

Comparative study of transistors electrical characteristics made in BICMOS technology

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Abstract

In this paper, a comparative study of two bipolar transistors realized according to the same BICMOS-0.35 technology, but with two different architectures (self-aligned and quasi-self-aligned) is presented. In each case, the type of material forming the base and the geometric differences existing between the two considered structures are taken into account. The simulation allowed us to demonstrate the interest in introducing germanium in quasi-self-aligned bipolar transistors. In addition, it has been found that in low and medium injection, the electrical characteristics of the self-aligned bipolar transistor deviate greatly from the experimental results. With the quasi-self-aligned architecture, this gap remains moderate. In strong injection, and in both types of transistors, the electrical characteristics are very close to those obtained experimentally.

Keywords: Transistor; Heterojunction; BICMOS; SiGe; Modelling.

1. Introduction

The development of BICMOS technology has progressively led to the integration of SiGe thereby leading to the creation of SiGe heterojunction bipolar transistors, HBTs [1-3]. The advantage of this approach lies in the very close properties between the two materials of silicon and germanium, which at low cost, allows the large-scale manufacture of structures for high frequency applications. In this paper, we present a study of etching effects on two types of bipolar transistors, belonging to the same 0.35 BiCMOS technology with polysilicium emitters, but made according to two different architectures (fig.1 and fig 2). The purpose of this investigation is to make a comparative study to underline the combined influence of the of the considered componets architecture and the material type forming the base on the electrical characteristics of the transistors. This study is based on simulations realized with our 2DHBTsim (Heterojunction Bipolar Two Dimensional Simulator) software developed as part of a research work [4-5].

2. The studied structure

The two types of structures targeted by this study are realized according to 0.35 μ m BICMOS technology but with different bases and architectures such as:

- The first transistor is an homojunction type with a silicon base (TB-Si) and produced according to

the self-aligned simple polysilicon architecture (fig.1).

- The second transistor is an heterojunction type with silicon-germanium alloy (TB-SiGe) base and

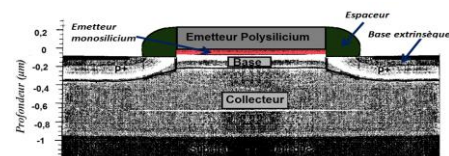


Figure 1. Schematic cross-section of self-aligned TB-Si in 0.35 BiCMOS technology [6] .

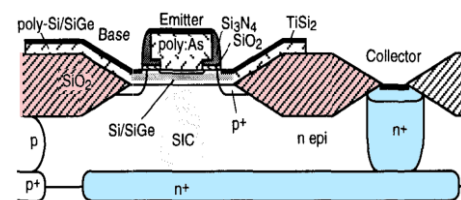


Figure 2. Schematic cross-section of the BICMOS6G technology [7]

made according to the self-aligned simple polysilicon architecture (fig.2).

3. Description of the numerical model

The equations governing the transport phenomena in the two types of transistors are [5]:

$$\text{div}(\varepsilon \cdot \overrightarrow{\text{grad}}\varphi) = -\rho \quad (1)$$

$$\frac{\partial n}{\partial t} = g_n + \frac{1}{q} \cdot \overrightarrow{\nabla} \vec{J}_n \quad ; \quad \frac{\partial p}{\partial t} = g_p - \frac{1}{q} \cdot \overrightarrow{\nabla} \vec{J}_p \quad (2)$$

$$\begin{aligned} \vec{J}_n &= q \cdot n \cdot \mu_n \cdot \vec{E} + q \cdot D_n \cdot \overrightarrow{\nabla} n \\ \vec{J}_p &= q \cdot p \cdot \mu_p \cdot \vec{E} - q \cdot D_p \cdot \overrightarrow{\nabla} p \end{aligned} \quad (3)$$

With ρ : The charges density;

ε : Material permittivity

$\vec{J}_{n,p}$: Current density for electrons, holes;

$D_{n,p}$: Diffusion constant for electrons, holes

$\mu_{n,p}$: Mobility of electrons, holes;

K_B : Boltzmann constant

T : The temperature

These expressions of J_n and J_p can also be expressed as a function of the generation-recombination terms GR_n (for electrons) GR_p (for holes) such that:

$$\begin{aligned} \overrightarrow{\nabla} \vec{J}_n &= GR_n \\ \overrightarrow{\nabla} \vec{J}_p &= -GR_p \end{aligned} \quad (4)$$

