SIMULATION OF ALGAN/GAN HEMTS WITH INGAN CAP LAYER

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AlGaN/GaN high electron mobility transistors (HEMTs) are favored for the use in high-power and high-frequency applications. Normally-off operation has been desired for various applications, but proved to be difficult to achieve. Recently, a new approach was proposed: a thin InGaN cap layer introduces a polarization field, which raises the conduction band of the AlGaN/GaN interface. As a result, the threshold voltage is shifted in positive direction. We present a simulation study of these novel devices: some device specific effects are explored and the AC characteristics are analyzed.

Keywords: device simulation, InGaN, E-mode high-electron mobility transistors

1. INTRODUCTION

As AlGaN/GaN depletion mode (D-mode) HEMT technology has been significantly improved in the recent years, no comparable progress of the enhancement counterparts (E-mode) could be noted. However, the latter exhibit features, which give them advantages over traditional D-mode HEMTs in some applications. In low-power digital circuitry they allow HEMT-based direct-coupled FET logic. In analog circuits they offer reduced complexity due to the elimination of the negative voltage supply and fail-safe power-switching. Several groups have proposed different approaches to the design of E-mode HEMTs in the past years. While some of those methods deliver excellent results, stability concerns remain. The most recent approach (proposed by Mizutani *et al.*) adopts a thin InGaN cap layer, which raises the conduction band, thereby achieving a normally-off operation [1].

2. DEVICE STRUCTURE

The investigated InGaN/AlGaN/GaN device structure as described in [1] is shown in Fig. 1. A 3 µm thick GaN layer is grown on a sapphire substrate. A 20 nm thick $Al_{0.25}Ga_{0.75}N$ layer is deposited next: the first 5 nm undoped, 10 nm highly-doped $2\times10^{18}cm^{-3}$ supply layer, and 5 nm undoped material. On-top a 5 nm thick $In_{0.2}Ga_{0.8}N$ layer is deposited. All layers are non-intentionally doped, except the supply layer. The gate length l_g=1.9 µm, source-gate distance is 1.5 µm, and gate-drain distance is 2.4 µm. We study three different HEMT structures: the proposed novel normally-off device (Fig. 1), a device with the InGaN layer removed in the access regions (only the InGaN film under the gate is left), and a conventional normally-on device (as in Fig. 1, but without the InGaN layer). We assume a diffusion of the metal source and drain contacts reaching the highly-doped layer.

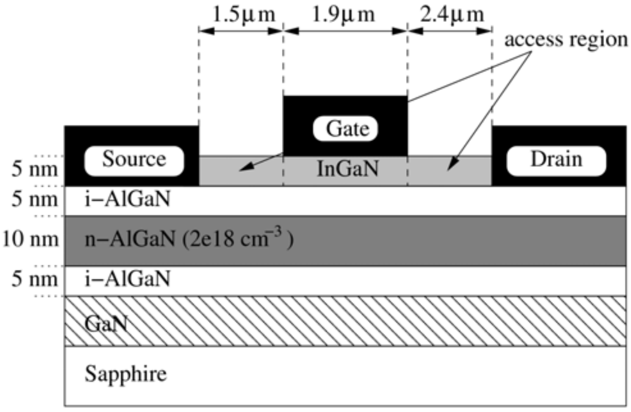

Figure 1. Schematic layer structure of the three HEMTs under investigation.

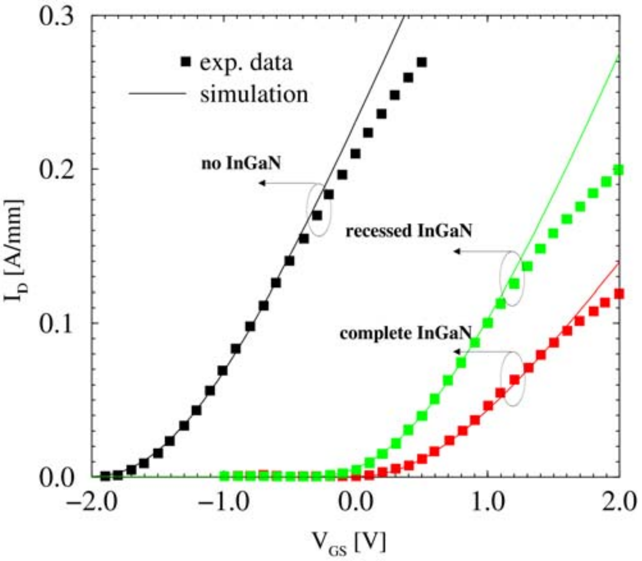

Figure 2. Comparison of simulated and measured transfer characteristics for the three devices.

