Paper

Modeling SiGe-base HBT using APSYS 2000 – a 2D simulator

Adam Linkowski, Lidia Łukasiak, and Andrzej Jakubowski

Abstract — The paper is devoted to optimization of SiGe-base HBT with respect to operation speed by means of numerical simulation. The influence of design parameters on f_T is studied.

Keywords — ***base transit time, cut-off frequency, HBT, SiGe-base.***

1. Introduction

Rapid progress in microelectronics created conditions for the development and widespread use of simulation techniques in the design of semiconductor devices. These techniques are based on numerical methods of solving a set of transport equations. The advantage of simulations lies in the fact that the number of costly experiments may be significantly reduced, moreover it is possible to analyze completely novel designs. Unfortunately, commercially available simulators are far from ideal. Often they are based on simplified calculations through the omission of certain second- and third-order phenomena.

This work is devoted to the illustration of the possibilities offered by APSYS 2000 (a 2D simulator [1]) to optimize the design of SiGe HBT's with respect to their speed of operation.

2. Results

A cross-section of the simulated transistor is shown in Fig. 1. This device is the both the result of initial optimization and the basis for further work on increasing f_T.

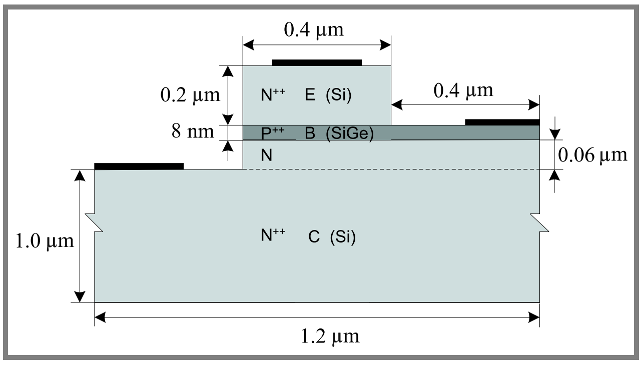


Fig. 1. A cross-section of a SiGe HBT.

The doping profile of the considered transistor is shown in Fig. 2.

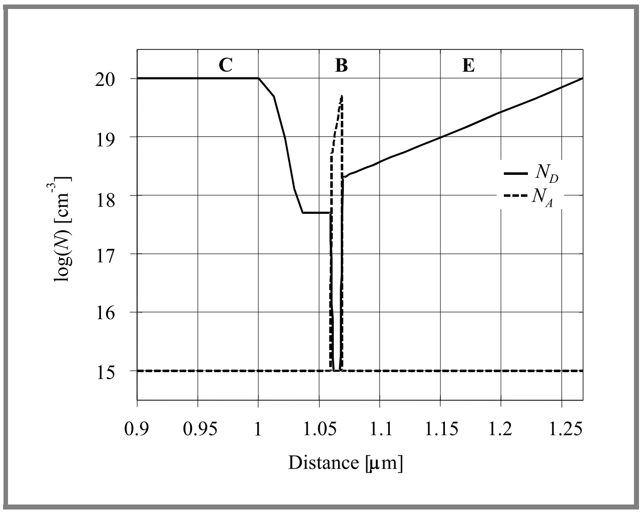


Fig. 2. HBT doping profile.

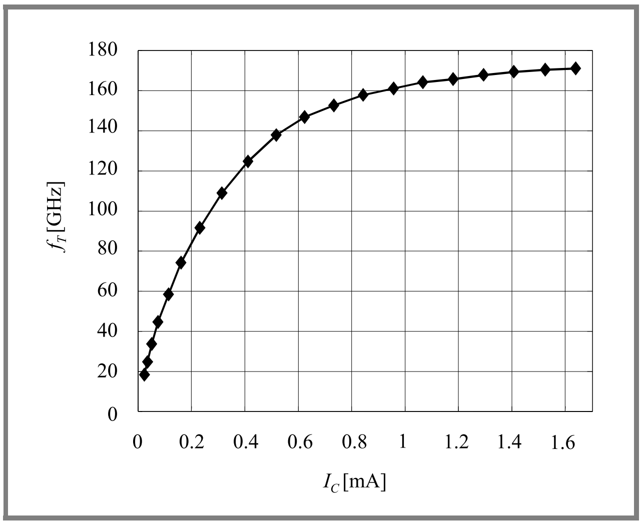


Fig. 3. Cut-off frequency f_T as a function of the collector current I_C.

The maximum cut-off frequency f_T determined from the $f_T = f(I_C)$ dependence shown in Fig. 3 is about 170 GHz. This is by no means the highest possible value, the designer is, however, limited by the fact that the calculations performed by the simulator do not always converge.

Despite this difficulty a designer often has at his disposal more than one way to improve a given parameter.

