Numerical Investigate of Base Doping for Minimum Base Transit Time

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Abstract—In this paper numerical optimum base doping for minimum base transit time is presented. The bandgap-narrowing effect, high-injection effect, and carrier velocity saturation at the base edge of the base collector junction, and also doping and field dependence of mobility, are considered. Many doping profile are investigated including, linear, exponential doping concentration, we assumed uniform, exponentially and Gaussian doping profiles .Base transit time is investigated numerically for optimum base doping profile.

Keywords- Base transit time, bipolar junction transistors, high injection

I. INTRODUCTION

The time that the minority carriers take to traverse the quasi-neutral base of a bipolar junction transistor (BJT) is called base transit time τ_B and is important in determining different performance parameters like the unity gain cut-off frequency f_T, the maximum frequency of operation $f_{\mathbf{max}}$ and the noise figure of a BJT. Modern high speed bipolar transistors request optimum base doping profiles and high collector current densities. to reduce base transit times τ_B [l, 2]. Suzuki has proposed an analytical J, and τ_B for a uniform doping base and expression for the current density, J, and high injection levels [3], and developed it for arbitrary base doping profiles before the onset of the Kirk effect using a perturbation method [4].

Since the early work of Moll and Ross [5], a great deal of interest has focused on developing simple analytical formulations for the minority carrier distribution and current in the base region of bipolar transistors. Such analytical models increase insight into the dependence of the device performance on physical and technological parameters, and are a useful tool in device design and optimization. In addition, closed form analytical models for the base region are extremely useful for developing compact models for BJTs [6, 7] and HBTs[8].

In this paper, based on analytical relations [9, 10, and 11] the optimum base doping profile for a minimum base transit time is investigated. This paper is organized as follows. Section 2 explains an analytical model valid at any injection level before the onset of the Kirk effect, and for arbitrary base doping profiles. Section 3 presents the numerical results for different base doping concentration and the results are discussed. Conclusions are given in Section 4.

II. THEORY

For a p-type base region, the electrical field E(x), the collector current density J_n, the electron profile n(x), and the base transit time τ_B can respectively be expressed as [9]:

$$E(x) = V_T \frac{d}{dx}[\ln(\frac{n+N_B}{n_{ie}^2})] \quad (1)$$

$$J_n = \frac{qn_i^2 \exp(V_{BE}/V_T)}{\sqrt{\frac{n_i^4 \exp(V_{BE}/V_T)}{v_s \cdot n_{ie}^2(W_b)} + \frac{1}{4}[\frac{n_i^2 \cdot N_B(W_b)}{v_s \cdot n_{ie}^2(W_b)} + \int_0^{W_b} \frac{n_i^2}{n_i^2 \cdot D_n}(n+N_B)dx]^2} + \frac{1}{2}[\frac{n_i^2 \cdot N_B(W_b)}{v_s \cdot n_{ie}^2(W_b)} + \int_0^{W_b} \frac{n_i^2}{n_i^2 \cdot D_n}(n+N_B)dx]} \quad (2)$$

$$n(x) = [J_n \cdot n_{ie}^2 \cdot \int_x^{W_b} \frac{n+N_B}{qn_{ie}^2 D_n} d_x + \frac{J_n \cdot n_{ie}^2}{n_{ie}^2(W_b)qv_s}[\frac{J_n}{qv_s} + N_B(W_b)] + \frac{N_B^2}{4}]^{\frac{1}{2}} - \frac{N_B}{2} \quad (3)$$

Upon calculating $n(x)$ and J_n, base transit time is determined from:

$$\tau_b = q \cdot \int_0^{W_b} n(x)dx / J_n \quad (4)$$

With the boundary condition $n(W_b) = J_n / q v_s$. Here, N_B is the base doping profile, V_T the thermal voltage, n_{ie} the effective intrinsic carrier concentration, q the electron charge, D_n the electron diffusion coefficient, v_s the saturate velocity at b-c junction, W_b the base width, and V_{BE} the e-b junction voltage drop. The electron mobility is a

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function of N_B and E [10, 11]. Equations (1)-(3) are non-linear and must be solved iteratively. Utilizing a suitable set of initial conditions can greatly minimize the computation time and lead to calculation results with acceptable accuracy. The analytical solutions for the base transit time and the collector current density are achievable for low injection initial conditions [13]. According to Equations (1)-(3),

$$E(x) = f_1(n, N_B) \quad (5)$$

$$J_n = f_2(n, N_B) \quad (6)$$

$$n(x) = f_3(n, J_{nL}, N_B) \quad (7)$$

The initial conditions can be written as [13]:

$$E_l(x) = f_1(0, N_B)0 \quad (8)$$

$$J_{nl} = f_2(0, N_B) \quad (9)$$

$$n_l(x) = f_3(0, J_{nL}, N_B) \quad (10)$$

Where, the subscript ``L'' represents the low injection condition.