3. PHYSICAL AND MATERIAL MODELS

Our two-dimensional device simulator Minimos-NT [2] has proven to be a suitable tool for the analysis of heterostructure devices [3]. Recently, it has been used for the study of a whole generation of AlGaN/GaN-based HEMTs [4]. Since the longitudinal electric field in the channel reaches peak values of above 500 kV/cm, the hydrodynamic transport model is used to properly model electron transport and energy relaxation. Self-heating effects are accounted for by using a global self-heating model, which calculates a spatially constant lattice temperature. This model has been chosen for the reasonable computational effort and convergence behavior. We further assess the impact of thermionic emission and field emission (tunneling) effects which determine the current transport across the heterojunctions. The energy barrier reduction is modeled based on the electric field perpendicular to the interface and the effective tunneling length [5]. The material models employed for GaN and InN are described in [6].

4. SIMULATION RESULTS

The simulation results for the transfer characteristics of the three devices are compared to the measurements of Mizutani *et al*. in Fig. 2 for V_{DS}=5 V. Good overall agreement is achieved. All simulations were conducted using the same parameter setup, except for the work-function energy difference of the gate Schottky contact (depending on the underlying material). The values for the interface charge density are assumed as follows: 1×10^{13} at the GaN channel / AlGaN interface, -6×10^{12}

between the AlGaN layer and the passivation (in the case of D-mode and recessed E-mode), -2.2×10^{13} between the InGaN cap layer and the AlGaN supply layer (both E-mode devices), and 1.4×10^{13} between the InGaN cap layer and the passivation (E-mode non-recessed).

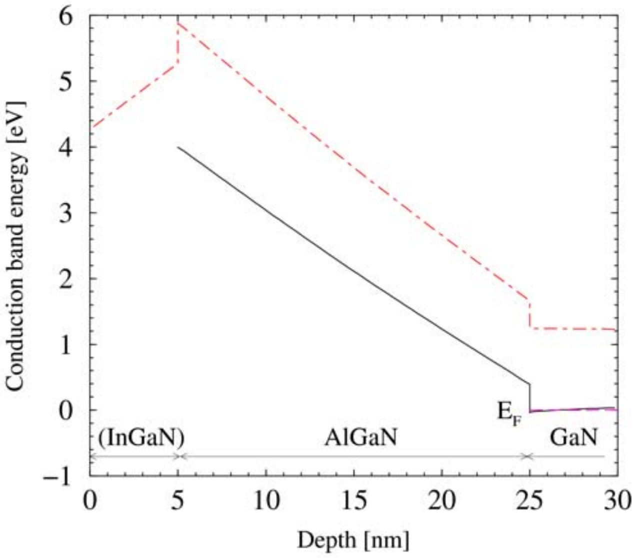

Figure 3. Energy band diagrams of a HEMT with (dot-dashed line) and without (solid line) InGaN layer.

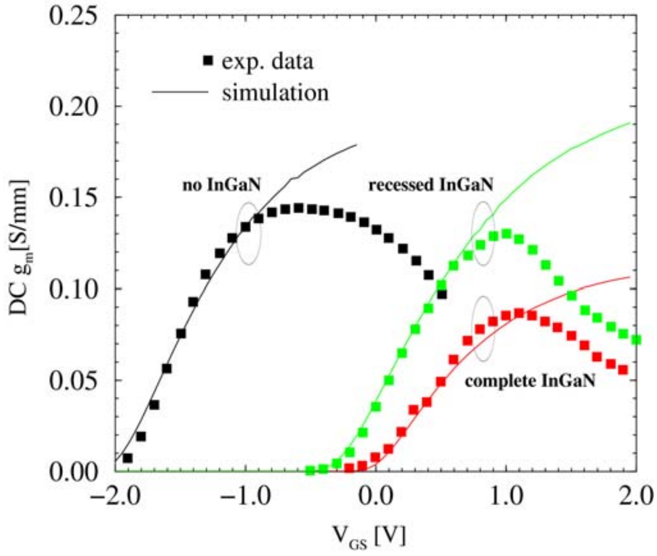

Figure 4. Simulated transconductance DC g_m for the three devices.

