ORIGINAL PAPER

IMPROVEMENT OF THE STATIC AMPLIFICATION FACTOR β IN THE CASE OF BJT

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Abstract. *A junction made of two materials of the same type is named homojunction. If the two regions of junction are made of different types of semiconductors, then we talk about a heterojunction. The paper submits to your attention some ways of improving the values of a very important parameter of the bipolar junction transistors (BJT), namely the current static amplification factor (β). A new phase in the evolution of the semiconductor devices is the manufacturing and using of the heterojunctions on a large scale.*

Keywords: *BJT, base current transport factor, injection efficiency, current static amplification factor, Matlab.*

1. INTRODUCTION

The bipolar junction transistor is made of two back to back junctions (e.g. PN) P region of the first junction issues carriers in base N and is called emitter, and the other region P collects them and is named collector. If the base is thick, the carriers injected by the emitter disappear by recombination process before reaching the collector. There are only two diodes that do not collaborate.

The bipolar junction transistor is made of three regions: emitter (E), base (B) and collector (C). The emitter and collector have the same type of doping, while the base situated between the emitter and collector has an opposite type of doping.

If the base is thin, very few carriers recombine while passing through it, the current injected by the emitter reaching almost entirely the collector. This way the two junctions are electrically coupled and form together a transistor. The device is named bipolar device because both the electrons and the gapes take part in its functioning [1-3].

According to the doping, the transistors can be PNP or NPN. They can be made using homojunctions (BJT) or heterojunctions (HBT) [4-15].

2. CALCULUS OF THE CURRENT STATIC AMPLIFICATION FACTOR

BJT transistors function in three configurations: common emitter, common base and common collector. In what concerns the current amplification, the static gain β in arrangement with a common emitter is the main quality factor of a transistor.

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Base current transport factor is the proportion between the current of electrons which reaches the collector-base junction and the current of electrons injected from the emitter in the situation V_{BC} =0 and is given by the relation:

$$\alpha_T \approx 1 - \frac{1}{2}\left(\frac{w_B}{L_{nb}}\right)^2 \qquad (1)$$

Injection efficiency of the emitter represents the proportion between the current of electrons injected by the emitter and the total emitter's current in the situation V_{BC} =0 and is given by the relation:

$$\gamma \approx \frac{1}{1 + \frac{D_{pe}}{D_{nb}}\frac{w_B}{w_E}\frac{N_A}{N_D}} \qquad (2)$$

The approximate relation that gives the value of the static current gain β for the BJT transistor is:

$$\frac{1}{\beta} = \frac{D_{pe}}{D_{nb}}\frac{w_B}{w_E}\frac{N_A}{N_D} + \frac{1}{2}\left(\frac{w_B}{L_{nb}}\right)^2 \qquad (3)$$

where the first term represents the injection efficiency and the second is the recombination in the base, and the equation (3) becomes:

$$\frac{1}{\beta} = \alpha_T - \frac{1}{\gamma} \qquad (4)$$

For the analysis of the static current factor we used the following constants of material:

- The proportion of the thicknesses of the neutral regions in the base w_B and in the emitter w_E is:

$$\frac{w_B}{w_E} = \frac{1}{2} \qquad (5)$$

- The diffusion length of the electrons in the base:

$$L_{nb}^2 = D_{nb} * \tau_{nb} \qquad (6)$$

where τ_{nb} is the life time of the electrons in the base;

- Diffusion coefficient of the carriers for gaps:

$$D_{pe} = 1 + \frac{12{,}5}{1 + \left(\frac{N_D}{10^{17}}\right)^{0{,}6}} \quad (7)$$

where N_D (cm^{-3}) is the density of donor atoms.

- Diffusion coefficient of the carriers for electrons:

$$D_{nb} = 1{,}8 + \frac{35}{1 + \left(\frac{N_A}{10^{17}}\right)^{0{,}6}} \quad (8)$$

where N_A (cm^{-3}) represents the density of the acceptor atoms.

- Total life time:

$$\frac{1}{\tau_{nb}} = \frac{1}{\tau_{Shockley}} + \frac{1}{\tau_{radiativ}} + \frac{1}{\tau_{Auger}} \quad (9)$$

where:

$$\tau_{Shockley} = \frac{\tau_0}{1 + \frac{N_A}{K}}, \quad (10)$$

is the Shockley – Read – Hall recombination life time:

$$\tau_{radiativ} = \frac{1}{B_n N_A}, \quad (11)$$

represents the radiative recombination life time; B_n is a constant;

$$\tau_{Auger} = \frac{1}{C_n N_A^2}, \quad (12)$$

represents the Auger recombination life time.