Using the first iteration we can obtain:

$$E_1(x) = f_1[n_L, N_B] \quad (11)$$

$$J_{n1} = f_2[n_L, N_B] \quad (12)$$

$$n_1(x) = f_3[n_L, J_{nL}, N_B] \quad (13)$$

This process is continued until the algorithm converges figure (1) shows the flowchart of iterative calculative.

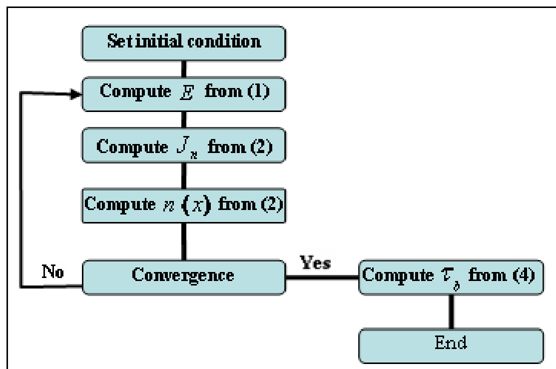

Figure 1. flowchart of iterative calculative

III. BASE DOPING PROFILE

In order to determine the optimum base doping profile, we applied various forms of base doping concentrations including, exponential, supper exponential and uniform base doping profile. For all cases we assumed velocity saturation equal to 105mS and e-b junction voltage Vbe=0.98V.

In order to considering bandgap narrowing we use: (Fig.2)

$$n_{ie} = n_i(T) \exp\left(\frac{\ln \frac{N_D + N_A}{N_0} + \sqrt{\ln^2\left(\frac{N_D + N_A}{N_0}\right) + c}}{\frac{2V_T}{V_1}} \right) \quad (14)$$

Where V1=9mv, N0=1017 and C=0.5 are constants.

A. Linear Base Doping Concentration

For linear base doping profile the peak base doping concentration 1018Cm-3 is chosen (Fig. 3):

$$N_B = -9 * 10^{24} X + 10^{18} \quad (15)$$

We assumed a base width of 100nm. For vs=105m/S, the base transit time τb found after one iteration (=11.14ps).The algorithm of Fig(1) converges after one iteration, this is shown in Fig. 4

B. Exponential and Gaussian Base Doping Concentrations

The base doping profile NB(x) is used as [12]:

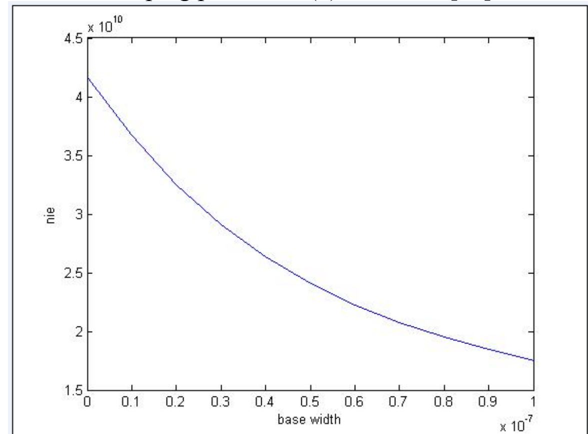

Figure 2. n_{ie} for Linear base doping profile

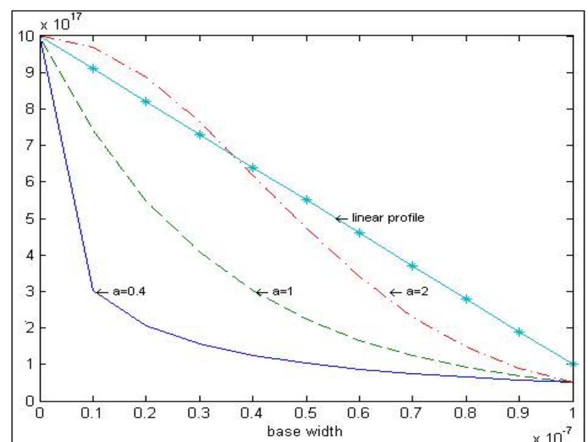

Figure 3. arious base doping concentrations

$$N_B(x) = N_0 \exp[-(\frac{x}{W_B})^{\alpha} \ln(\frac{N_0}{N_c})] \quad (16)$$

Where N0 is the peak doping concentration and N0=NB(0), N_c is the collector doping concentration and Nc=NB(WB), α is the doping profile factor, α = 1 represents the exponential profile, α = 2 the Gaussian profile (Fig.3). In this case, for an exponential base doping concentration and vs= 105m/S, the base transit time τb found after one iteration (=10.85ps) and also for the collector current density Jn the algorithm took one iteration.

