Extended Abstracts of the 1999 International Conference on Solid State Devices and Materials, Tokyo, 1999, pp. 130-131

Design of SiGe HBTs for High Frequency Operation

Frank Schwierz, Jörg Gessner and Dagmar Schipanski

Technische Universität Ilmenau, Institut Festkörperelektronik, PF 100565, 98684 Ilmenau, Germany
Phone: (+49) 3677-69-3120 Fax: (+49) 3677-69 3132 email: schwierz@e-technik.tu-ilmenau.de

1. Introduction

Since the first demonstration of SiGe HBTs in 1987 [1], these transistors evolved to well accepted RF devices with commercial applications. Currently SiGe HBTs get into frequency ranges that have been the domain of III/V devices in the past. Recently SiGe HBTs with outstanding RF properties in terms of the maximum frequency of oscillation (f_{max}) and the cut off frequency (f_T) have been reported. At present the record values of f_{max} and f_T obtained with these devices are 160 GHz [2] and 156 GHz [3], respectively. Moreover, Hitachi researchers reported a SiGe HBT with both extremely high f_{max} (108 GHz) and f_T (92 GHz) [4].

In the competition between SiGe HBTs and III/V devices a point of issue is the question of the frequency limits of SiGe HBTs. Recently we published the results of an extensive simulation study in which we investigated the optimum Ge profile in the base of SiGe HBTs [5]. In this work we use the simulator PROSA developed in our laboratory and described e.g. in [5], to extend the study and examine the influence of the base Ge content and the collector design on SiGe HBT RF performance.

After a comparison between experiment and simulation, the effects of the Ge content (x) in the base on f_T and of the use of a selectively implanted collector (SIC) under the emitter area on both f_{max} and f_T are presented. The results indicate that the RF properties of SiGe HBTs may be further improved by carefully optimized devices structures.

2. Comparison between Simulation and Experiment

To check the validity of the simulation results of our device simulator PROSA, a comparison between measured f_T of experimental devices fabricated by our industrial partner and simulated f_T has been carried out. Figure 1 shows the measured cut off frequency of a typical SiGe HBT for application in the lower GHz range as a function of collector current and the PROSA results obtained by simulations based on the classical drift diffusion model (DDM) and on the more advanced hydrodynamic model (HDM) which takes into account effects of nonstationary carrier transport such as velocity overshoot. While the DDM simulation gives too small values for f_T, the HDM predicts the HBT behavior in an excellent way and good agreement between experiment and simulation has been obtained.

3. Dependence of f_T on the Ge Content in the Base

As described in [5], [6], there are two basic design philosophies for SiGe HBTs. The investigations of this work focus on the design with doping inversion (high base and low emitter doping). In Fig. 2 the dependence of f_T on the Ge content in the base is shown. The simulated HBT structure is characterized by a Ge box profile in the 10 nm wide base and by a 100 nm wide low doped collector region followed by a high doped subcollector.

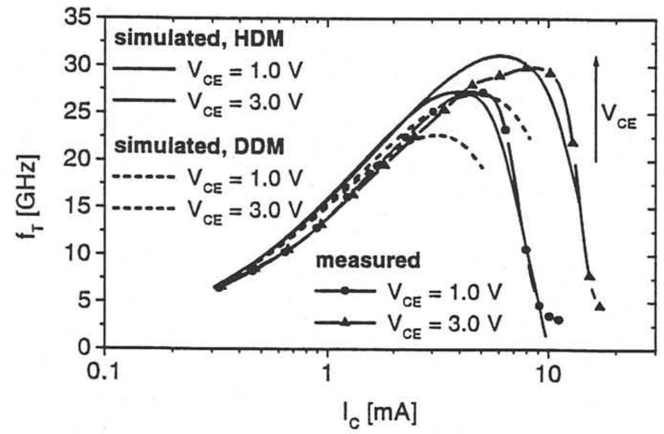

Fig. 1 Comparison between measured and simulated cut off frequencies (f_T vs. collector current). Full lines: HDM; dotted lines: DDM; full lines with symbols: experiment.

A previous investigation revealed that a Ge box profile is optimum for SiGe HBTs with such narrow base layers [5]. Further details of the transistor structure can be found in [5]. In Fig. 2 a strong increase of f_T can be observed when the Ge content is raised in the range from 5% to 25 % while above 25% Ge f_T saturates. In other words, there is no need to increase the Ge content much above 25 % because the HBT behavior improves only slightly while the problems of strain relaxation might become serious.

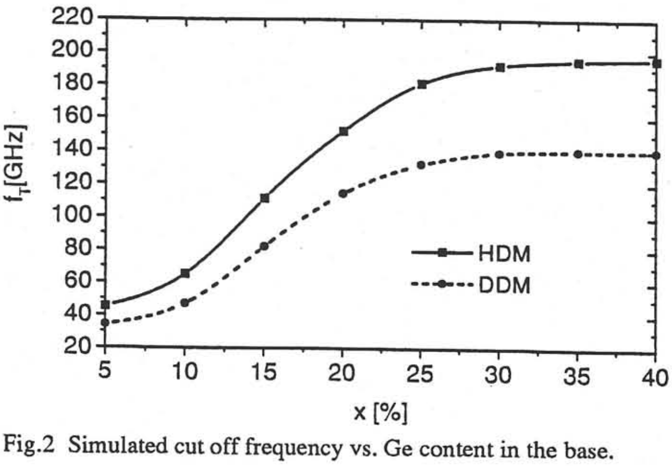

Fig.2 Simulated cut off frequency vs. Ge content in the base.