From the relations (10), (11) and (12) in (9) and taking into account the constants $K=7*10^{15}$, $B_n=2*10^{-14}$, $C_n=10^{-31}$, results:

$$\frac{1}{\tau_{nb}} = \frac{1 + \frac{N_A}{7*10^{15}}}{\tau_0} + 2*10^{-14} * N_A + 10^{-31} * N_A^2. \quad (13)$$

2. ANALYSIS OF THE CURRENT STATIC AMPLIFICATION FACTOR β IN RELATION WITH THE BASE DENSITY, FOR VARIOUS THICKNESS VALUES OF THE BASE IN THE CASE OF A BJT TRANSISTOR USING MATLAB

The analysis of the transport factor through the base was made using Matlab [16]. The results are shown by the following acquired diagrams (Figs. 1-3) and Tables 1-3.

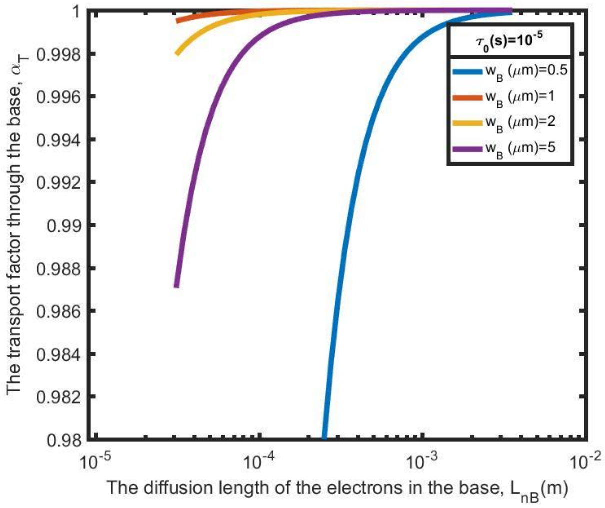

Figure 1. The transport factor through the base, α_T, depending on the diffusion length of the electrons in the base, L_{nB} (case τ_0=10^{-5} s).

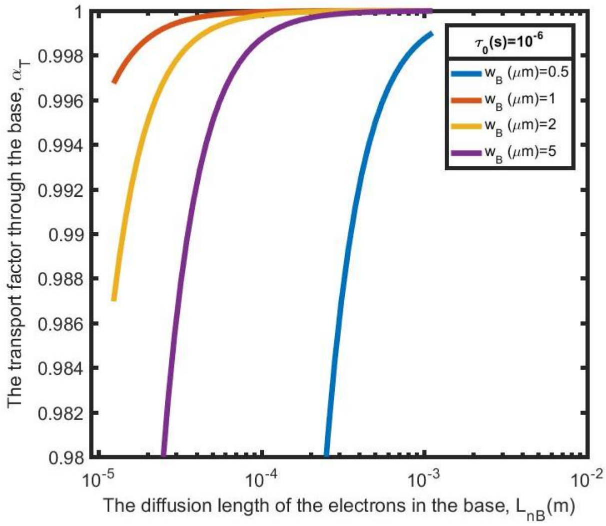

Figure 2. The transport factor through the base, α_T, depending on the diffusion length of the electrons in the base, L_{nB} (case τ_0=10^{-6} s).

Table 1. The transport factor through the base α_T for a value of the carriers life time τ_0=10^{-5} s.

α_T	L_{nB} (μm)	w_B (μm)	τ_B (s)
0.9999	95	0.5	2.86e-9
0.9996	95	1	2.86e-9
0.9984	95	2	2.86e-9
0.9901	95	5	2.86e-9

Table 2. The transport factor through the base α_T for a value of the carriers life time τ_0=10^{-6} s.

α_T	L_{nB} (μm)	w_B (μm)	τ_B (s)
0.8676	97	0.5	1.78e-9
0.9999	97	1	1.78e-9
0.9989	97	2	1.78e-9
0.9987	97	5	1.78e-9

Table 3. The transport factor through the base α_T for a value of the carriers life time τ_0=10^{-7} s.

α_T	L_{nB} (μm)	w_B (μm)	τ_B (s)
0.8702	98	0.5	0.96e-9
0.9999	98	1	0.96e-9
0.9998	98	2	0.96e-9
0.9987	98	5	0.96e-9

