51. IWK

Internationales Wissenschaftliches Kolloquium
International Scientific Colloquium

PROCEEDINGS

11-15 September 2006

FACULTY OF ELECTRICAL ENGINEERING AND INFORMATION SCIENCE

INFORMATION TECHNOLOGY AND ELECTRICAL ENGINEERING - DEVICES AND SYSTEMS, MATERIALS AND TECHNOLOGIES FOR THE FUTURE

Startseite / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=12391

TECHNISCHE UNIVERSITÄT
ILMENAU

Impressum

Herausgeber: Der Rektor der Technischen Universität Ilmenau
Univ.-Prof. Dr. rer. nat. habil. Peter Scharff

Redaktion: Referat Marketing und Studentische Angelegenheiten
Andrea Schneider

Fakultät für Elektrotechnik und Informationstechnik
Susanne Jakob
Dipl.-Ing. Helge Drumm

Redaktionsschluss: 07. Juli 2006

Technische Realisierung (CD-Rom-Ausgabe):
Institut für Medientechnik an der TU Ilmenau
Dipl.-Ing. Christian Weigel
Dipl.-Ing. Marco Albrecht
Dipl.-Ing. Helge Drumm

Technische Realisierung (Online-Ausgabe):
Universitätsbibliothek Ilmenau
Postfach 10 05 65
98684 Ilmenau

Verlag:
Verlag ISLE, Betriebsstätte des ISLE e.V.
Werner-von-Siemens-Str. 16
98693 Ilrnenau

ISBN (Druckausgabe): 3-938843-15-2
ISBN (CD-Rom-Ausgabe): 3-938843-16-0

Startseite / Index:
http://www.db-thueringen.de/servlets/DocumentServlet?id=12391

51. Internationales Wissenschaftliches Kolloquium
Technische Universität Ilmenau
September 11 - 15, 2006

C. Schippel / F. Schwierz/ J. Fu

Investigations on the Non-Ideality of the Base Current of RF Bipolar Transistors

Abstract

The non-ideal characteristics of the base current of an experimental SiGe-HBT has been investigated through 2D device simulation. To determine the origin of the device's imperfect DC behaviour, several mechanisms of charge carrier recombination within the transistor has been investigated. Since such recombination mechanisms influence the characteristics of the device differently, the origin of non-idealities can be identified by comparision of measurement and simulation.

1 Introduction and Motivation

When an established manufacturing process for semiconductor devices is modified, many uncertainties are involved. Subsequently, the devices fabricated in the first runs of the modified process do not perform as expected. At this point device simulation is able to provide insights into the origins of the these far-from-perfect device characteristics through applying appropriate physical assumptions. Thereby the technologists can be supported to get the new processes from an experimental to a ready for production state with minimum effort in time and costs.

This work is based on 2D device and technology simulations of experimental Silicon-Germanium heterojunction bipolar transistors (SiGe HBTs) in a BiCMOS process flow (see Fig. 1). In our study the simulators *ATLAS* [1] and *ATHENA* [2] have been used. Fig. 2 shows the Gummel plot of imperfect devices having an unusually high ideality factor of the base current η_{I_B}. From the circuit designer's point of view this is a highly unpleasant device characteristic since the current gain β is degraded (Fig. 1(b)). Such a device behaviour can be modelled by assuming a low lifetime of the majority charge carriers in the base (see again Fig. 2 for the agreement between measurement and simulation). However, this approach does not provide a meaningful physical explanation and it is useless for the optimisation of the technology. Therefore, in the present work a more fundamental approach is applied. Through making educated guesses on the origins of the imperfection, their influence on the device characteristics can be simulated. Subsequently, by comparision

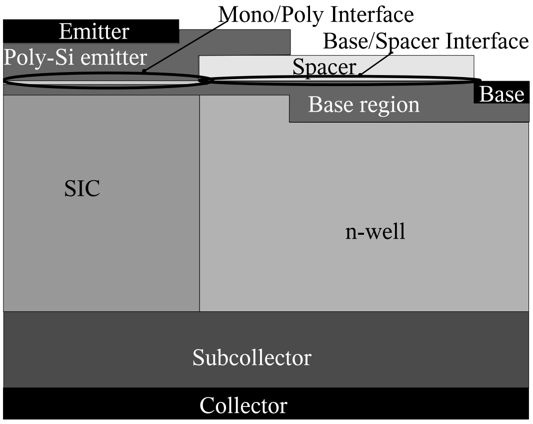


Figure 1: Investigated device structure and its main regions: emitter length $0.25\mu m$, base width 70nm, base-subcollector separation (SIC width) 700nm, lateral emitter-base separation 750nm

