Towards a calibrated TCAD model of an AlGaN/GaN HEMT device

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Due to physical limitations of silicon-based semiconductor devices, like poor electrical stability under high temperature and electric fields, the use of III-V materials like GaN has a major focus in research [1]. An important use case of this material is the AlGaN/GaN high-electron mobility transistor (HEMT). The two-dimensional electron gas (2DEG) that forms at the hetero junction has outstanding properties for high-frequency and high-power electronics [2]. To accurately predict and understand the electrical behaviour of such devices TCAD-simulations can be employed for device-design and optimization, as well as verification of fabrication processes. We aimed to reproduce the experimental transfer and output characteristics of AlGaN/GaN-HEMTs (

Fig. **1**) by TCAD numerical simulations to identify the key factors and their sensitivity that contribute towards those characteristics.

The work was based on an example for a AlGaN/GaN HEMT provided by Sentaurus from Synopsys [3]. Most of the example's physics, including e.g. high field saturation, thermionic emission and a simplified piezoelectric polarisation model, were deemed essential for the replication of the baseline behaviour. The dimensions and doping levels of the layers, as stated by the specifications of the device, were adjusted to our device. Additionally, the documented value for the work function for Nickel-Gold Schottky contacts of around 5.1 eV was set [4].

For the threshold voltage the main contribution is the density of the 2DEG which mainly depends on the thickness and mole fraction of the AlGaN-layer. Another important factor was the Fe-doping in the buffer layer which was introduced as acceptor states 0.7 eV below conduction band [5] with a concentration of $1.2 \cdot 10^{18}$ cm^{-3}, in order to compensate the intrinsic charge carriers within the GaN-buffer that shift the threshold voltage towards higher reverse bias.

To achieve the off-current of the experimental device, which was multiple magnitudes higher than what was reached by the simulation, trap-assisted tunnelling (TAT) was implemented. As literature suggests it can be a reason for the experimentally observed leakage current [6]. For this, acceptor states at 0.5 eV below the conduction band with a density of $5 \cdot 10^{12}$ cm^{-2} were added at the GaN-cap/AlGaN-interface that facilitated a tunnelling path through the GaN-cap- and AlGaN-barrier.

The on-current is influenced by the contact resistance which was measured at 3.2 Ω·mm for the device and by the sheet resistance that was modified by setting a constant mobility within the channel region of 2200 cm$^{2}\cdot$V$^{-1}\cdot$s^{-1}. This was done to fit the simulated data to the linear slope of the output characteristic as shown in

Fig. 2 b). A discrepancy remains at higher drain voltages where the experimental data shows a more prominent degradation of the current. While a better fit can be achieved by reducing the high field saturation velocity of the electrons with the channel region from $1.8 \cdot 10^{7}$ cm·s^{-1} to $6.4 \cdot 10^{6}$ cm·s^{-1}, we assume that self-heating [7] is mostly responsible for this effect and will be investigated in the future.

With these modifications a high level of agreement between the simulated and experimental characteristics can be achieved as shown in

Fig. 2. The determined 2DEG density of $4.8 \cdot 10^{12}$ cm^{-2} and a sheet resistance of 619 Ω/sq are both within the range that was determined experimentally for our devices. Thus, the TCAD AlGaN/GaN HEMT calibration was successfully allowing to support optimization and device design at the institute.

