Student paper

Normally-Off AlGaN/GaN HEMTs with InGaN Cap Layer: A Theoretical Study

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AlGaN/GaN high electron mobility transistors (HEMTs) are favored for the use in high-power and high-frequency applications. However, in order to successfully apply them in circuit design normally-off HEMTs are needed. Conventional normally-off HEMTs [1] are plagued by several production and performance issues. Recently, a new approach was proposed by Mizutani *et al.* [2]: a thin InGaN cap layer introduces a polarization field, which raises the conduction band of the AlGaN/GaN interface. As a result a threshold voltage shift to the positive direction is observed. Relying on the experimental work of Mizutani *et al.* we conduct a theoretical study of the proposed devices. We calibrate our simulation tool against the measured DC characteristics. Using this setup, we can further explore the device specific effects and conduct a predictive analysis of the AC characteristics. The presented methodology is a valuable tool for the design and optimization of novel devices.

We employ the two-dimensional device simulator MINIMOS-NT [3], which has proven to be a suitable tool for the analysis of HEMTs [4]. Since the longitudinal electric field in the channel reaches high peak values, a hydrodynamic approach is required to properly model electron transport and energy relaxation. The low-field mobility used in the software tool is fitted to own Monte Carlo (MC) simulation results. The high-field mobility model includes energy-dependent electron relaxation times. A modified hydrodynamic mobility model [5], which accounts for specific effects of GaN-based materials is used. It is calibrated to give the best agreement with the velocity-field characteristics provided by the MC simulations. In the case of InN our approach assumes a bandgap of 0.9 eV and proper electron masses in agreement with recent studies. We further assess the impact of thermionic emission and field emission (tunneling) effects which critically determine the current transport across the heterojunctions. Self-heating effects are accounted for by using a properly adapted ambient temperature.

The investigated $In_{0.2}Ga_{0.8}N/Al_{0.25}Ga_{0.75}N/GaN$ device structure as described in [2] is shown in Fig. 1. We study three HEMTs: 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). 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. An overall good agreement is achieved. All simulations were conducted using the same parameter setup, except for the workfunction energy difference of the gate Schottky contact (depending on the underlying material) and the value of the charge density at the InGaN/AlGaN interface. The measurements exhibit a small threshold voltage shift in negative direction for recessed structures compared to full cap layer devices. This effect was reproduced in the simulation through reducing the charge density at the InGaN/AlGaN interface from $-1.2\times10^{13}\text{cm}^{-2}$ down to $-0.9\times10^{13}\text{cm}^{-2}$, which is in agreement with the proposed strain relaxation. A relatively good agreement between the simulated and measured output characteristics for a device with InGaN layer is achieved (Fig. 3). We suppose, that for an even better agreement at high V_{gs} a more sophisticated self-heating model might be required.

Theoretical results for the AC characteristics were obtained using the calibrated setups. Fig. 4 shows the cut-off frequency for the two devices featuring InGaN layers with peak values of 7 GHz and 9.5 GHz, respectively. Reasonably higher values can be achieved by shorter gatelengths (e.g. peak f_T=30 GHz for l_g=0.8 μm) and by optimization of device geometry.

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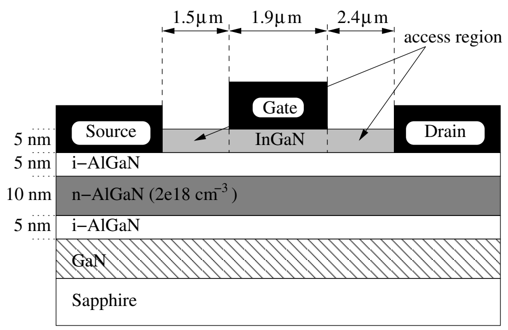

Fig. 1: Schematic layer structure of the three HEMTs under investigation.

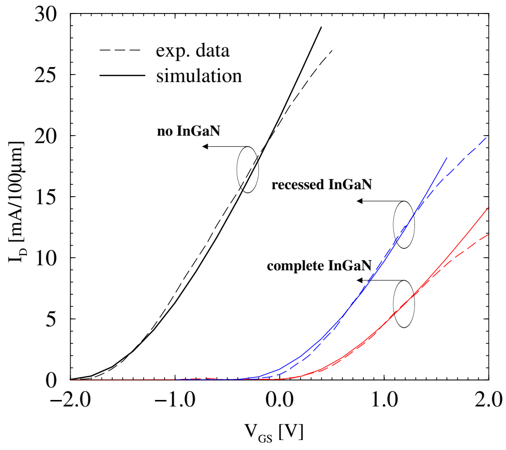

Fig. 2: Comparison of simulated and measured transfer characteristics for the three devices.

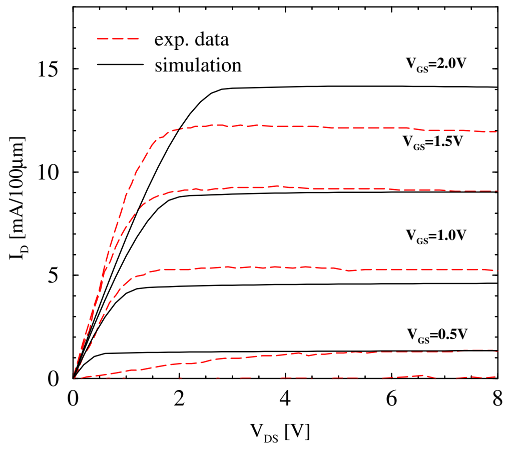

Fig. 3: Output characteristics of a HEMT with InGaN cap layer.

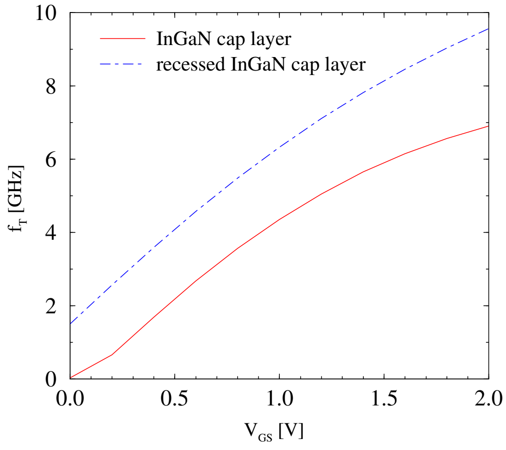

Fig. 4: Predicted cut-off frequency f_T vs. V_{gs} for InGaN/AlGaN HEMTs.

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