Optimization of SiGe HBTs for Industrial Applications

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We give an overview of the state-of-the-art of heterostructure device simulation for industrial application based on SiGe/Si material system. The work includes a detailed comparison of device simulators and current transport models to be used, and addresses critical modeling issues. Results from two-dimensional hydrodynamic simulations of SiGe Heterojunction Bipolar Transistors (HBTs) with MINIMOS-NT are presented in good agreement with measured data. The simulation examples are chosen to demonstrate technologically important issues which can be addressed and solved by device simulation.

SiGe HBTs progressively replace III-V devices for their typical applications, e.g. low noise amplifiers and frequency dividers up to 99 GHz[1], and are considered essential for 40 Gb/s optical communication systems. $f_T \times BV_{CE0}$ of 380 GHz·V and ring oscillator delays of 4.3 ps have been achieved [2]. Transit frequencies of 288 GHz [3] and maximum oscillation frequencies of 285 GHz [4] were recently reported. The devices are fully compatible with the existing state-of-the-art 0.13 μm CMOS technology [4, 5]. Digital application-specific integrated circuits (ASICs) are combined with SiGe HBT circuits in the so-called SiGe BiCMOS technology and are in volume production.

With the shrinking of device dimensions and the replacement of hybrid mounted transistors by MMICs, circuit simulations with distributed devices need to be carried out by state-of-the-art simulation tools, accounting for physical effects on a microscopic level. Several questions during device fabrication, such as device optimization and process control, can today be addressed by device simulation. The constantly increasing computational power of computer systems allows the use of TCAD tools on a very large scale. Several commercial device simulators, e.g. [6]-[11], company-developed simulators, e.g. [12, 13] and University developed simulators, e.g. [14]-[20], claim the capability to handle SiGe devices.

However, these simulators differ a lot in dimensionality (1D, /quasi-/2D, or /quasi-/3D), in the choice of carrier transport model (drift-diffusion, energy-transport, or Monte Carlo statistical solution of the Boltzmann equation), and in the capability of coupling the latter to electrothermal simulations. In addition, quantum mechanical effects are neglected or accounted for by models for quantum corrections, as solving the Schrödinger or the Wigner equation is extremely expensive in terms of computational resources. Another issue is the quality of the physical models and the model parameters for SiGe which often are simply inherited from Silicon.

Beside mainstream Silicon, the three-dimensional device simulator MINIMOS-NT[21] can deal with different complex structures and materials, such as SiGe and various III-V binary and ternary compounds, with arbitrary material composition profiles in a wide temperature range. All the important physical effects, such as band gap narrowing, anisotropic electron minority mobility in strained SiGe, carrier transport through heterointefaces, surface recombination, impact ionization, and self-heating, are taken into account.

As an example, the influence of the selectively-implanted-collector (SIC) implant on device performance was studied by means of process simulation using DIOS, followed by two-dimensional device simulation using the commercial device simulator DESSIS and MINIMOS-NT. As can be seen in Fig. 1 DESSIS, but also MINIMOS-NT, failed to explain the experimentally observed f_T using the drift-diffusion transport model, but after Phosphorus profile calibration for two of the four devices and using a hydrodynamic transport model much better agreement was achieved with MINIMOS-NT (see Fig. 2). Optimization of the SIC profile revealed an improvement of the $f_T \times BV_{CE0}$ by factor of 1.5.

Acknowledgment

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References

[1] Böck, et al., "Sub 5 ps SiGe Bipolar Technology," in *IEDM Tech.Dig.*, 2002 (in print).

[2] B. Heinemann, et al., "Novel Collector Design for High-Speed SiGe:C HBTs," in *IEDM Tech.Dig.*, 2002 (in print).

[3] J.-S. Rieh, et al., "SiGe HBTs with Cut-off Frequency Near 300 GHz," in *IEDM Tech.Dig.*, 2002.

[4] B. Jagannathan, et al., "Self–Aligned SiGe NPN Transistors with 285 GHz f_{MAX} and 207 GHz f_{T} in a Manufacturable Technology," *IEEE Electron Device Lett.*, vol. 23, no. 5, pp. 258–260, 2002.

