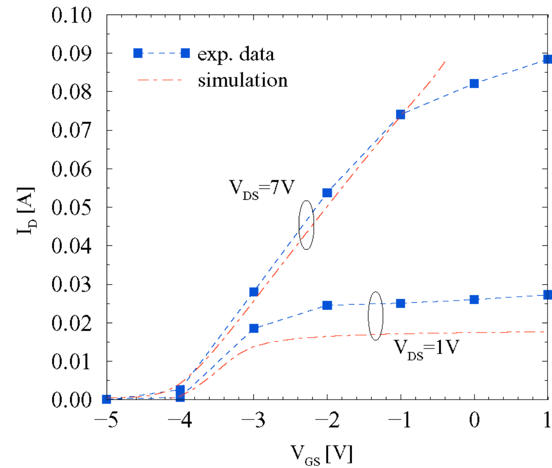

FIGURE 5. Transfer characteristics

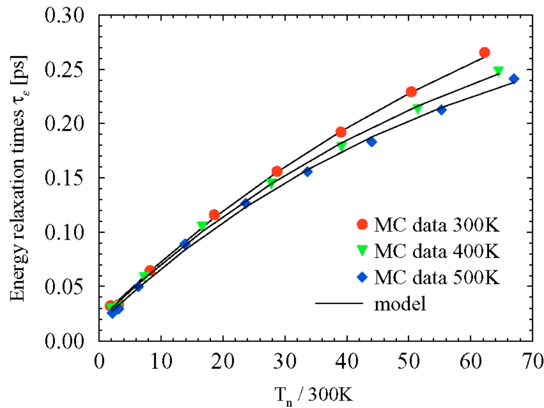

FIGURE 2. Electron energy relaxation times as a function of electron temperature for different lattice temperatures

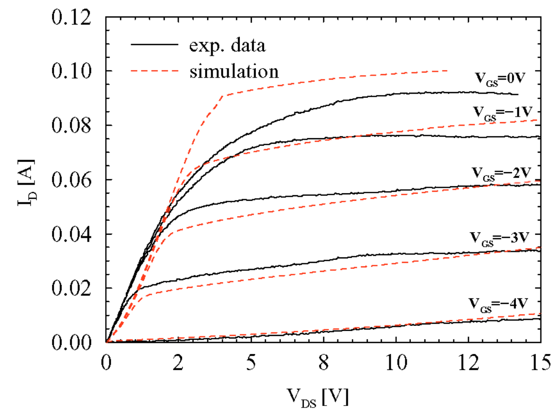

FIGURE 6. Output characteristics

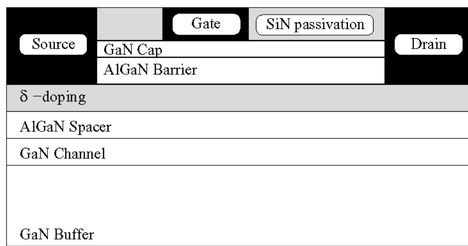

FIGURE 3. Layer structure of high electron mobility transistors considered in this work

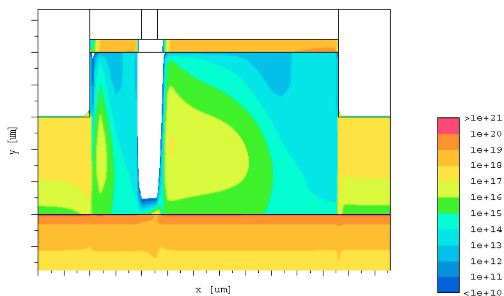

FIGURE 4. Electron concentration [cm^{-3}] in the device

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