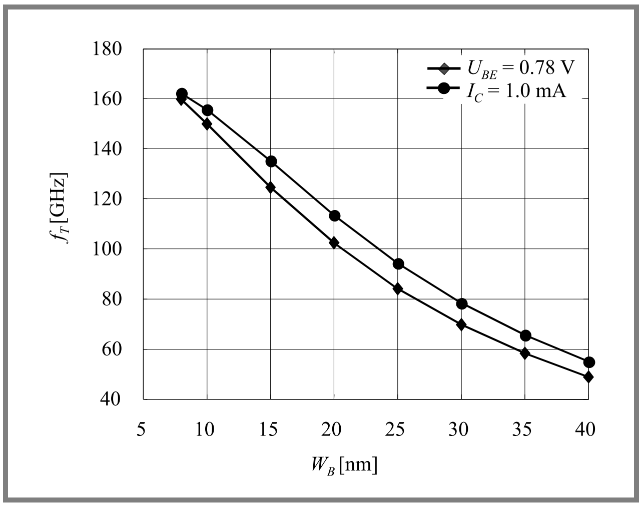


Fig. 4. Cut-off frequency f_T as a function of base width W_B (values of U_{BE} and I_C are kept constant).

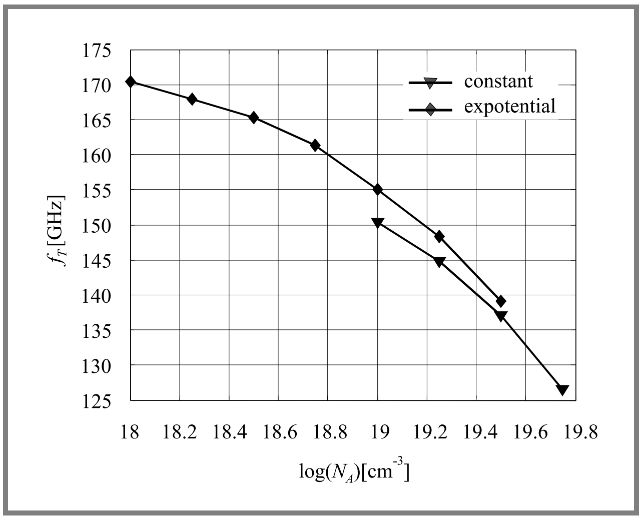


Fig. 5. Cut-off frequency f_T as a function of base doping level (constant and exponential doping profile).

The cut-off frequency is defined mostly by the carrier transit time through the active region, that is the base and the depleted regions of the E-B and B-C junctions. Thus it may be expected that the most important parameter affecting f_T is the effective base width. This is also confirmed in Fig. 4. The effective base width may be changed through fabrication of ever thinner SiGe layers or through the manipulation of the base doping profile, which affects the thickness of the region consumed by the B-C junction. Minimization of the width modulation effect requires relatively high doping concentration in the base, which also decreases the width of the B-C junction. The speed of operation is further improved by the built-in field associated with the exponential doping profile in the base (Fig. 5).

The built-in field in the base may be also obtained using a linear gradation of the Ge content but, as can be seen in Fig. 6, f_T decreases with increasing Ge content (lower carrier mobility, e.g. [2]), while the additional built-in field is of little importance.

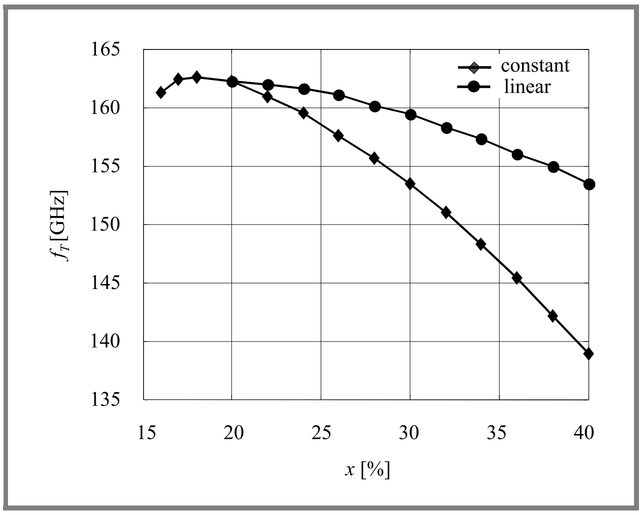


Fig. 6. Cut-off frequency f_T as a function of Ge content x for constant and linear Ge profile.

Junction capacitances are the other two important parameters affecting f_T. The simplest way to reduce them is to decrease the junction area, which may be achieved through the reduction of the dimensions L_1 and L_2, marked in Fig. 1. This, indeed, leads to higher f_T (Fig. 7).

