# The Leti-HSP Surface-Potential-Based SPICE Model for AlGaN/GaN Power Devices

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We present a new compact model for III-nitride HEMTs power transistors developed for SPICE circuit simulations. The Leti-HSP model (acronym for HEMT Surface-Potential model) pursues a physical approach for power devices modeling. Exploiting the experience gained in the trial-and-error history that led the development of high-quality MOS models (PSP, HiSIM, BSIM6), we try to overcome the known limitations of empirical [1-2] and threshold-voltage based [3] formulations using the surface-potential approach [4] by continuous calculation of the Fermi potential. This technique has already been applied to HEMT by Cheng [5], Khandelwal [6] and Radhakrishna [7] for analog/RF models. Striving to obtain a predictive model, a physical approach is adopted for Al barrier content and thickness, spontaneous and piezoelectric polarization, AlGaN doping and incomplete ionization modeling [8-10]. The HSP model flow is presented in Fig. 1. Results of the HSP model after parameter extraction on experimental data from literature [11] are presented in Fig. 2. Moreover we introduce a new implementation of the self-heating effect (SHE) accounting for the heat diffusion generated under the gate near the drain to substrates of different thermal conductivity and thickness (Figs. 3 and 4), knowing that large diameter silicon wafers would be attractive substrates to reduce production costs while achieving high performances. Similarly to the best-practice known from established MOSFET models, a calculation of intrinsic node charges is used in spite of the capacitances to assure charge conservation (Fig. 5). Extrinsic charges due to the presence of source/gate field-plates, which are necessary to maintain high voltage performances, are also modeled (Fig. 6). HSP is also an interesting tool for the optimization of AlGaN/GaN HEMTs since its physical approach allows also estimating the impact of technological variations on the device electrical performances during technology development (Fig. 7). For RF applications, symmetric, smooth and continuous current derivatives are observed (Fig. 8). The model is implemented in the Verilog-A behavioral language and tested with different commercial simulators. Care has been taken to implement a model featuring effortless convergence and suitable for power and analogue simulations. The Leti-HSP model has been retained by the GaN sub-committee of the Compact Modeling Coalition (CMC) during the second phase of the selection for a standard AlGaN/GaN HEMT SPICE compact model.

## References

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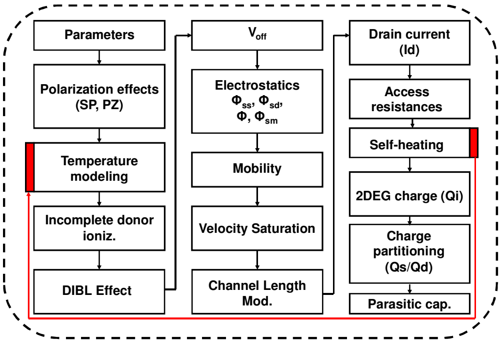

**Fig. 1** LETI-HSP model flowchart.

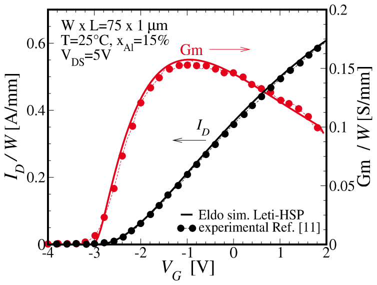

**Fig. 2** Experimental (dots) and simulated (lines) Id(Vg) and Gm(Vg). Experimental data from ref. [11].

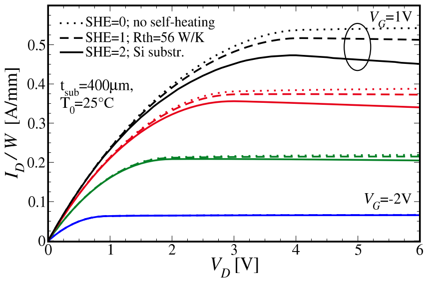

**Fig. 3** Impact on the output characteristic of Self-Heating Effect (SHE). SHE=1 corresponds to a simple thermal resistance Rth as usually implemented. In SHE=2 we adapt Canfield [12] GaAs substrate model to Silicon.

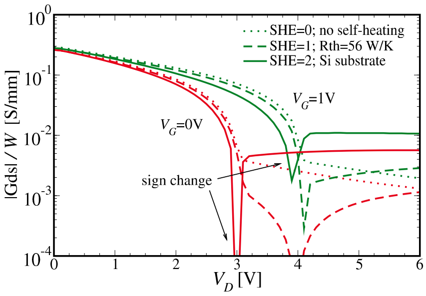

**Fig. 4** Absolute value of output conductance computed from Fig. 3 with (SHE=1,2) or without (SHE=0) self-heating modeling. Please notice that the sign change does not constitute a discontinuity in the model.

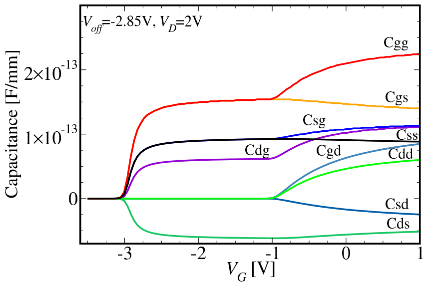

**Fig. 5** Calculated intrinsic trans-capacitances vs. gate voltage. Capacitances are continuous to the 2nd derivative (not shown) for good analogue behavior.

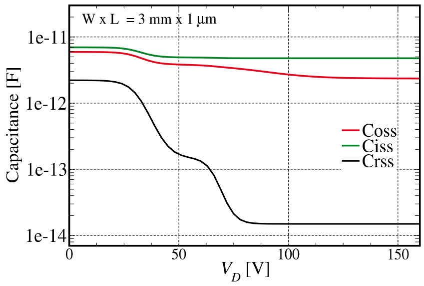

**Fig. 6** Field plate effect (simulation only) on the extrinsic capacitances of the device.

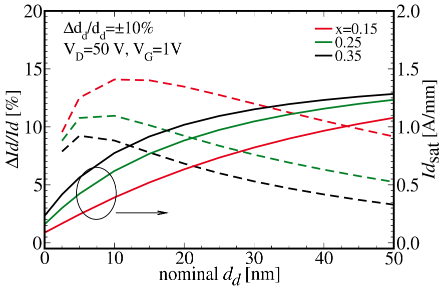

**Fig. 7** Drain current in saturation and relative current fluctuations assuming ±10 % fluctuations of the doped $Al_xGa_{1-x}N$ layer thickness $d_d$ for three $x_{Al}$ contents: 0.15, 0.25 and 0.35.

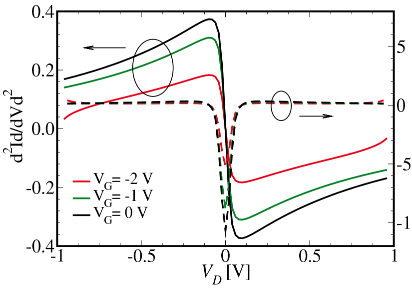

**Fig. 8** Gummel symmetry test for the 2nd and 3rd derivatives of drain current.