For the Gaussian doping profile, with a saturation velocity vs=105mS, we found the base transit time 11.39 pS. Also, for uniform profile the base transit time is higher than previous cases and equals to 12.03pS. For more comparison we determined τb for various α values. Figure (5) shows the base transit time versus α.

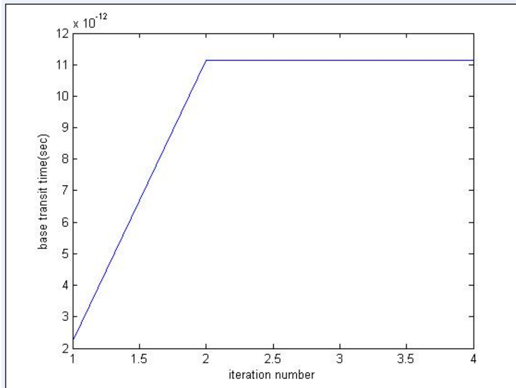

Figure 4. τ_b with V_{BE}=0.98v, N_c=5*10^5cm^-3

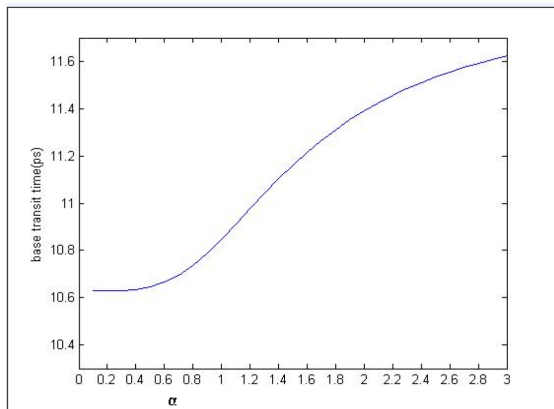

Figure 5. Base transit time for α=0.1 to 3

IV. CONCLUSIONS

In this paper numerical analysis of base transit time of a bipolar junction transistor is presented. The base transit time for various base doping profiles, such as exponential, Gaussian and linear, have been investigated based on a general exponential formula. The optimum base doping profile for minimum base transit time has been observed for exponent factor α=0.4.

REFERENCES

[1] P. J. Van Wijnen and R. D. Gardner, IEEE Electron Device Lett. EDL-II, 149 0990).

[2] J. S. Yuan, IEEE Trans. Electron Devices ED-41, 212(1994).

[3] K. Suzuki, Solid-St. Electron. 36, 109 (1993).

[4] K. Suzuki, IEDM, p. 409 (1992).

[5] Mall, J. L. and Ross, I. M.. Proc. IRE, 1956, 44, 72

[6] Graaff, H. C. and Kloosterman, W. J.. IEEE Trans. Electron. Devices, 1985, ED-32, 2415.

[7] de Graaff. H. C. and Klaassen, F. M., Compact Transistor Modelling for Circuit Design, Springer Verlag, New York, 1990

[8] Ryum, B. R. and Abdel-Motaleb, M., Solid-St. Electron., 1991, 34, 1125.

[9] Ma, P., Zhang, L. and Wang, Y.,Analytical model of collector current density and base transit time based on iteration method, Solid-State Electronics, 1996, 39, 1683±1686

[10] Slotboom, J. W. and de Graaf, H. C., Measurement of bandgap narrowing in Si bipolar transistors, Solid State Electronics, 1976, 19, 857±862

[11] Caughey, D. M. and Thomas, R. E., Carr mobile ties in silicon empirically related to doping and field ,Proc. IEEE, 1967, 52, 2192±2193.

[12] K. Suzuki, IEEE Trans. Electron Devices ED-38, 2128 (1991).

[13] Ma, P., Zhang, L. and Wang, Y., Analytical model of collector current density and base transit time based on iteration method, Solid-State Electronics, 1996, 39, 1683-1686