A Simulation Study of Enhancement-Mode AlGaN/GaN HEMTs with Recessed Gates

S. Vitanov, V. Palankovski, S. Maroldt*, and R. Quay*
Advanced Materials and Device Analysis Group,
Inst. for Microelectronics, TU Wien, Gusshausstr. 27–29, 1040 Wien, Austria
****Fraunhofer Inst. for Solid-State Physics (IAF), Tullastr. 72, 79108 Freiburg, Germany***
vitanov@iue.tuwien.ac.at

The properties of GaN and AlN and their heterostructures have encouraged the research of AlGaN/GaN based transistors for various applications in the last decade. Consequently, outstanding results have been reported for depletion-mode high electron mobility transistors (DHEMT) in recent years. However, for several applications (both analog and digital) enhancement-mode devices (EHEMT) are essential. There are few approaches for attaining normally-off characteristics. In this work, we analyze the trade-off between high frequency performance and threshold voltage achieved by gate recess technique [1]. Results from two-dimensional hydrodynamic simulations, supported by experimental data [2], are presented.

AlGaN/GaN DHEMT and EHEMT structures with T-gates of 250 nm length share the same layer specification and are processed on the same SiC wafer. The devices consist of GaN buffer, $Al_{0.22}Ga_{0.78}N$ (DHEMT) or $Al_{0.18}Ga_{0.82}N$ (EHEMT) barrier layer, GaN cap layer, and SiN passivation. The cap and part of the barrier layer under the gate of the EHEMT are recessed by Cl_2-plasma etching. A remaining AlGaN barrier thickness $t_{\mathrm{bar}} \approx 11$ nm is assumed. The Ohmic contacts are assumed to reach the 2DEG in the channel.

The devices are analyzed by means of two-dimensional hydrodynamic simulations using MINIMOS-NT, which was successfully employed for the development of new generation of AlGaN/GaN HEMTs [3], [4]. Material properties, such as band energies, carrier mobilities, and carrier energy relaxation times are properly modeled. The densities of the polarization charges at the channel/barrier interface and at the barrier/cap interface are determined by calibration against the experimental data to be 9×10^{12} cm^{-2} and -2×10^{12} cm^{-2}, respectively. Low Ohmic contact resistances of 0.2 Ωmm are considered [2]. Self-heating effects are accounted for by using substrate thermal contact resistance of $R_{\mathrm{th}}=5$ K/W. This value lumps the thermal resistance of the nucleation layer and the substrate.

The simulated transconductance compares very well to experimental data (Fig. 1). Both devices are simulated using the same set of models and model parameters, including the interface charge densities. The measured drop of g_{m} at high V_{gs} for the recessed device is due to gate leakage, which is not reproduced in the simulation. A good agreement is obtained, both for the transfer and output characteristics. The RF simulations provide slightly higher cut-off frequency f_{T} than the experiments for both structures (Fig. 2). Note, that both the measured and simulation data show an increase of f_{T} and f_{max} for the EHEMT structures.

Since the gate capacitance depends on the gate - channel distance, we perform several simulations with variable recess depths, i.e. variable barrier thickness t_{bar} under the gate. As expected a shift in the threshold voltage is observed (Fig. 3), and g_{m} increases with decreasing t_{bar} (Fig. 4) due to the lack of charge control for thicker layers. However, the simulated f_{T} characteristics show no noticeable change (Fig. 5). Fig. 6 shows that the gate-source capacitance C_{gs} increases with decreasing t_{bar}, so it compensates the increase in g_{m}, thereby resulting in a nearly constant f_{T} ($f_{\mathrm{T}} \approx g_{\mathrm{m}}/C_{\mathrm{gs}}$). Thus, the major reason for the rise of f_{T} and f_{max} of the EHEMTs in comparison to DHEMTs (Fig. 2) is the absence of barrier/cap negative interface charges under the gate. The exact depth of the recess has less influence on f_{T} and f_{max}, but has significant impact on the threshold voltage and the transconductance.