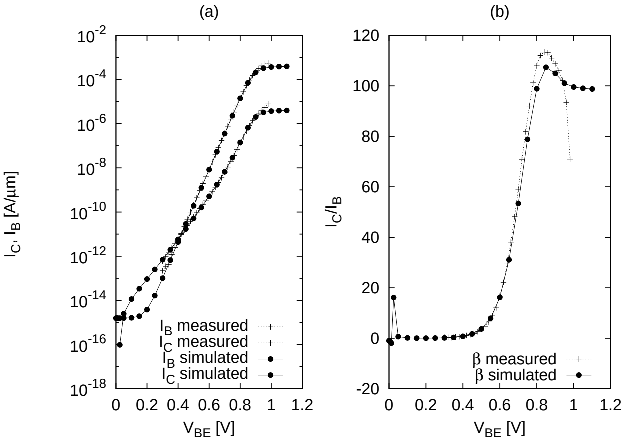


Figure 2: Gummel plot (a) and current gain β (b) of an experimental SiGe HBT and its simulated counterpart at $V_{CB} = 0V$. The agreement was achieved by assuming a carrier life time of the holes in the base region of $4 \times 10^{-10} s$

of measurement and simulation the different origin can be discarded or confirmed.

2 Basics

In general, the short lifetime of the charge carriers is caused by an increased recombination rate. The recombination takes place either at interface traps or at bulks traps [3]. In the case of the given HBT, the interfaces between monocrystalline and polycrystalline emitter and between base region and the SiO_2 spacer, as well as bulk traps in the base region are relevant (see again Fig. 1).

The Gummel plot of I_B can be divided into low, medium and high current injection regions. While the last one is dominated by parasitics like emitter and base resistances, the other regions are heavily influenced by recombination processes. They can, therefore, be used for investigations on the origins of the non-ideal characteristics.

The base current I_B is described, in logarithmical form, by the equation

$$\ln(I_B) = \ln(I_{B0}) + \frac{q \cdot V_{BE}}{\eta_{I_B} \cdot k \cdot T} \tag{1}$$

with the parameters saturation base current I_{B0} and ideality factor η_{I_B}. For both measured and simulated Gummel plots, these parameters can be obtained by fitting.

3 Results

For the investigation of the recombination mechanisms, devices with various interface and bulk trap densities in extremely wide ranges have been simulated. Afterwards the ideality factors η_{I_B} of these devices have been determined and compared to the η_{I_B}=1.75 of the real device.

- Influence of the Bulk Material of the Base: The density of acceptoric traps in the base has been varied between $10^{12}cm^{-3}$ and $10^{17}cm^{-3}$. As can be seen from Figs. 3 and 4, at lower trap densities the ideality factors η_{I_B} of the low and medium current injection regions are different. For trap densities of about $10^{17}cm^{-3}$ the η_{I_B} of the experimental HBT has been reproduced. However, such a trap concentration is highly unrealistic. Therefore is cannot be used to explain the imperfection of the investigated device.

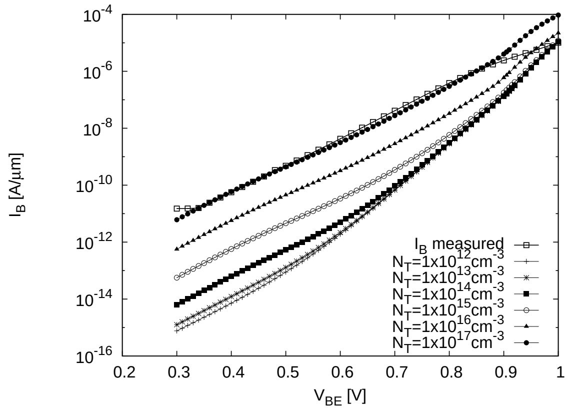


Figure 3: Gummel plot of I_B of the simulated HBT assuming various bulk trap densities N_T.