4. Influence of Collector Design on f_T and f_{max}

In principle, increased collector dopings result in SiGe HBTs with higher f_T's. The disadvantages of a high doping concentration in the collector are a low breakdown voltage and an increased collector base capacitance C_{CB}, which again affects f_{max}. A possibility to reduce the influence of collector doping on f_{max} is the use of a selectively implanted collector (SIC). It is characterized by a high doping in the part of the collector located directly under the emitter window (i.e. in the intrinsic collector) and a much lower doping in the extrinsic collector. In this way, the highly doped intrinsic collector ensures a high f_T while C_{CB}, which is the sum of the intrinsic C_{CB} (increased by the high doped SIC) and the extrinsic C_{CB} (low due to the low doped extrinsic collector) remains relatively low.

We simulated SiGe HBTs with an emitter length of 200 nm, an emitter base spacing of 80 nm and different SIC dopings. The 10 nm base has a Ge box profile (x=25%) and the collector thickness (which is equal to the SIC thickness) is 150 nm. The extrinsic collector doping is $10^{16}cm^{-3}$.

In Fig. 3 the simulated cut off frequencies of the investigated HBT structures are shown as a function of collector current. The qualitative trend predicted by DDM and HDM (increased SIC doping causes a strongly enhanced f_T and a higher collector current for the maximum f_T) is the same but the quantitative values differ considerably. HBTs with SIC dopings in the range between $5\times10^{17}cm^{-3}$ and $10^{18}cm^{-3}$ show cut off frequencies in the order of 200 GHz.

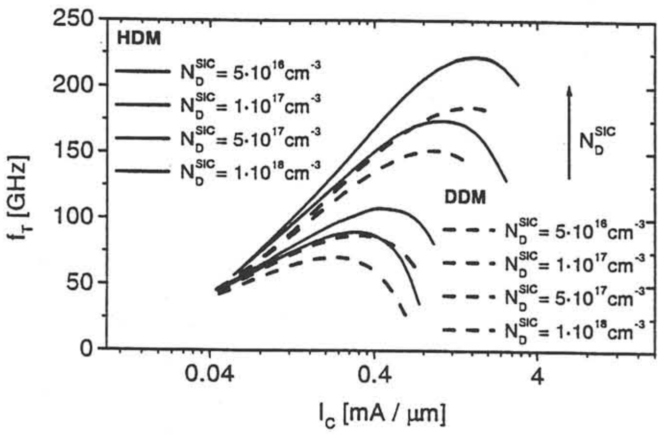

Fig. 3 Simulated cut off frequency vs. collector current, parameter SIC doping. Full lines: HDM (lowest curve SIC doping $5\times10^{16}cm^{-3}$, uppermost curve SIC doping $10^{18}cm^{-3}$); dotted lines: DDM (SIC doping as in the HDM case).

Figure 4 shows the calculated f_{max} values (only HDM) for the same HBTs as in Fig. 3. An increase of SIC doping from $5\times10^{16}cm^{-3}$ up to $5\times10^{17}cm^{-3}$ results in enhanced f_T's (195 GHz compared to 215 GHz). SIC dopings higher than $5\times10^{17}cm^{-3}$ do not give any improvement in f_T. The degree of f_{max} enhancement due to the use of a SIC depends on the ratio of the intrinsic and extrinsic collector areas.

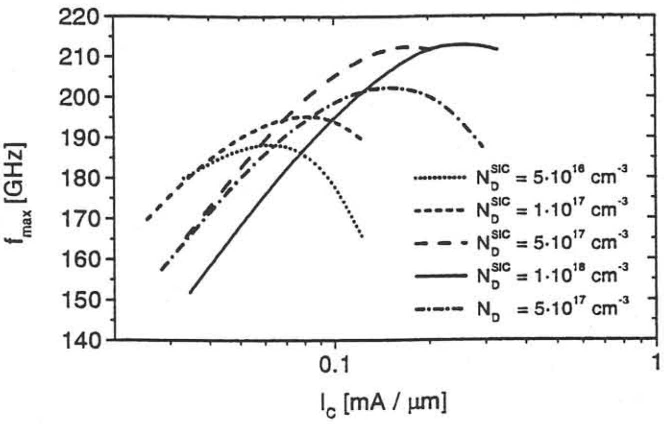

Fig. 4 Simulated maximum frequency of oscillation vs. collector current, parameter SIC doping. The dot-slash line represents f_{max} of a SiGe HBT without SIC and a collector doping of $5\times10^{17}cm^{-3}$ in both the intrinsic and the extrinsic collector.

5. Conclusion

By means of extensive SiGe HBT simulations (based on the hydrodynamic model) important design criteria for transistors with extremely high f_T and f_{max} have been worked out. In the case of scaled SiGe HBTs with doping inversion, emitter lengths of 200 nm and narrow (10 nm) high doped base layers, extraordinary high values for both f_T and f_{max} in the order of 200 GHz can be obtained when a box like Ge profile with a Ge content of 25...30% and a selectively implanted collector with a doping concentration of about $5\times10^{17}cm^{-3}$ are used. These results show that the recently reported record values for f_T and f_{max} do not represent the frequency limits of SiGe HBTs and that by device scaling and structure optimization the RF behavior of these device can be further improved.

Acknowledgment

The authors thank Dr. U. Baumann for the RF measurements. This work has been supported by the German Ministry of Research and Technology in the frame of the research activities "Nanoelectronics" (BMBF contract no. M 2410 C/3).

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