High-Temperature Small-Signal Analysis of AlGaN/GaN HEMTs

Stanislav Vitanov and Vassil Palankovski (Faculty Mentor)
Advanced Material and Device Analysis Group
Institute for Microelectronics, TU Wien
Vienna, Austria
Email: {`vitanov,palankovski`}`@iue.tuwien.ac.at`

Abstract — *Gallium Nitride high electron mobility transistors (HEMTs) are considered for high-power high-frequency applications at elevated temperatures. Consequently, a proper modeling of the temperature behavior is important. We present two-dimensional hydrodynamic simulations of AlGaN/GaN HEMTs at high temperatures. The temperature dependence of the small-signal characteristics of a quarter-micron device are analyzed and compared to measured data.*

I. INTRODUCTION

Several groups have studied the high-temperature DC operation of AlGaN/GaN HEMTs [1, 2]. AC measurements at elevated temperatures however are sparse: e.g. the temperature dependence of the cut-off frequency is compared to that of the transconductance [3]. Beside that, the theoretical studies of GaN-based transistors at higher temperature are also rare. There are few analytical models developed, however those are tailored for use in circuit simulation, not for device optimization. Therefore, we have introduced a set of material and model parameters for the hydrodynamic simulation of AlGaN/GaN HEMTs. The set was validated against experimental data [4, 5]. In this work we use the calibrated simulation tool to study the small-signal characteristics of a l_g=0.25 μm structure at elevated temperatures.

II. DEVICE STRUCTURE

The epitaxial structure used in this work was grown by metal-organic chemical vapor deposition (MOCVD) on semi-insulating SiC substrates. The layers consist of a highly-resistive GaN buffer, followed by a $Al_{0.22}Ga_{0.78}N$ barrier and a thin GaN cap layer. The T-gate with a gate length of l_g=0.25 μm was defined by e-beam lithography.

III. SIMULATION SETUP

We perform two-dimensional hydrodynamic electrothermal simulations with our device simulator Minimos-NT, which proved to be a suitable tool for the optimization of different GaN structures and the design of new device generations [6]. Our choice of transport model aims to achieve maximum accuracy combined with computational efficiency. Since the drift-diffusion transport model is not able to deliver accurate results for sub-micron GaN FETs we employ the hydrodynamic transport model. Relevant physical effects, such as self-heating, are accounted for. A thermal resistance R_{th}=7 K/W at the substrate thermal contact is assumed. This value lumps the thermal resistance of the buffer layer and the substrate, and possible three-dimensional thermal effects.

IV. SIMULATION RESULTS

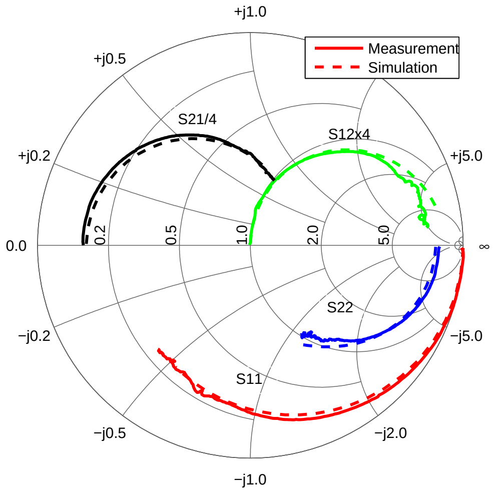
The devices were measured and simulated at ambient temperatures of 300 K, 365 K, and 425 K. Using an interface charge density of 9.5×10^{12} cm^{-2} at the channel/barrier interface and a complementary charge of -2.5×10^{12} cm^{-2} at the barrier/cap interface (both induced by polarization effects) a very good agreement between measurement data and simulation results for the transfer characteristics and output characteristics of the device are achieved. Our setup allows for a proper modeling of the drain current at all three temperatures [5].

The RF device performance is studied by small-signal AC analysis. The parasitic inductances and pad capacitances are L_S=1 pH, L_G=44 pH, L_D=46 pH, and C_{PGS}=18 fF, C_{PGD}=6 fF, C_{PDS}=9 fF respectively. A contact resistance of 0.2 Ωmm is assumed at all contacts according to experimental data. Figure 1 compares simulated and measured extrinsic S-parameters in the range 100 MHz – 26 GHz at V_{DS}=7 V and I_D=260 mA/mm. An excellent agreement is achieved in a wide temperature range (300 K – 425 K).