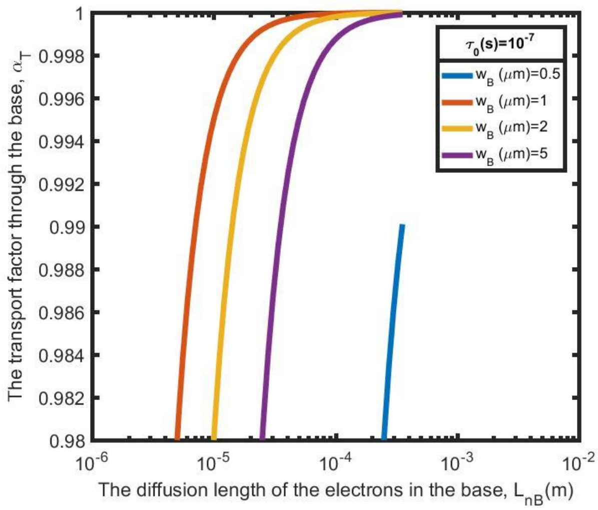

Figure 3. The transport factor through the base, α_T, depending on the diffusion length of the electrons in the base, L_{nB} (case τ_0=10^{-7} s).

From the computer analysis (Figs. 1-3 and Tables 1-3) we concluded that L_E>>w_E and L_B>>w_B, therefore both the base and emitter are thin, this condition being required in order to have an as much possible higher transport factor ($\alpha_{T,max}$=1). In addition to this condition, the transistor should have a high value life time for the minorities in the base, τ_B.

In Fig. 4 and Table 4 we highlighted another important parameter of the BJT transistors, namely the injection efficiency.

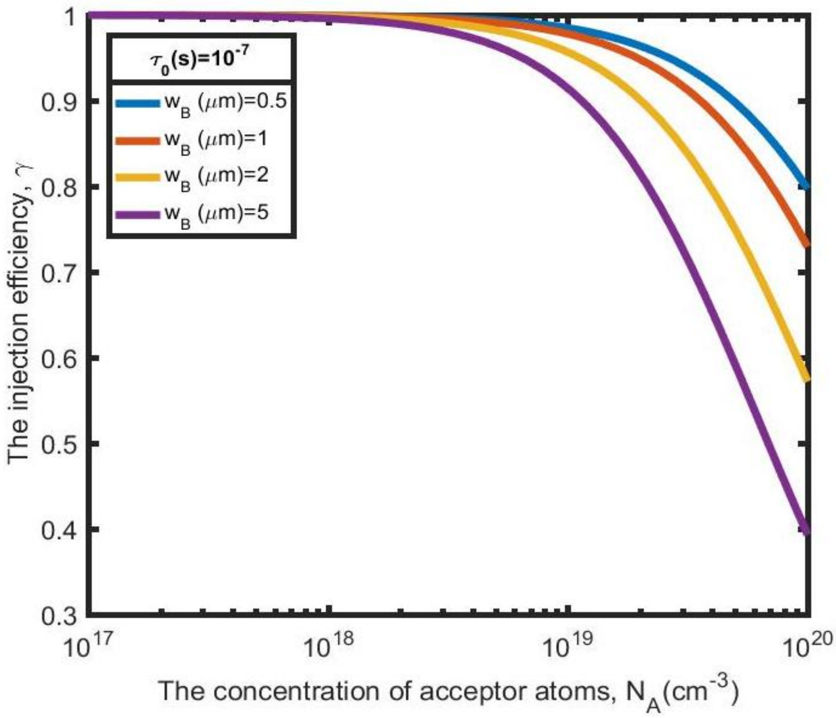

Figure 4. The injection efficiency γ in relation to the concentration of acceptor atoms N_A (case τ_0=10^{-7} s).

Table 4. The injection efficiency γ for a carriers life time τ_0=10^{-7} s.

γ	L_{nB} (μm)	w_B (μm)	τ_B (s)
1	355	0.5	6.54e-9
1	355	1	6.54e-9
0.9999	355	2	6.54e-9
0.9998	355	5	6.54e-9

From Fig. 4 and Table 4 we noticed that a high level of injection efficiency (γ_{max}=1) can be obtained by minifying the proportion of the doping densities N_A/N_D. The homojunction transistors commonly use a ratio $N_A/N_D \approx 10^2$.

As a result of the analysis made using Matlab, we got the following results of the static gain in the current (Figs. 5-7 and Table 5).

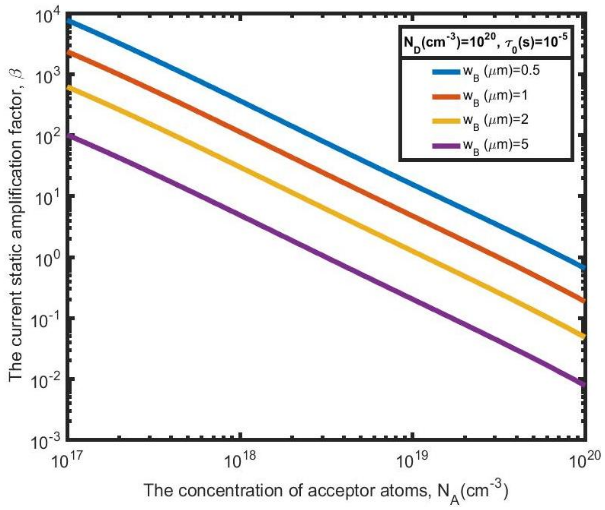

Figure 5. Variation of current static amplification factor β in relation to the concentration of acceptor atoms N_A, for various values of base thickness for the BJT transistor (τ_0=10^{-5}s).