Generation-recombination terms are related to different mechanisms that disrupt carrier densities. They are developed according to the SHR model (Shockley Read Hall) such as:

$$GR_n = GR_p = \frac{n \cdot p - n_{ie}^2}{\tau_p \cdot (n + n_i) + \tau_n \cdot (p + n_i)} \quad (5)$$

Carriers lifetimes, $\tau_{n,p}$, are dependent on the electrical properties of the defects. They are given by:

$$\tau_n = \frac{1}{C_n} \quad ; \quad \tau_p = \frac{1}{C_p} \quad (6)$$

The Capture rates C_n and C_p are given by:

$$C_n = \sigma_n N_t v_{thn} \quad ; \quad C_p = \sigma_p N_t v_{thp} \quad (7)$$

To calculate the electrical potential distribution, we consider the Poisson equation:

$$\text{div}(\varepsilon \cdot \overrightarrow{\text{grad}}\varphi) = -q \times (p - n + dop + N_{TD}^+ - N_{TA}^-) \quad (8)$$

In this equation, defects are taken into account through the terms N_{TD}^+ and N_{TA}^- which are respectively donor and acceptor traps densities. They are calculated from the Shockley, Read and Hall model [8]:

$$\begin{aligned} N_{TD}^+ &= N_{TD} \cdot \frac{C_p \cdot p + C_n \cdot n_1}{C_n \cdot (n + n_1) + C_p \cdot (p + p_1)} \\ N_{TA}^- &= N_{TA} \cdot \frac{C_n \cdot n + C_p \cdot p_1}{C_n \cdot (n + n_1) + C_p \cdot (p + p_1)} \end{aligned} \quad (9)$$

With

$$n_1 = N_C \cdot e^{E_T - E_C} \quad ; \quad p_1 = N_V \cdot e^{E_V - E_T} \quad (10)$$

The quasi-Fermi energies are given by :

$$E_{Fn} = E_C - q \cdot \gamma_n + k_B T \cdot \ln\left(\frac{n}{N_C}\right) \quad (11)$$

$$E_{Fp} = E_V + q \cdot \gamma_p + k_B T \cdot \ln\left(\frac{p}{N_V}\right)$$

$$E_C = -q \cdot \varphi + \frac{E_G}{2}$$

$$E_V = -q \cdot \varphi - \frac{E_G}{2} + \Delta E_v \quad (12)$$

The system of Eqs. (1) -(8) has been discretized on a two-dimensional finite differences mesh.

4. Results and discussions

The doping profiles of the two transistors types are shown in figures 3 and 4.

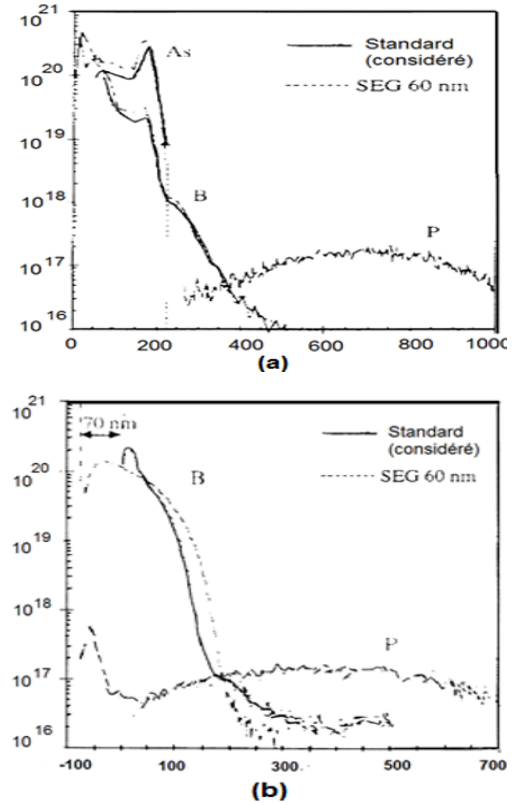


Figure 3. SIMS profiles of self-aligned TB-Si in 0.35 BiCMOS technology with [6]:
a) intrinsic region & b) extrinsic region