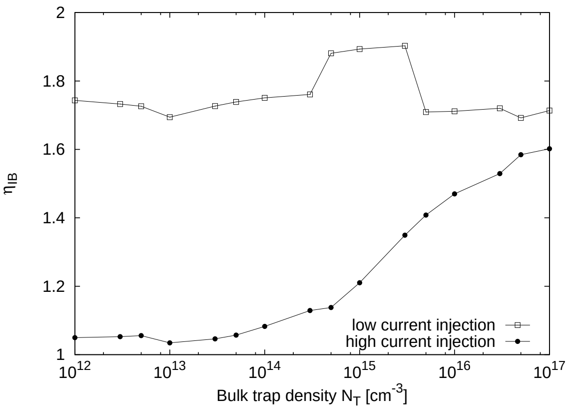


Figure 4: Ideality factor η_{I_B} vs. bulk trap density N_T.

- Influence of the Mono/Poly Interface: The density of acceptoric traps N_T at the interface between the monocrystalline and polycrystalline parts of the emitter has been varied between $10^{5}cm^{-2}$ and $10^{13}cm^{-2}$. The correspondig Gummel plots are depicted in Fig. 5. Fig. 6 shows the η_{I_B} vs. N_T characteristics obtained from these results. For low trap densities, different ideality factors for the low and medium

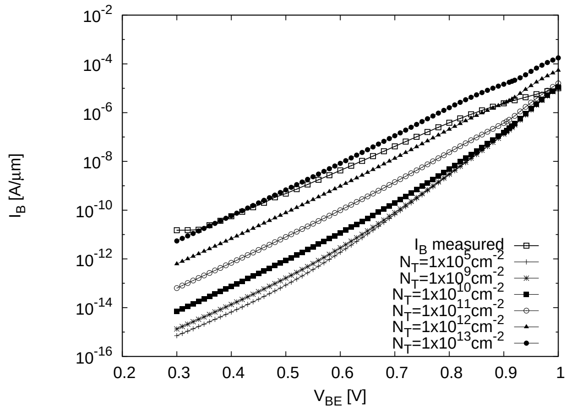


Figure 5: Gummel plot of I_B of the simulated HBT assuming different interface trap densities at the monocrystalline/polycrystalline interface N_T.

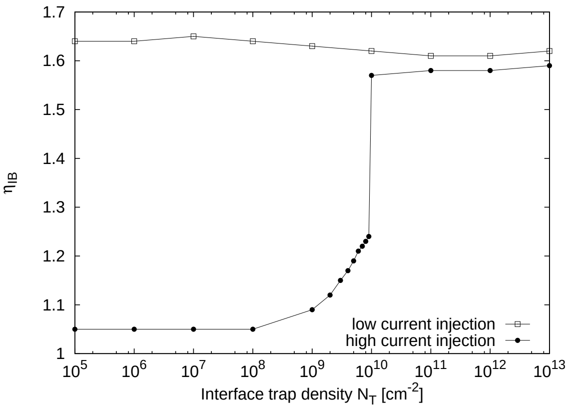


Figure 6: Ideality factor η_{I_B} vs. interface trap density at the monocrystalline/polycrystalline interface N_T.

current injection regions have been observed. However, the results indicate that even for very high trap densities the η_{I_B} of the measured device cannot be reproduced. Therefore it is most unlikely that the mono/poly interface causes the problems in the manufactured device.

- Influence of the Spacer/Base Interface: Variing the trap density in this region between $10^{10} cm^{-2}$ and $10^{13} cm^{-2}$ results in values for η_{I_B} between 1.18 and 1.93 (see Fig. 8). The experimental value of 1.75 is well within this range and can be achieved by the assumption of a trap density of about $5 \times 10^{11} cm^{-2}$, which seems to be a realistic value. Furthermore, as shown in Fig. 9, the absolute values for the measured and simulated base current match perfectly in the low and medium current injection regions. This is an additional indication for the appropriateness of our assumption.