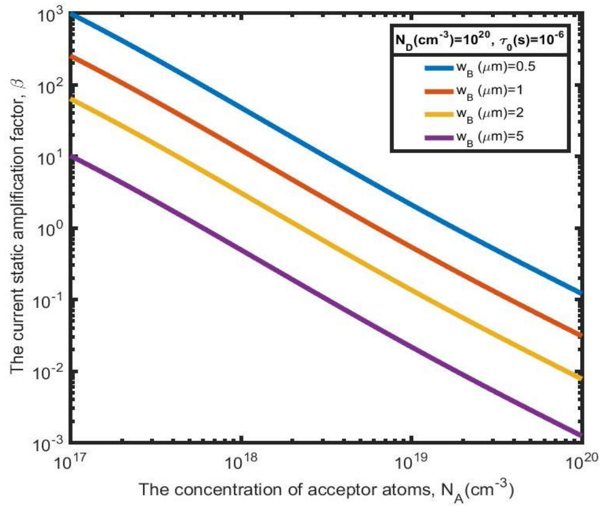

Figure 6. Variation of current static amplification factor β in relation to the concentration of acceptor atoms N_A, for various values of base thickness for the BJT transistor (τ_0=10^{-6}s).

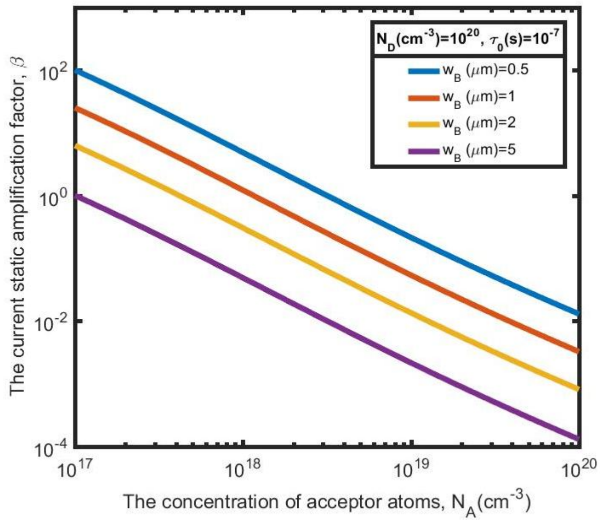

Figure 7. Variation of current static amplification factor β in relation to the concentration of acceptor atoms N_A, for various values of base thickness for the BJT transistor (τ_0=10^{-7}s)

Table 5. Current static amplification factor β.

β	α_{max}	γ	w_B (µm)	τ_0 (s)
10^4	0.9999	0.9964	0.5	10^{-5}
10^3	0.9990	0.9964	0.5	10^{-6}
10^2	0.9901	0.9964	0.5	10^{-7}

Analysing the values from Figures 5-7 and Table 5 is noticed that the current static amplification factor reaches a maximum value of 10^4 for a base thickness of 0.5 μm and a life time $\tau_0 = 10^{-5}$ (s).

3. CONCLUSIONS

The value of the static gain in the current in case of a certain transistor is influenced by the losses of minority carriers in the neutral region of the base and by the parasite injection of the carriers from the base to the emitter. In normal technological conditions the relation $L_{nb} >> w_B$ is fulfilled and recombination in the neutral base can be neglected. Therefore, the transport factor through the base is approximatively unitary, $\alpha_T \approx 1$, the current gain being determined only by the injection characteristics of the junction emitter-base.

The value of the current static gain β, in the conditions of $\alpha_T \approx 1$, becomes when we refer to the BJT transistor:

$$\beta_{\max}(BJT) \approx \frac{D_{nb}}{D_{pe}} \frac{w_E}{w_B} \frac{N_D}{N_A}$$

If D_{nb} and D_{pe}, respectively w_E and w_B, have the same size order, the relation is as following:

$$\beta_{\max}(BJT) \approx \frac{N_D}{N_A}$$

In case of a classic transistor the improvement of the current gain is realised by the maximisation of the proportion between the emitter density and base density. The condition $\beta_{\max} \geq 100$ imposes the projection relation for the BJT transistor,

$$\frac{N_D}{N_A} \geq 10^2.$$

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