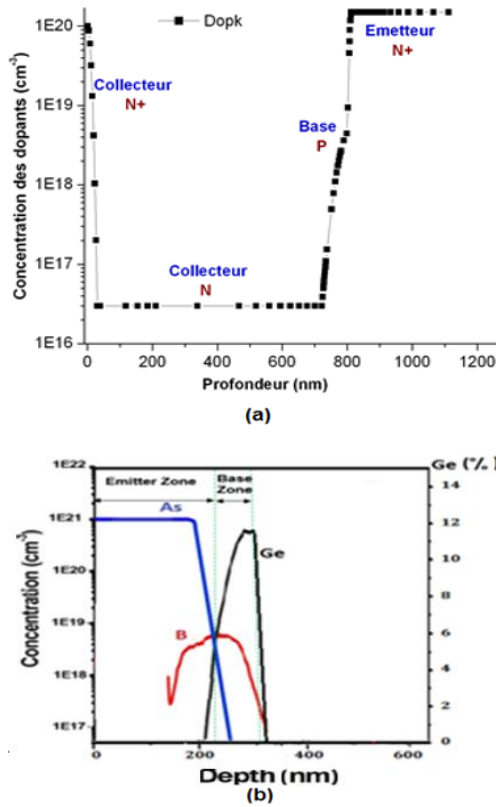


Figure 4. Doping profile of the BICMOS6G structure [5]

Figures 5-a and 5-b show the energy band diagrams respectively for TB-Si and HBT-SiGe. These curves demonstrate that the potential barrier seen by electrons to cross the base-emitter junction is larger in the case of TB-Si than in the case of HBT-SiGe. However, this same barrier seen by the holes, remains identical in both types of components. This difference is due to the germanium presence in the base. This one being voluntarily introduced to reduce the bandgap of this zone: *effect of bandgap engineering* (figure 6).

Figure 7 shows the simulated Gummel curves, which are obtained by varying the emitter-base junction voltage (V_{BE}) in the range of 0 to 1 volt, while maintaining the base-collector junction under inverse polarization (V_{BC}) constant: equal to 1 volts for TB-Si and 2 volts for HBT-SiGe. The characteristics demonstrate that the level of the collector current (I_c) is higher in HBT-SiGe than in TB-Si. This is quite predictable because the presence of germanium in the first transistor reduces the potential barrier seen by the electrons which facilitates their injection into the base (very small size) and automatically induces a growth of this current (I_c). For the holes, the barrier seen by these carriers is not affected by the presence of germanium and for this purpose; it is not possible to compare the base currents of the two transistors based on the presence of this material but only with respect to experimental results.

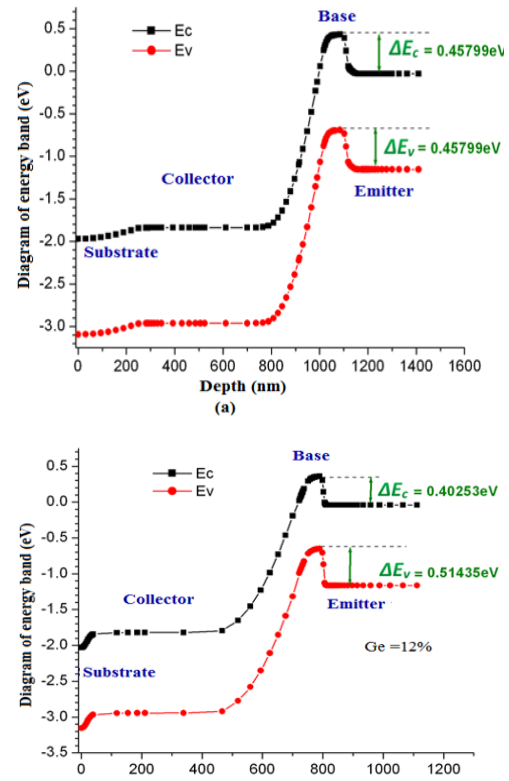


Figure 5. Diagram of energy bands in both types of transistors : a) TB-Si & b) HBT-SiGe