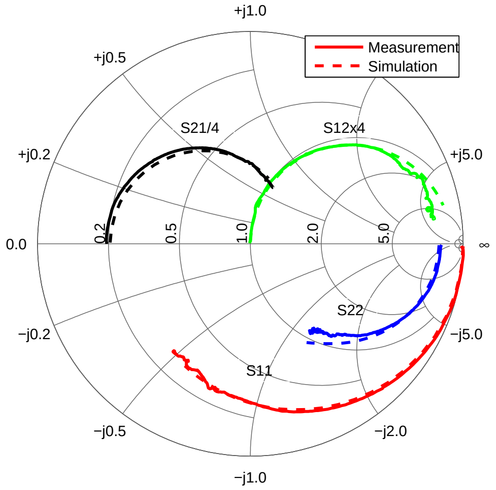
Based on the established eight element small-signal equivalent circuit (Figure 2), the small-signal parameters are extracted from the simulated and measured S-parameters at 10 GHz (Table 1). A good overall agreement is achieved for all temperatures. The underestimation of the gate-source capacitance C_{GS} can be contributed to parasitics between the gate fingers of the real structure. The gate-source (R_{GS}) and gate-drain (R_{GD}) resistances rise, which is more pronounced in the experiment, can be attributed to a possible temperature dependence of the contact resistances, which is not considered in this work.

V. CONCLUSION

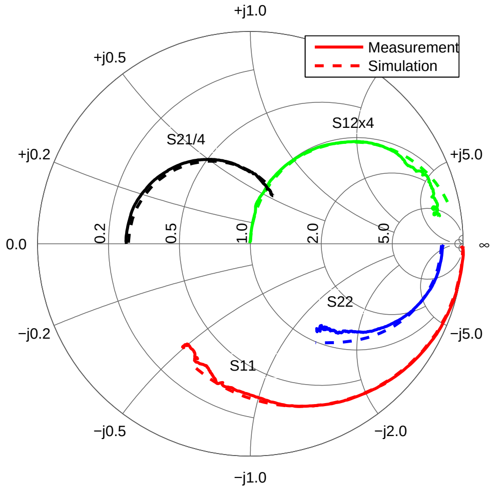
Using a calibrated set of material and model parameters small-signal simulations of an AlGaN/GaN HEMT structure are performed. All relevant physical effects are accounted for. Our simulations yield an excellent agreement with the measured data and allow further studies of the equivalent circuit parameters at high temperatures.



(a) 300 K.



(b) 365 K.



(c) 425 K.

Figure 1: Comparison of measured and simulated extrinsic S-parameters.

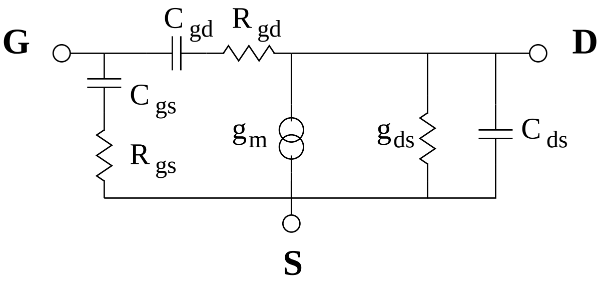


Figure 2: Small-signal equivalent circuit.

T [K]	g_m [mS]	C_{GS} [fF]	C_{GD} [fF]	C_{DS} [fF]	g_{DS} [mS]	R_{GS} [Ω]	R_{GD} [Ω]	τ [ps]
300	33.7	116	34	31	1.38	7.3	26.1	1.74
300	34.7	150	39	29	1.02	6.5	21.3	2.17
365	28.5	115	34	30	1.21	9.1	30.6	1.91
365	29.6	143	40	28	1.00	9.3	28.5	2.32
425	25.2	113	34	29	1.1	10.9	35.2	2.08
425	25.4	141	41	27	0.94	12.2	36.5	2.53

Table 1: Comparison of intrinsic equivalent circuit parameters extracted from simulated (dark) and measured (light) S-parameters.

ACKNOWLEDGMENT

The authors acknowledge support from the Austrian Science Fund (FWF), Project START Y247-N13. Special thanks go to S. Maroldt and Dr. R. Quay for providing the experimental data.

REFERENCES

[1] R. Cuerdo, F. Calle, A. Brana, Y. Cordier, M. Azize, N. Baron, S. Chenot, and E. Munoz. High temperature behaviour of GaN HEMT devices on Si(111) and sapphire substrates. *Phys.stat.sol.(a)*, 5(6):1971–1973, 2008.

[2] W. Tan, M. Uren, P. Fry, P. Houston, R. Balmer, and T. Martin. High temperature performance of AlGaN/GaN HEMTs on Si substrates. *Solid-State Electron.*, 50(3):511–513, 2006.

[3] M. Akita, S. Kishimoto, and T. Mizutani. High-frequency measurements of AlGaN/GaN HEMTs at high temperatures. *IEEE Electron Device Lett.*, 22(8):376–377, 2001.

[4] S. Vitanov, V. Palankovski, S. Maroldt, and R. Quay. High-temperature modeling of AlGaN/GaN HEMTs. In *Proc. Intl. Semiconductor Device Research Symp.*, 2 pages, CDROM, Maryland, December 2009.

[5] S. Vitanov, V. Palankovski, S. Maroldt, and R. Quay. High-temperature modeling of AlGaN/GaN HEMTs. *Solid-State Electron.*, 2010. (submitted).

[6] S. Vitanov and V. Palankovski. Enhancement mode HEMTs: Evaluation of two approaches by numerical simulation. In *Proc. Junior Scientist Conf.*, pages 221–222, Vienna, November 2008.