

## TWO-DIMENSIONAL PHYSICAL AC-SIMULATION OF GAAS HBTs

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*In this work, results from fully two-dimensional physical device simulation of Gallium Arsenide (GaAs) heterostructure bipolar transistors (HBTs) are presented. Scattering parameters (S-parameters) are directly obtained from small-signal AC-analysis of real devices. A comparison reveals very good agreement with measured data.*

**Keywords:** GaAs HBTs, physical modeling, device simulation

### 1. INTRODUCTION

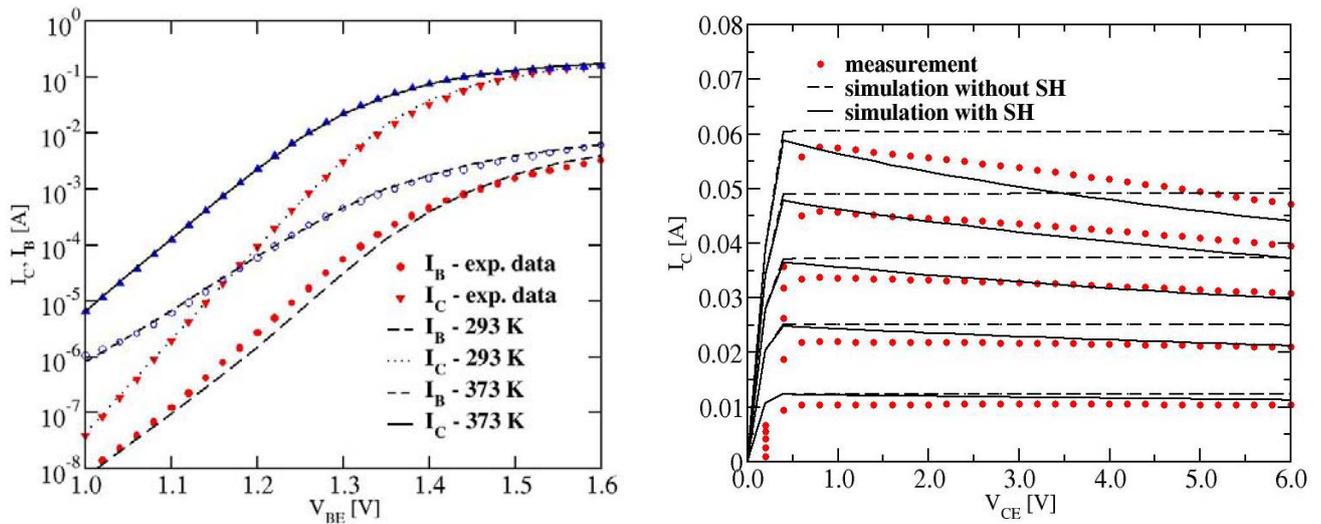
Heterojunction Bipolar Transistors (HBTs) are among the most advanced semiconductor devices today. Two-dimensional device simulation proved to be valuable for understanding the underlying device physics [1] and for improving the device reliability [2]. Bias-dependent S-parameters hold the full small-signal RF-information about the device behavior and allow process control beyond the information about the DC-quantities.

There are several approaches to compute bias-dependent S-parameters, e.g. [3, 4], applying quasi-static or equivalent-circuit parameter models. These approaches employ transformations in the time domain to extract S-parameters. All these methods are both more CPU-time consuming (steady-state has to be reached for each bias and frequency) and more inaccurate (only a limited number of time-steps in reasonable CPU-time, equivalent-circuit approximation, etc.) compared to AC-analysis [5]. We implemented a feature for direct extraction of either extrinsic or intrinsic (de-embedded) S-parameters from AC-simulation in the three-dimensional device simulator Minimos-NT [6]. Thus, we use a combination of rigorous modeling of III-V semiconductor materials and the ability to simulate in the frequency domain.

### 2. MODELING ISSUES

Minimos-NT is a multi-dimensional device simulator, which deals with different complex structures and materials. Various physical effects, such as doping-induced bandgap narrowing, surface recombination, transient trap recombination, self-heating, and hot electron effects, are taken into account. Non-trivial modeling issues, such as enhanced electron mobility in the p-GaAs base and carrier transport through heterointerfaces, are carefully resolved. The models are based on experimental or/and Monte Carlo simulation data and cover the whole material composition range for ternary compounds. The model parameters are checked against several independent HEMT and HBT technologies to obtain one concise set used in all simulations. The

efficiency is proven by hydrodynamic DC-simulations with self-heating, e.g. as shown in Fig. 1.



**Figure 1.** Forward Gummel plots at  $V_{CB} = 0$  V for GaAs HBT (left): Comparison with measurement data at 296 K and 376 K. Output characteristics (right): Simulation with and without self-heating (SH) compared to measurement data at constant  $I_B$  stepped from 0.1 to 0.5 mA.