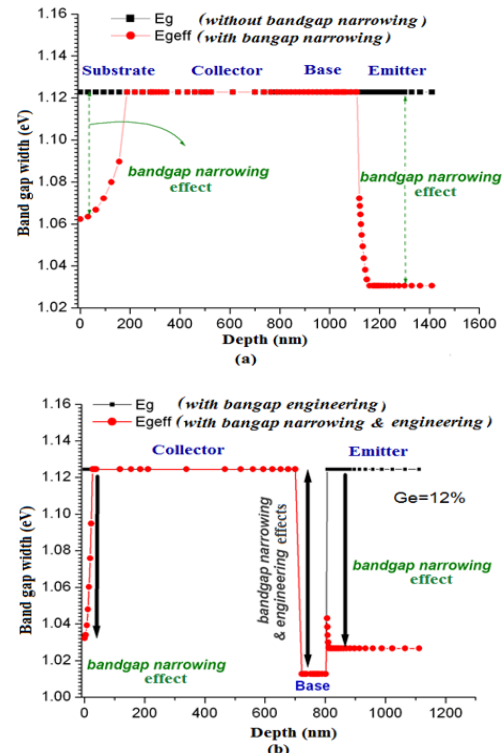


Figure 6. Band gap widths in both types of transistors: a) TB-Si & b) HBT-SiGe

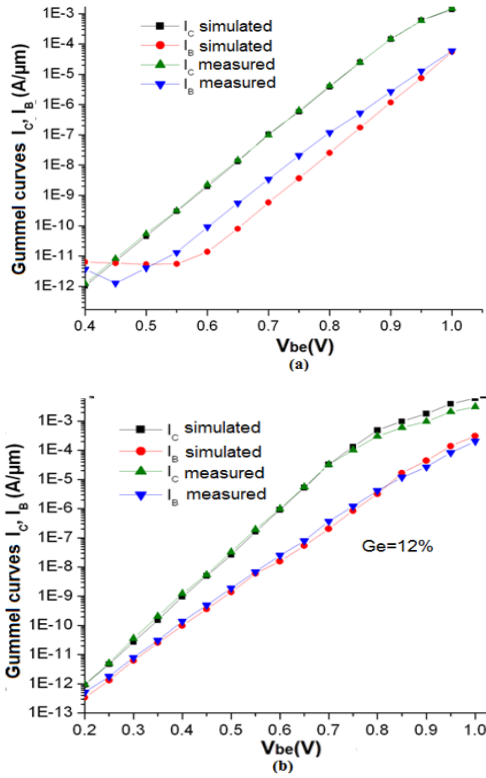


Figure 7: Gummel curves in both types of transistors: a) TB-Si & b) HBT-SiGe

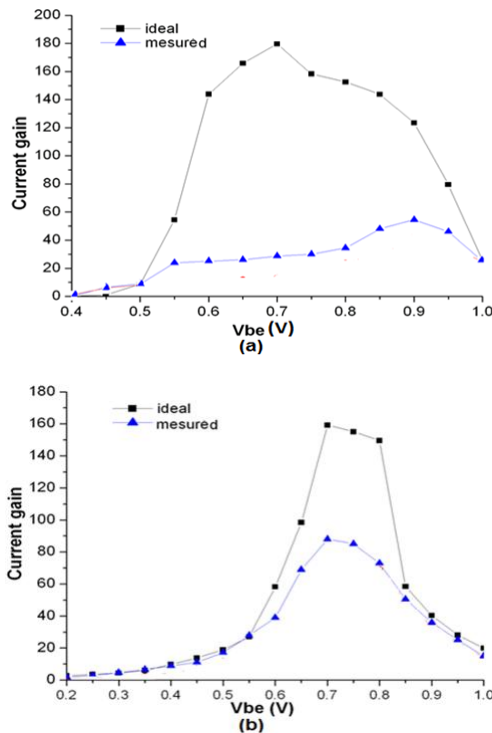


Figure 8. Variation of current gain in both types of transistors: a) TB-Si & b) HBT-SiGe

In fact, it has been found that in low and medium injection, the base current and the current gain (figure 8) of the self-aligned bipolar transistor differ greatly from those measured experimentally. However, with the quasi-self-aligned architecture, this gap is smaller. On the other hand, in strong injection, and in both types of transistors, the electrical characteristics are very close to those obtained experimentally. To interpret this phenomenon, we think that BT-Si is more exposed than HBT-SiGe to etch defects [9-10]. The latter induce generation-recombination centers [11-13] which tend to trap the holes thus increasing the component of the recombination current that will be added to the base current. Thus, under these conditions the current gain is also reduced and more particularly in the case of TB-Si

5. Conclusion

The simulation results have allowed us to demonstrate that the introduction of germanium into HBT-SiGe structures considerably improves the efficiency of this component since this material facilitates the passage of electrons from the emitter to the base without facilitating the holes one. In addition, in the case of TB-Si, it has been found that at low and medium injection level, a fairly large difference is found between the simulated electrical characteristics and those obtained experimentally. However, for HBT-SiGe, this difference is smaller. In strong injection, in both types of transistors, the electrical characteristics are very close to those obtained experimentally.

As continue of this work, we plan to study the influence of engraving defects in order to explain this difference and take it into account in our equations in order to correct our simulation model.

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