References

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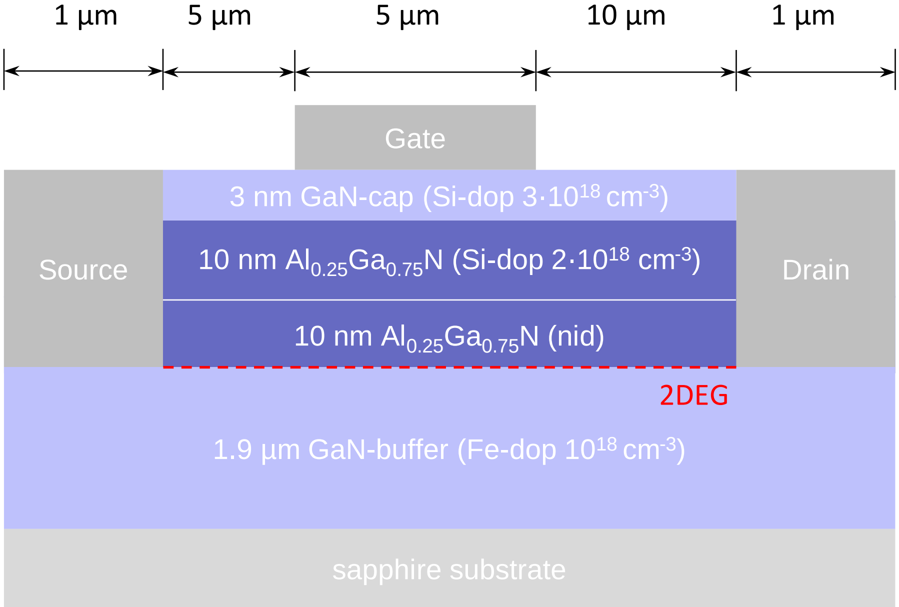

Fig. 1 Basic structure of simulated AlGaN/GaN HEMT device

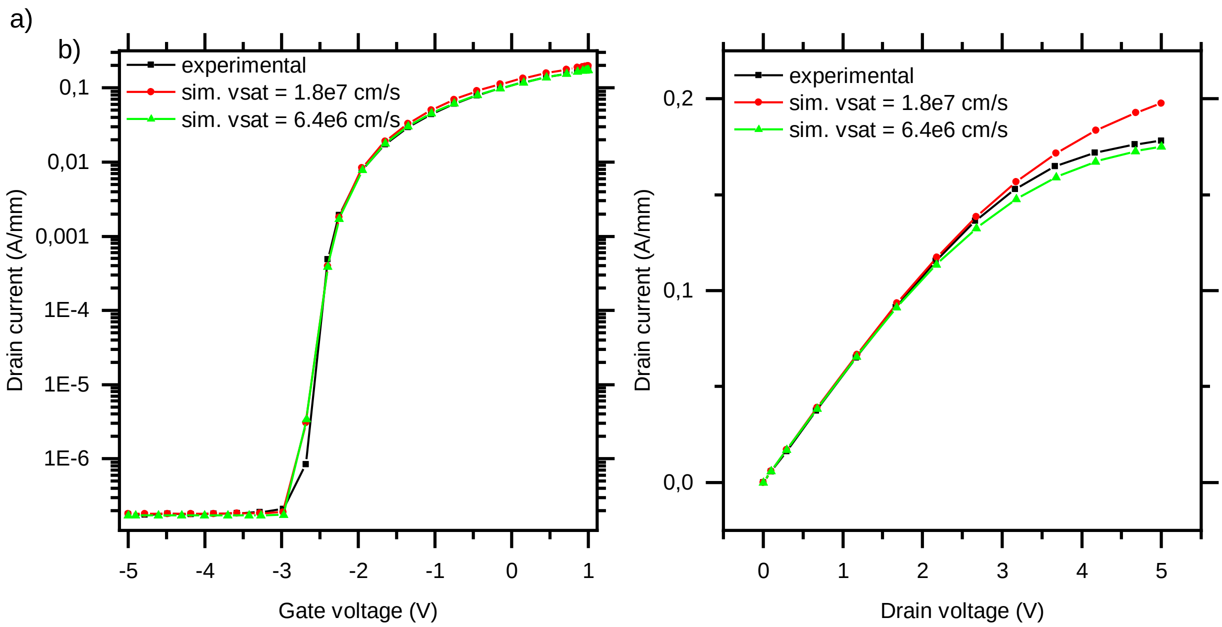

Fig. 2 a) Transfer and b) output characteristic at 5 V drain-source voltage and 1 V gate voltage respectively; compares experimental data with simulated data with red – default high field saturation velocity and blue – reduced