### 3. AC-SIMULATION EXAMPLE

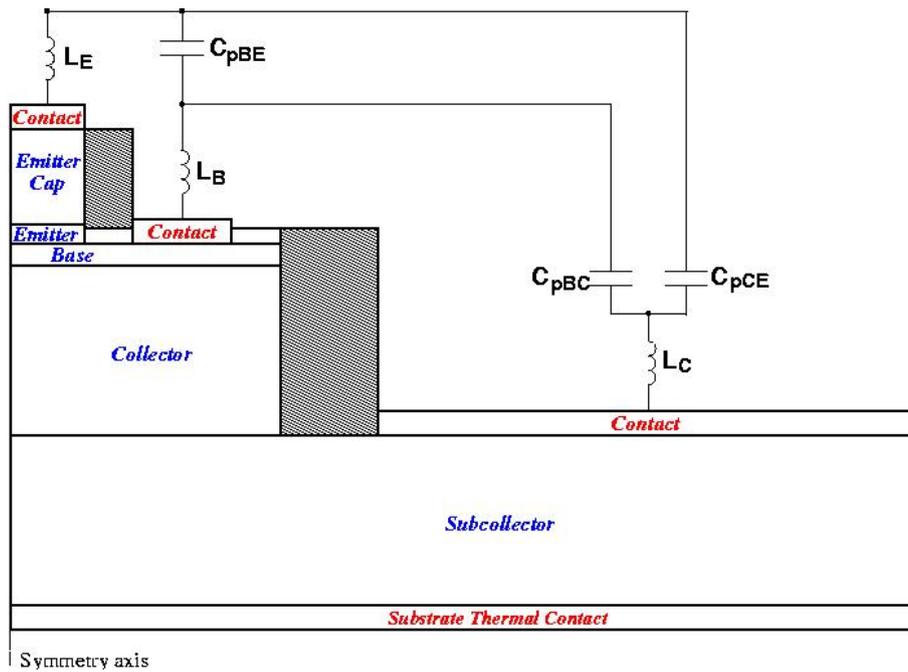
By means of two-dimensional device AC-simulation, S-parameters are extracted for a one-finger InGaP/GaAs HBT with emitter area of  $3 \mu\text{m} \times 30 \mu\text{m}$ . Fig. 2 shows the simulated device structure and the pad parasitics (capacitances and inductances) in the two-port pad parasitic equivalent circuit, which is used to transform the intrinsic parameters to extrinsic ones. The parasitics result from measurements of open/short thru-test-structures [7]. The pad capacitances are  $C_{pBE} = 150$  fF,  $C_{pCE} = 75$  fF, and  $C_{pBC} = 24$  fF, while the parasitic inductance values are  $L_E = 1$  pH,  $L_B = 75$  pH, and  $L_C = 50$  pH. Any resistive parasitics are neglected, since we consider a rather small device and, therefore, only low currents.

The combined smith/polar charts in Fig. 3 show a comparison of simulated and measured S-parameters at  $V_{CE} = 3$  V and  $V_{CE} = 3.5$  V, with current densities  $J_C = 2 \times 10^3$  A/cm<sup>2</sup>,  $J_C = 8 \times 10^3$  A/cm<sup>2</sup>, and  $J_C = 15 \times 10^3$  A/cm<sup>2</sup>, respectively, for the frequency range between 50 MHz and 10 GHz.

### 4. COMPUTATIONAL EFFORT

The AC-simulation takes about 200 s CPU-time on a 2.4 GHz Linux Pentium machine for S-parameters computation with 20 frequency steps. For comparison, the conventional small-signal equivalent-circuit approach [3] takes about 590 s CPU-time at the same machine for 200 time steps at a given frequency. The time for post-

processing of the transient simulation results to obtain the S-parameters at all frequencies is not included.



**Figure 2.** Simulated device structure together with pad parasitics used for S-parameter calculation.

## 5. CONCLUSION

The quality and the efficiency of our approach are demonstrated by the good agreement between simulated and measured data and the speed-up achieved. At this instance, the shown approach enables further extensive optimization tasks with hundreds of runs in a reasonable time. In addition, the two-dimensional physical simulation allows for a direct relation between the material properties and the high-frequency device behavior.