[5] T. Hashimoto, et al., "Integration of a 0.13-m CMOS and a High Performance Self-Aligned SiGe HBT Featuring Low Base Resistance," in *IEDM Tech.Dig.*, 2002.

[6] APSYS, http://www.crosslight.com/downloads/downloads.html

[7] ATLAS/Blaze, http://www.silvaco.com/products/vwf/atlas/atlas/atlas_br.html

[8] BIPOLE3, http://www.bipsim.com/mainframe.html

[9] DESSIS and DIOS, http://www.ise.com/products/index.html

[10] G-PISCES-2B, http://www.gateway-modeling.com/products.htm

[11] MEDICI and TSUPREM4, http://www.synopsys.com/products/avmrg/device_sim_ds.html

[12] Buturla, et al., "Finite-Element Analysis of Semiconductor Devices: The FIELDAY Program," http://www.research.ibm.com/journal/rd/441/buturla.pdf

[13] NEMO, http://www.cfdrc.com/nemo/

[14] PISCES-ET, http://www-tcad.stanford.edu/tcad.html

[15] FLOODS and FLOOPS, http://www.tec.ufl.edu/ flooxs/

[16] C. Jungemann, et al., "Full-Band Monte Carlo Device Simulation of a SiGe/Si HBT with a Realistic Ge Profile," *IEICE Trans.Electron.*, vol.E83-C, no.8, pp.1228–1234, 2000.

[17] DEVICE, http://www.uv.ruhr-uni-bochum.de/Forschungsbericht/e14/e141302/b141302.htm

[18] nextnano3, http://www.webplexity.de/nextnano3.php

[19] J. Gessner, et al., "Simulation of the Frequency Limits of SiGe HBTs," in *Proc. Modeling and Simulation of Microsystems*, Puerto Rico, USA, pp. 407-410, 1999.

[20] Glasgow, http://www.elec.gla.ac.uk/groups/dev_mod/

[21] Minimos-NT, http://www.iue.tuwien.ac.at/software/minimos-nt

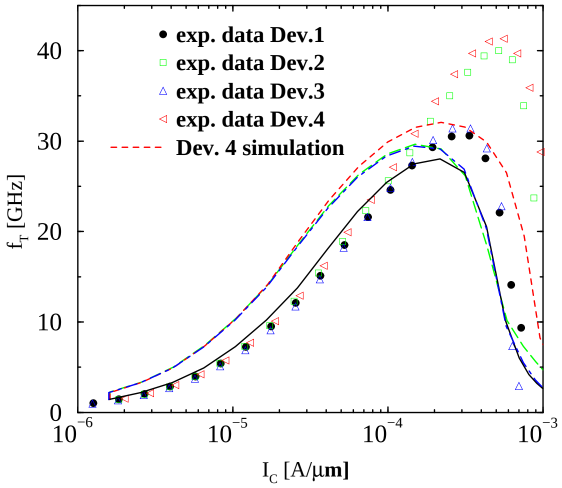

Fig. 1: f_{T} vs. I_{C} at V_{CE} = 1.5 V. Comparison between measurement and simulation with DESSIS [9].

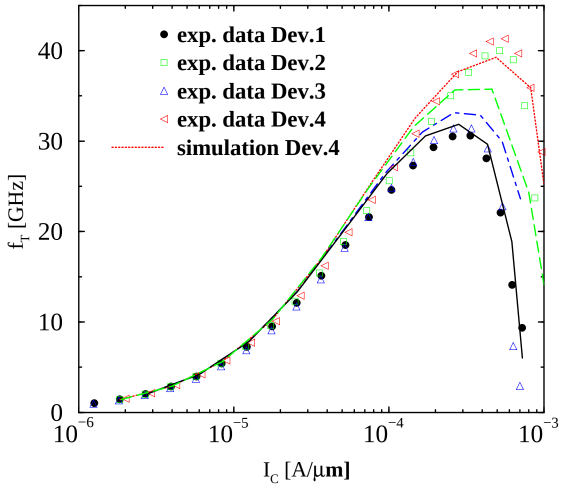

Fig. 2: f_{T} vs. I_{C} at V_{CE} = 1.5 V. Comparison between measurement and hydrodynamic simulation with MINIMOS-NT.