Mathematical approach and Optimization of Nanometric Base Thickness for an HBT Dedicated to Radiofrequency applications.

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Extended Abstract

We present, in this paper the mathematical approach for optimization nanometric thickness of the SiGeC base heterojunction bipolar transistors (HBTs), realized in BiCMOS industrial process. However, use of these components in applications microwave radio frequencies implores the use of complex structures shrinking. The base SiGeC is the active part of the transistor, the optimization of the nanometric thickness is a crucial aspect in order to accurately predict the characteristics of the component.

Numerical approach modeling is investigated, using our 2D simulator SIBIDIF, based on the drift-Diffusion Model (DDM). It solves the continuity equations for electrons and holes, coupled with the Poisson’s equation, based on the concept of the finite difference mesh using a revised Schafetter- Gummel type approach and solved numerically with the Gauss Seidel’s method and matrix algebra. Simulation results obtained in this study are efficiently compared with electrical characteristics obtained by measurements.

Keywords- Numerical modeling; SiGe(C); Base; HBT; BiCMOS; Nanometric thickness.

1 Introduction.

In the recent years band gap engineering of Si based materials, e.g., SiGe or SiGeC has raised considerable attention for various device applications. Strained SiGe (C) layers are interesting for applications in ultra-fast heterojunction bipolar transistors (HBTs).
The principal challenge is to develop silicon based bipolar transistors having cut-off frequencies competing with III-V devices. A fist challenge is to develop silicon based bipolar transistors having cut-off frequencies competing with III-V device[1]. A second one is to offer these devices in a CMOS environment in order to combine assets of Si/SiGe HBTs for optical and millimeter wave applications with those of CMOS devices for complex digital and analogue integrated circuitry of high speed communication systems could be achieved [2].

Nanometric thickness of the SiGeC base thereby improving the current gain of the transistor and the transition frequency $f_T$.

We report in this paper, the optimization performed of nanometric thickness of the SiGeC base into SiGeC (HBT) devices realized in an industrial BiCMOS $Si_{1-x}Ge_xCy$ 0.13 m process, using our own software simulator (Simulation Bidimensional by Finite Difference) $SIBIDIF$, taking into account an approach of non uniform heterostructure parameters.

2 Mathematical approach

The studied structure is a SiGeC bipolar transistor that is integrated using polysilicon emitter quasi self aligned structure with selective epitaxial growth of the base, similar to the SiGe HBT investigated in ST-BiCMOS9 0.13m.

We will provide a development of fundamental equations to analyze the electrical behaviour in semiconductors; we base our analysis on a macroscopic description of semiconductors with possible non uniform composition.

$SIBIDIF$ [3], is a two dimensional Drift-Diffusion Model (DDM) simulator. It solves the continuity equations for electrons and holes, coupled with the Poisson’s equation, based on the concept of the finite difference mesh using a revised Schafetter-Gummel type approach and solved numerically with Gauss Seidel’s method and matrix algebra.

Numerical methods were first applied to heterostructures by Sutherland and Hauser to analyze solar cells [4].The model used here is the so-called DDM (Drift Diffusion model). It links ambipolar continuity equation for electrons and holes and Poisson’s one.

Poisson equation:

$$\nabla^2 \phi = -\frac{q}{\varepsilon} (p - n + N_D^+ - N_A^-)$$  \hspace{1cm} (1)

Continuity equations for electrons and holes:

$$\frac{\partial n}{\partial t} = GR_n + \frac{1}{q} \frac{dJ_n}{dx}$$  \hspace{1cm} (2)

$$\frac{\partial P}{\partial t} = GR_p - \frac{1}{q} \frac{dJ_p}{dx}$$  \hspace{1cm} (3)
Current equations for electrons and holes:

\[ J_n = -q n \mu_n \frac{d\phi_n}{dx} \] (4)

\[ J_p = -q p \mu_p \frac{d\phi_p}{dx} \] (5)

The equations and physical models involved in the simulation \( Si_{1-x}Ge_xCy \) HBTs are implemented in our program \( SIBIDIF \) which is a 2-D simulator dedicated to silicon germanium bipolar device optimization, in finite difference.

To model SiGeC heterostructure, we need appropriate physical parameters for each material \([5]\).

3 Electrical characteristics

Main active part of the bipolar transistor, the base largely determines its static and dynamic performance. The optimization of the thickness of the base is a major element in the study of electrical characteristics of the HBT.

Thus, a fine base supports a reduced transit time, because the path followed by the electrons is shorter, resulting in an increase in crossover frequency and maximum frequency of oscillation \((f_{max} \text{ and } f_T)\). Thus, it is beneficial to reduce the thickness of the neutral base. It must, however, the boron atoms are fully contained in the SiGe layer; otherwise the benefit of the heterojunction is lost. It is therefore not possible to bases as thin as desired, under penalty of boron spread outside the base.

It is seen from the figure 1, that the transistor having a thin base has the highest gain. Indeed, the greater the base is thin, the higher the density of holes decreases and the base current decrease significantly. This causes an increase in gain However, it is recommended not significantly reduce the thickness of the base because they can It can lead to phenomena such as tunneling and piercing of the base.

To use a TBH as an amplifier at high frequencies, it is also important to study the evolution of the power gain \(MUG\) (Mason Unilateral Gain) as a function of frequency. This determines the maximum frequency of oscillation \(f_{max}\). The simulation of the transistor for a voltage \(V_{BE} = 0.7V\), allowed us to extract the maximum frequency of oscillation \(f_{max}\) from the curve of the power gain as a function of frequency.

Moreover, from (figure2), we note that the maximum frequency of oscillation \(f_{max}\) increases as the thickness of the base is reduced. For example, it is pertinent to note that \(f_{max}\) to 225GHz 131GHz increases when the thickness of the base is reduced from 100 nm to 30 nm.
4 Conclusion

The electrical performances of high-speed SiGeC HBTs 0.13m have been obtained for thicknesses base ranging from 100nm to 30nm, using our numerical device simulator SIBIDIF for the steady state.

We observe, a thin base has the highest current gain. Indeed, the greater the base is thin, the higher the density of holes decreases and the base current decrease significantly. This causes an increase in gain and maximum frequency of oscillation.

References


Figure 1: Current gain for HBT SiGeC, simulated by SIBIDIF for a base thickness varied between 100nm and 30nm.

Figure 2: The maximum frequency of oscillation $f_{\text{max}}$ as a function of the thickness base.