## ACKNOWLEDGMENT

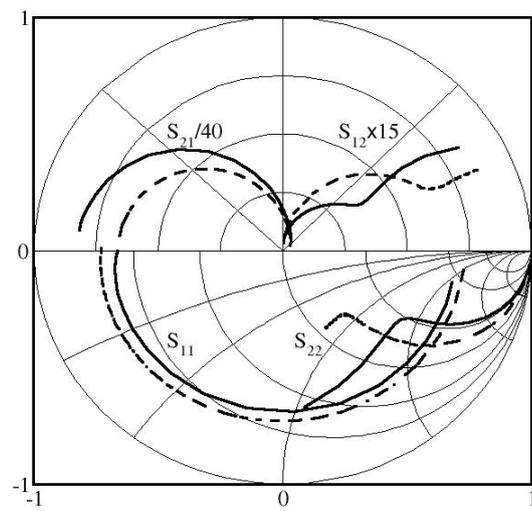
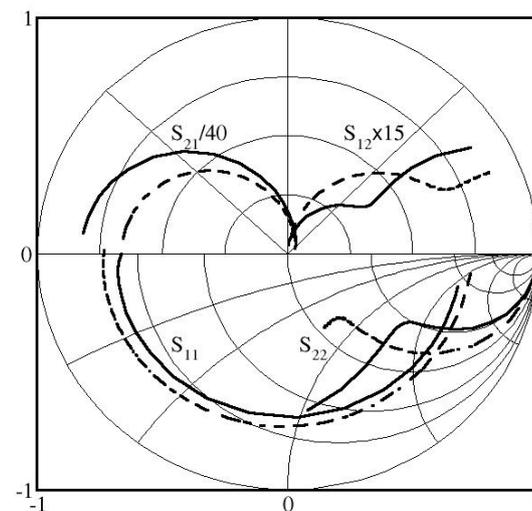
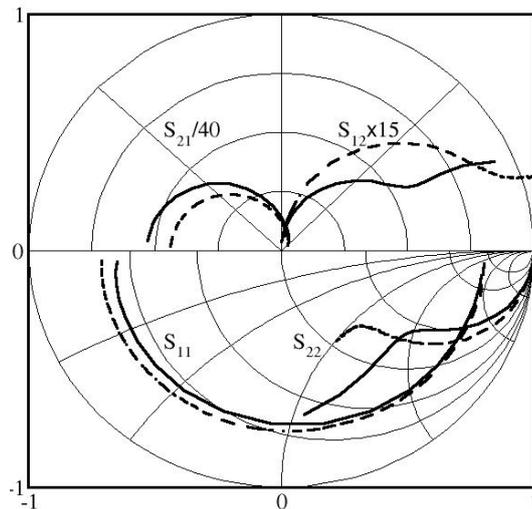
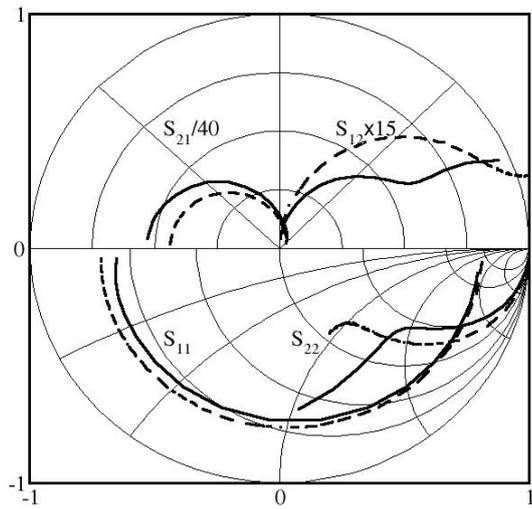
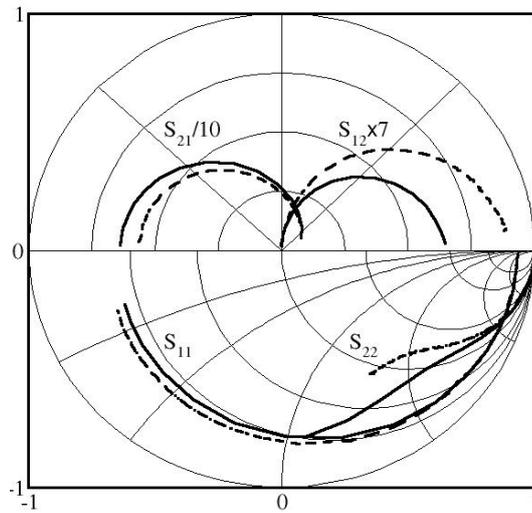
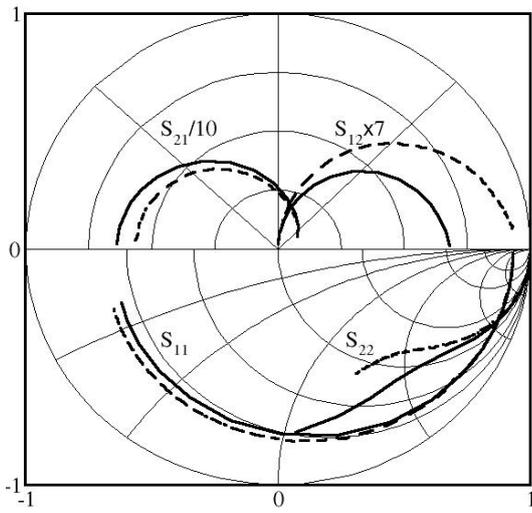
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**Figure 3.** S-parameters in a combined Smith chart ( $S_{11}$  and  $S_{22}$ ) and a polar graph ( $S_{21}$  and  $S_{12}$ ) from 50 MHz to 10 GHz at  $V_{CE} = 3$  V (left column) and  $V_{CE} = 3.5$  V (right column),  $J_C = 2 \times 10^3$  A/cm<sup>2</sup> (row 1),  $J_C = 8 \times 10^3$  A/cm<sup>2</sup> (row 2), and  $J_C = 15 \times 10^3$  A/cm<sup>2</sup> (row 3): Simulation (solid lines) vs. experiment (dashed lines).