In this work we study the DC and RF performance of AlGaN/GaN HEMTs with recessed gate. Our device simulator is calibrated against measured data and used subsequently for the exploration of the impact of the gate recess depth. Our results show, that while the exact recess depth has a major impact on the threshold voltage and transconductance, the cut-off frequency of the EHEMTs remains relatively unchanged due to the increase of the gate-source capacitance.

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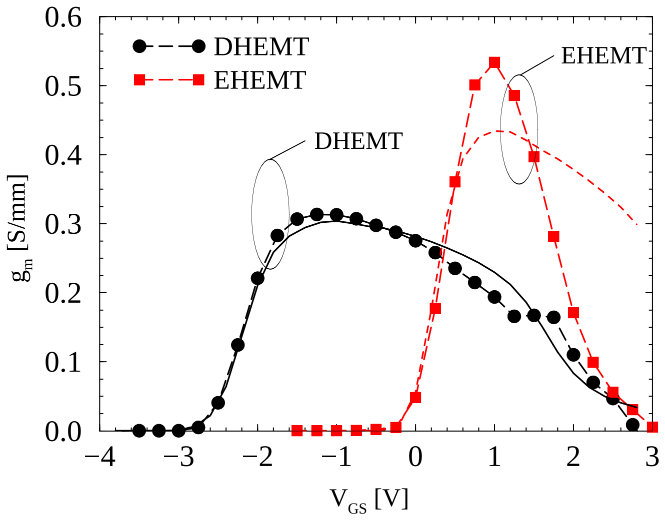

Fig. 1. Transconductance g_m at V_{ds}=7 V: lines - simulation, lines with symbols - experimental data.

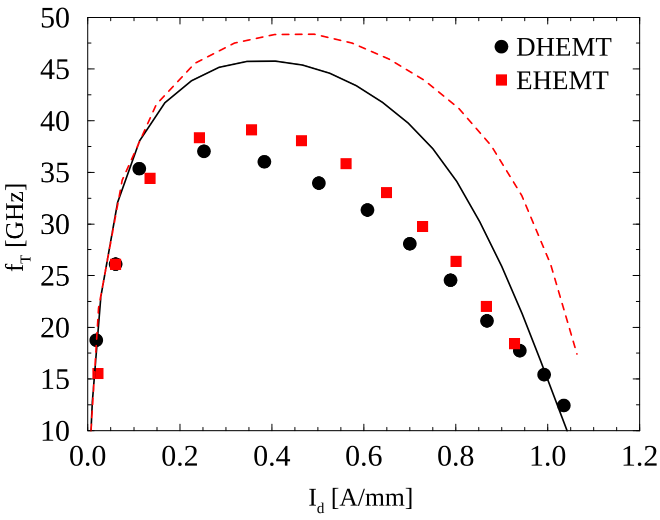

Fig. 2. Cut-off frequency f_T as a function of drain current: lines - simulation, symbols - experimental data.

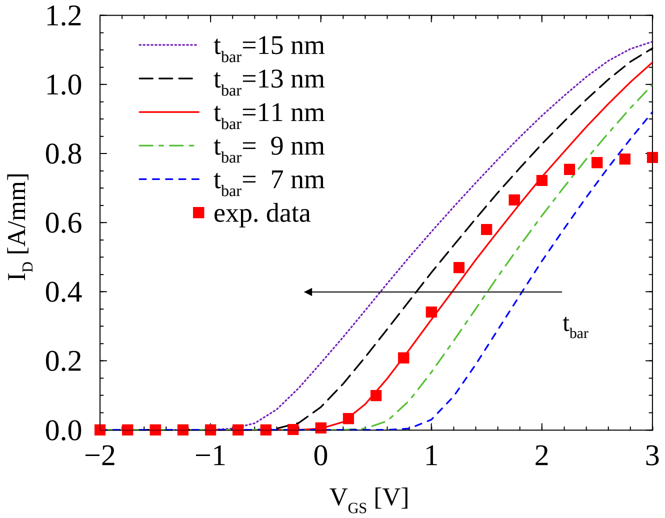

Fig. 3. Simulated transfer characteristics for EHEMTs with different barrier thickness t_{bar} under the gate.

