**Student Paper**

# High-Temperature Modeling of AlGaN/GaN HEMTs

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Wide bandgap, high saturation velocity, and high thermal stability are some of the properties of GaN, which make it an excellent material for high-power, high frequency, and high temperature applications. Given the predicted wide-spread use, reliable models are needed for simulation-based optimization. As several application areas require the devices to operate at elevated temperatures, a proper modeling of the temperature dependences of the band structure and transport parameters is highly important. We present two-dimensional hydrodynamic simulations of AlGaN/GaN high electron mobility transistors (HEMTs) supported by measured data at high temperatures.

The temperature dependence of the low-field mobility at low and high carrier concentrations is modeled by using power laws [1]. Fig. 1 shows our model for the electron mobility in GaN as a function of temperature in the two-dimensional electron gas in comparison to experimental values from various groups. The model parameters are calibrated against own Monte Carlo (MC) simulation results and consider high-quality GaN material. A decrease of the maximum mobility with temperature ($\sim T^{-1.5}$), in agreement with the power term of the acoustic phonon mobility expression [2] is assumed. Our MC simulation results and recent experiments from [3] confirmed that the latter is the dominant scattering mechanism at high temperatures. A weak temperature dependence ($\sim T^{-0.2}$) of the electron mobility at high concentrations is adopted. A two-valley hydrodynamic mobility model describes the high-field electron transport.

The model is used to simulate HEMT T-gate structures with the two-dimensional device simulator Minimos-NT [4]. Both the $l_g$=0.25 μm and $l_g$=0.5 μm devices share the same layer specification and gate width $w_g$=2x50 μm (taken as 1x100 μm in the simulation). The structures consist of GaN buffer, 22 nm thick $Al_{0.22}Ga_{0.78}N$ barrier layer, 3 nm thick GaN cap layer, and SiN passivation. The $l_g$=0.25 μm device is used for calibration. Self-heating effects are accounted for by using substrate thermal contact resistance. 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 $9.5\times10^{12}$ cm$^{-2}$ and $-2.5\times10^{12}$ cm$^{-2}$, respectively [5]. Thus, an excellent agreement is achieved both for the transfer (Fig. 2) and the output characteristics at all three ambient temperatures. As an example Fig. 3 shows the output characteristics at 425 K. Using the calibrated model set, the predicted results for the $l_g$=0.5 μm device match nicely the measured transfer characteristics at 300 K, 365 K, and 425 K (Fig. 4), and the output characteristics.

The RF device performance is studied by small-signal AC analysis. Fig. 5 shows the current gain $|h_{21}|$ for the 0.25 μm device for the three temperatures. The gain decrease with higher temperature in the simulation agrees well with the measurements, and consequently, the calculated cut-off frequency $f_t$ (Fig. 6). The slight overestimation of $f_t$ can be contributed either to the hydrodynamic model used, or to parasitics between the gate fingers of the real structure.

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## References

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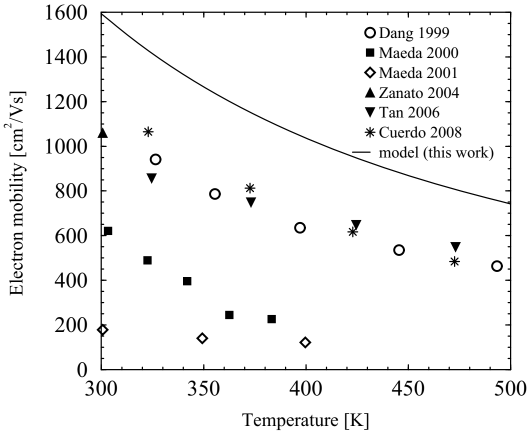