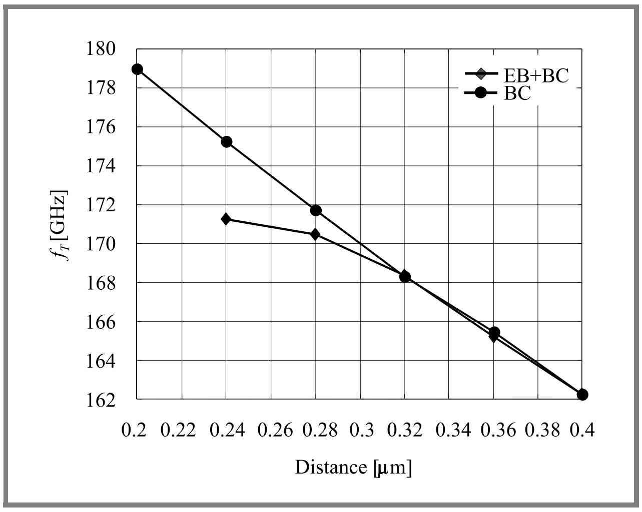


Fig. 7. Cut-off frequency f_T as a function of dimensions L_1 and L_2.

The cut-off frequency may be also improved by means of reducing the emitter width (Fig. 8). Of course, the effects obtained through the reduction of individual dimensions

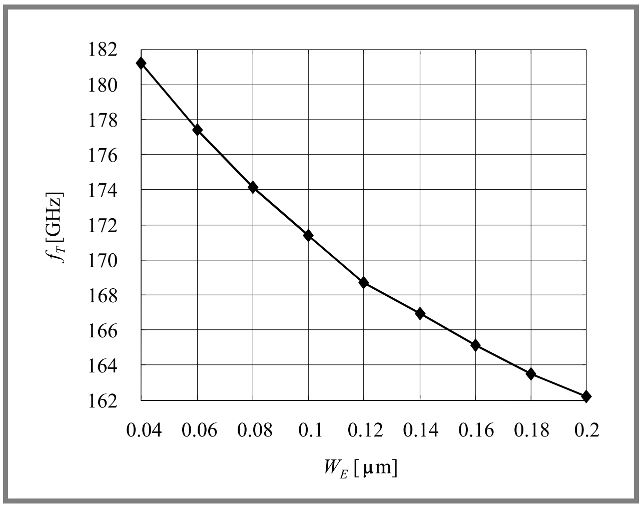


Fig. 8. Cut-off frequency f_T as a function of emitter width W_E.

cumulate. Thus, for example, a transistor with $W_E = 60$ nm, L_1 and $L_2 = 0.24$ μm (the calculations do not converge for L_1 lower than 0.24 μm) achieves f_T of 204 GHz.

3. Conclusions

The maximum f_T obtained by means of simulation using APSYS 2000 was approximately 200 GHz. This is considerably lower than f_T obtained experimentally [3]. The reason for this lies probably in the internal limitations of the simulator used in this work.

Acknowledgment

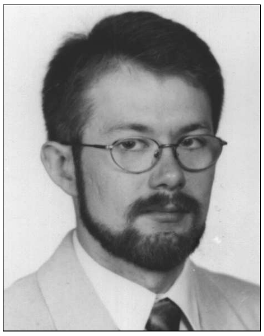
This work was supported by research project no. 8T11B07519 of the State Committee for Scientific Research.

References

[1] "APSYS user's manual, version 3.6", Crosslight Software Inc., Gloucester, Canada, 2000.

[2] V. Palankovski and S. Selberherr, "Critical modeling issues of SiGe semicondutor devices", *J. Telecommun. Inform. Technol.*, no. 1, pp. 15–25, 2004.

[3] J. S. Rieh, B. Jagannathan, H. Chen, K. T. Schonenberg, D. Angell, A. Chinthakindi, J. Florkey, F. Golan, D. Greenberg, S. J. Jeng, M. Khater, F. Pagette, C. Schnabel, P. Smith, A. Stricker, K. Vaed, R. Volant, D. Ahlgren, G. Freeman, K. Stein, and S. Subbanna, "SiGe HBTs with cut-off frequency of 350 GHz", *IEDM Tech. Dig.*, 2002.



Adam Linkowski received M.Sc. degree in 2000 from Warsaw University of Technology. He is currently working towards a Ph.D. His thesis is devoted to the design and modeling of SiGe-base HBT's. His research interests include also processing of radiolocation signals and optimization of aircraft detection and tracking algorithms.

e-mail: alinkows@o2.pl
Institute of Microelectronics and Optoelectronics
Warsaw University of Technology
Koszykowa st 75
00-662 Warsaw, Poland

Lidia Łukasiak, **Andrzej Jakubowski** – for biography, see this issue, p. 14.