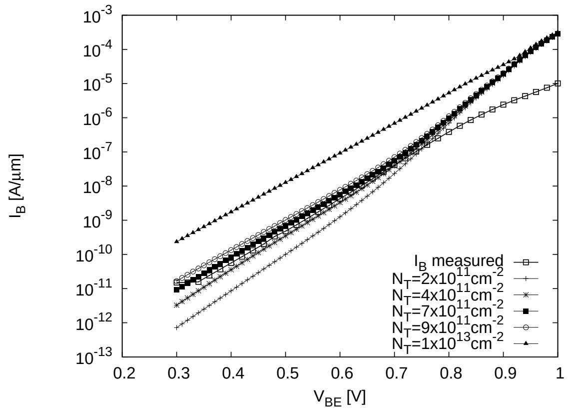


Figure 7: Gummel plot of I_B of the simulated HBT assuming different interface trap densities at the monocrystalline/polycrystalline interface N_T.

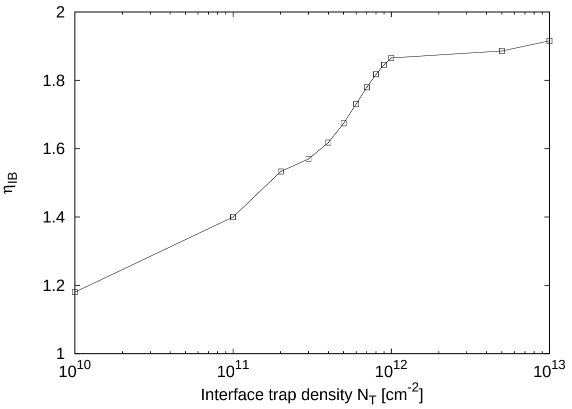
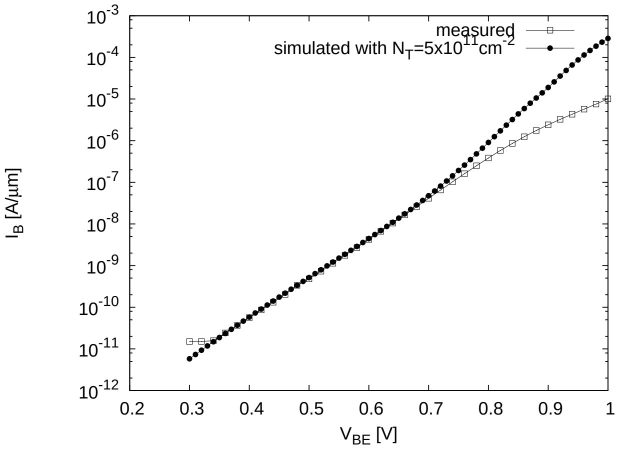


Figure 8: Ideality factor η_{I_B} vs. interface trap density at the monocrystalline/polycrystalline interface N_T.

Figure 9: Comparision of the measured and simulated base current. A trap density of $5 \times 10^{11} cm^{-2}$ at the spacer/base interface has been assumed. The disagreement in the high current injection region is due to external parasitic elements, which have been neglected.



4 Conclusions

A method to support the technology development through device simulation has been elaborated and demonstrated for a problem regarding the DC characteristics of RF HBTs. A similar procedure can be used in many other cases where the behaviour of real devices differs from the expected one, for example to explain degradation effects, and for reliability investigations.

Acknowledgements

The authors would like to thank Sebastian Schmidt and Wolfgang Einbrodt of the X-FAB Semiconductor Foundries AG. This work has been supported by the TMWTA under contract number B509-03006.

References

[1] Silvaco International, Santa Clara, CA 95054, USA *Device Simulation Software*, 2005

[2] Silvaco International, Santa Clara, CA 95054, USA *2D Process Simulation Software*, 2005

[3] W. Liu, *Handbook of III-V Heterojunction Bipolar Transistors*, John Wiley & Sons, Inc., ISBN 0-471-24904-1

Authors:

Dipl.-Ing. Christian Schippel
PD Dr. habil. Frank Schwierz
Technical University Ilmenau
Department of Solid State Electronics
PF 100565, 98684 Ilmenau
Tel: +49 3677 69 3225
Fax: +49 3677 69 3132
E-mail: christian.schippel@tu-ilmenau.de

Dr. Jun Fu
X-FAB Semiconductor Foundries AG
Haarbergstrasse 61
99097 Erfurt