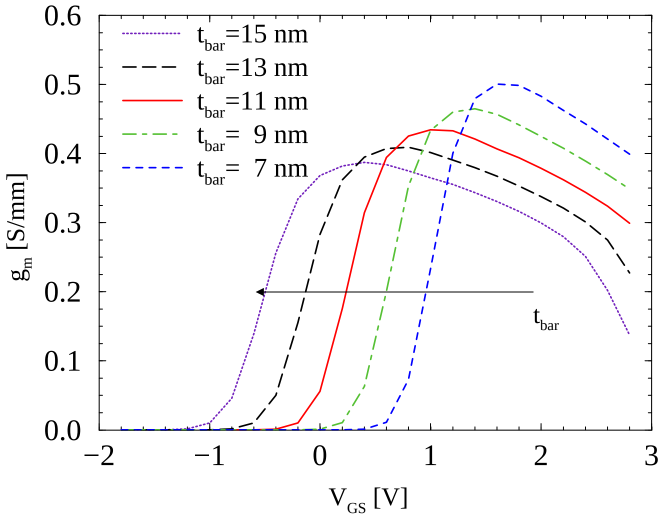

Fig. 4. Simulated transconductance g_m for EHEMTs with different barrier thickness t_{bar} under the gate.

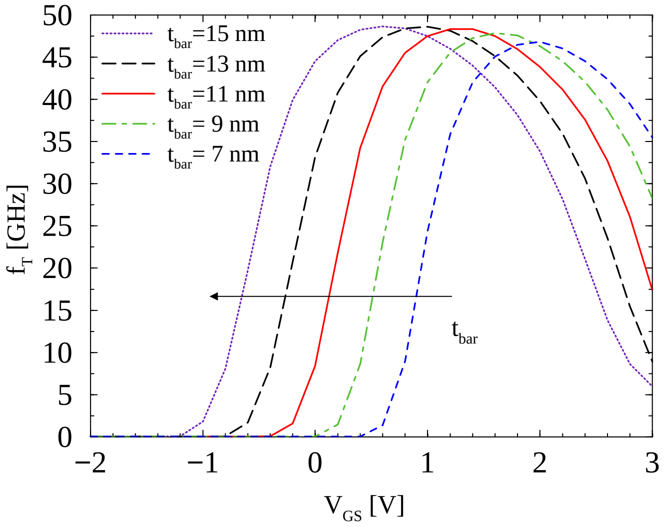

Fig. 5. Simulated cut-off frequency f_T for EHEMTs with different barrier thickness t_{bar} under the gate.

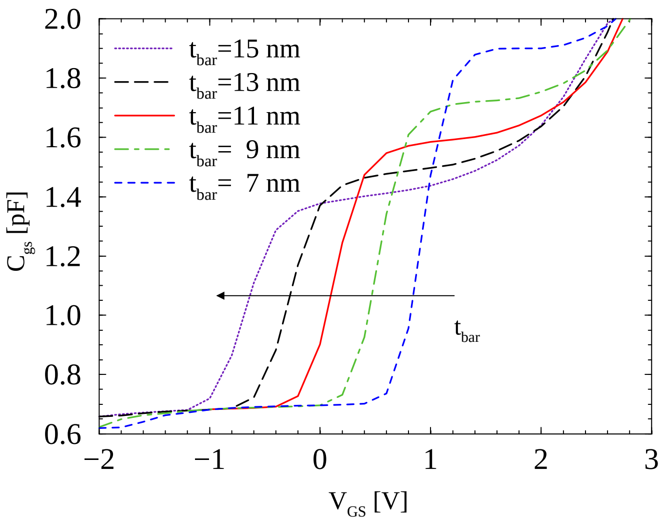

Fig. 6. Simulated gate-source capacitance C_{gs} for EHEMTs with different barrier thickness t_{bar} under the gate.