**Fig. 1** Low-field 2DEG mobility in GaN as a function of lattice temperature.

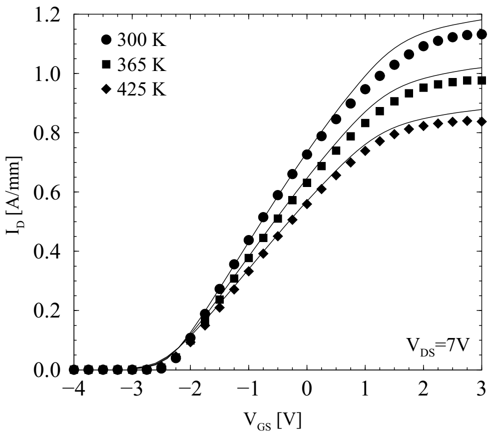

**Fig. 2** Calibrated transfer characteristics vs. exp. data (symbols) for $l_g$=0.25 µm HEMT.

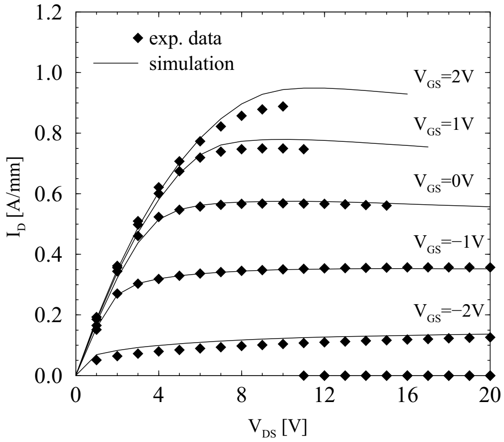

**Fig. 3** Calibrated output characteristics vs. exp. data for $l_g$=0.25 µm HEMT at 425 K.

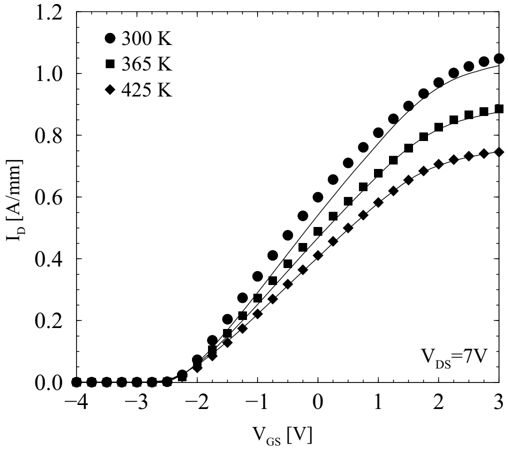

**Fig. 4** Predicted transfer characteristics (lines) compared to measured data (symbols) for $l_g$=0.5 µm HEMT.

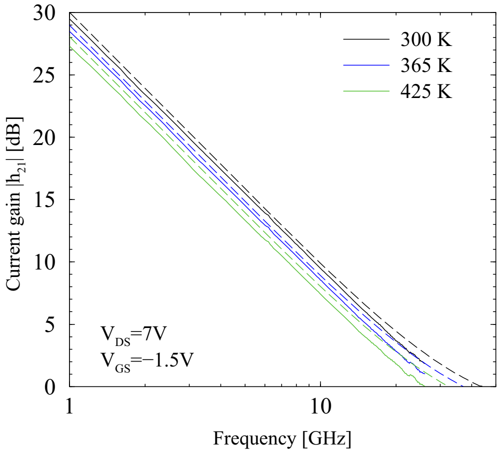

**Fig. 5** Current gain $|h_{21}|$ for $l_g$=0.25 µm HEMT, exp. data (solid lines) vs. simulation (dashed lines).

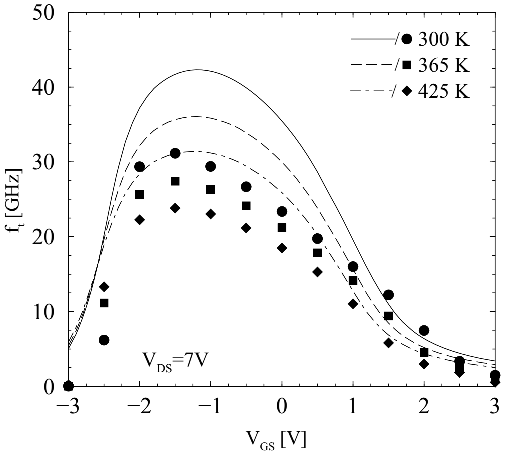

**Fig. 6** Simulated cut-off frequency $f_t$ (lines) compared to measurement (symbols) for $l_g$=0.25 µm HEMT.