Fig. 3 shows the effective conduction band energies of D-mode and E-mode HEMTs at V_{GS}=0 V, V_{DS}=5 V in a vertical cut under the gate metal, as computed by the simulator. The band diagrams are shifted, so that both Fermi levels are at 0 eV. Indeed, as suggested by Mizutani *et al.*, a two-dimensional electron gas channel is presented in the D-mode device, while the negative piezoelectric charge at the InGaN/AlGaN interface raises the conduction band in the E-mode structure. Thus, the channel is depleted even at V_{GS}=0 V, and the threshold voltage increases to positive values. Fig. 4 compares the simulated DC g_m for the three structures. The drop in the measured g_m at higher gate bias, might be due to non-idealities in the source and drain Ohmic contacts, which are not considered in our simulation. A relatively good agreement between the simulated and measured output characteristics for a device with InGaN layer is achieved (Fig. 5).

Small signal AC analysis using the calibrated setup delivers cut-off frequencies of f_T=7 GHz for the device featuring a complete InGaN layer, and f_T=10 GHz for the recessed structure, respectively (Fig. 6). Our simulations suggest, that reasonably higher values can be achieved by shorter gate lengths: e.g. peak f_T=30 GHz for l_g=0.8 µm.

5. CONCLUSION

A simulation study of HEMTs featuring InGaN cap layer is presented. All relevant physical mechanisms are accounted for. By using a calibrated parameter setup, a good agreement with experimental DC data is achieved. Theoretical expectations for the AC performance are presented.

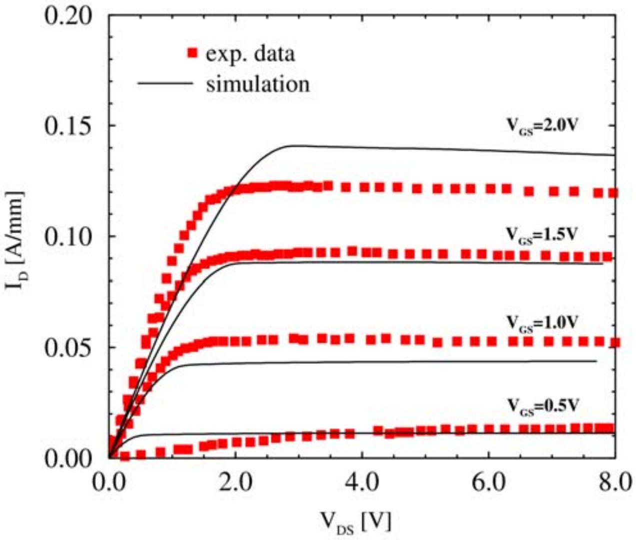

Figure 5. Output characteristics of a HEMT with non-recessed InGaN cap layer.

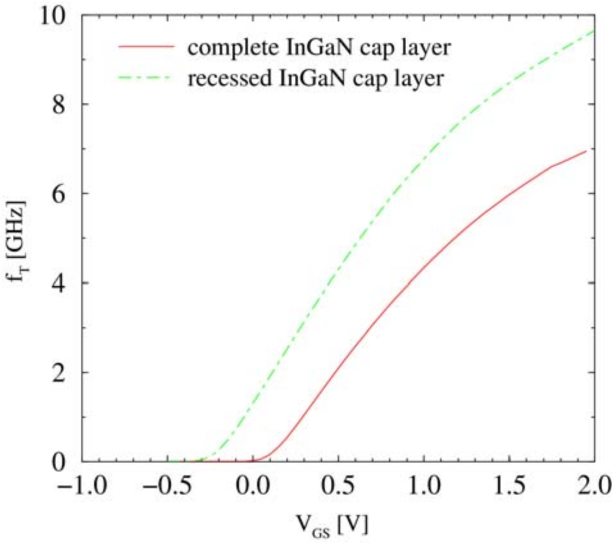

Figure 6. Simulated f_T for devices with complete and recessed InGaN cap layer.

6. ACKNOWLEDGMENT

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7. REFERENCES

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