Effects of Physical Models on Bipolar AC Characteristics

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1. Introduction

Physical models are important for the accuracy of bipolar device simulation. We have proposed the physical models for the mobility μ [1] and the apparent bandgap narrowing ΔE_g^{app} [2], and obtained an excellent agreement between the simulation and measurement of DC current-voltage characteristics [2].

However, the effects of physical models are combined in the DC characteristics [3]. Thus, the validity of individual physical models is not proved from DC measurements only. In order to confirm the physical models, an AC measurement for the cutoff frequency f_T is necessary.

In this article, the effects of individual physical models on f_T are discussed, using a small-signal AC analysis implemented in a two-dimensional device simulator MOS2C [4]. Also, the simulated values for f_T are compared with measurements.

2. Physical Models

Mathiessen's rule has been used for joining the minority carrier mobility $\mu_{minority}$ and the majority carrier mobility $\mu_{majority}$ [1]. In this work, we adopted a minority hole mobility $\mu_{p,\ minority}$ proposed by Law et al. [5] instead of that by Swirhun et al. [6], since $\mu_{p,\ minority}$ by Swirhun et al. was not self-consistent with the hole diffusion length data [5].

Figure 1 shows ΔE_g^{app} for measurement and models. The measured values by del Alamo and Swanson [7] were recalculated based on the corrected intrinsic carrier concentration n_i by Green [8] and the reliable data for $\mu_{p,\ minority}$ by Law et al. [5]. The proposed model is as follows.

$$\Delta E_g^{app} = q\ V_1\ \ln\left[\frac{1 + (N/N_0)^{\alpha}}{1 + (N/N_1)^{\alpha}}\right] \tag{1}$$

where $N = N_D^+ + N_A^-$, $V_1 = 25.16$ mV, $N_0 = 4\times10^{17}\text{cm}^{-3}$, $N_1 = 3\times10^{20}\text{cm}^{-3}$ and $\alpha = 0.8$.

3. Effects of physical models on f_T and comparison with measurements

Figure 2 shows the impurity profiles for the intrinsic region of bipolar transistors with the metal contacted emitter, where the SIMS profiles for arsenic, boron, and antimony were incorporated. These profiles were extended in two dimensions, and used for device simulation.

Figure 3 shows the effects of individual physical models on the $f_T - I_C$ characteristics for the epitaxial collector width $W_{epi} = 0.53$ µm. Starting with conventional models, the model for n_i, ΔE_g^{app} and $\mu_{majority}$ were subsequently replaced by the proposed models. The use of the proposed ΔE_g^{app} results in a decrease in the hole storage charge in the neutral emitter, so that f_T is increased. On the other hand, f_T depends weakly on n_i and $\mu_{minority}$. Since n_i has the same effect on both the storage charge Q and I_E, the delay time related to Q / I_E has a weak dependence on n_i. A difference between with and without $\mu_{n,\ minority}$ is small, since the base impurity concentration is less than $3\times10^{18}\text{cm}^{-3}$. For this bipolar transistor, only the effect of ΔE_g^{app} is seen in the $f_T - I_C$ characteristics.

Figure 4 shows comparisons between the simulated and measured $f_T - I_C$ characteristics for $W_{epi} = 0.19$, 0.53 and 0.83 µm. The symbols show the measured values obtained by on-wafer measurements. The simulated $f_T - I_C$ characteristics using the proposed models show sufficient agreements with the measurements, which confirms the validity of the proposed model for ΔE_g^{app}.

References

[1] N. Shigyo et al., Solid-St. Electron., **33** , p. 727, 1990.
[2] N. Shigyo et al., IEICE Trans., **E75-C** , p. 156, 1992.
[3] J. A. del Alamo et al., Solid-St. Electron., **28** , p. 47, 1985.
[4] T. Kobori and T. Wada, IEICE Trans., **E74** , p. 1634, 1991.
[5] M. E. Law et al., IEEE Electron Device Letters, **12** , p. 401, 1991.
[6] S. E. Swirhun et al., IEEE Trans. Electron Device Letters, **EDL-7** , p. 168, 1986.
[7] J. A. del Alamo and R. M. Swanson, IEEE Trans. Electron Devices, **ED-34** , p. 1580, 1987.
[8] M. A. Green, J. Appl. Phys., **67** , p. 2944, 1990.

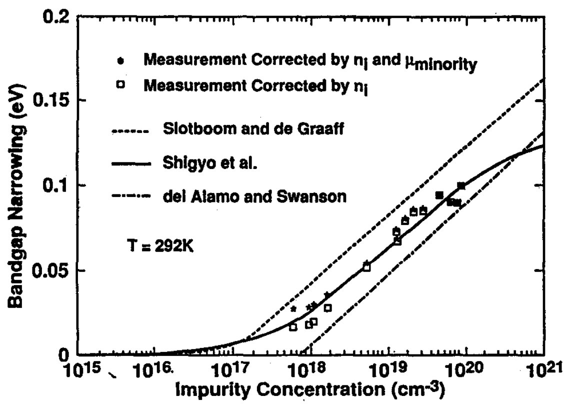

Fig. 1 Apparent bandgap narrowing ΔE_g^{app} for measurement and models.

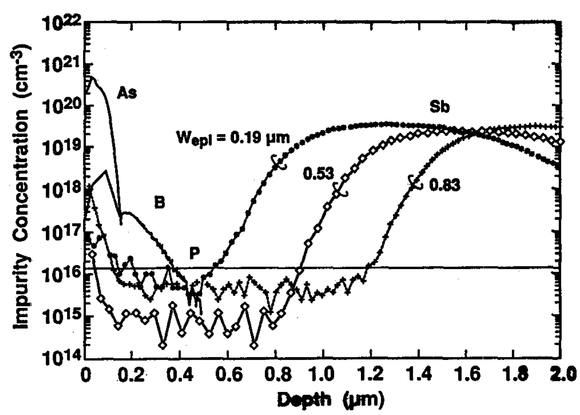

Fig. 2 Impurity profiles for intrinsic bipolar region.

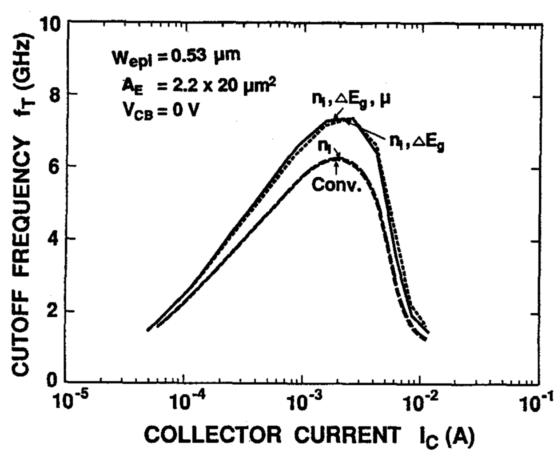

Fig. 3 Influences of individual physical models on $f_T - I_C$ characteristics.

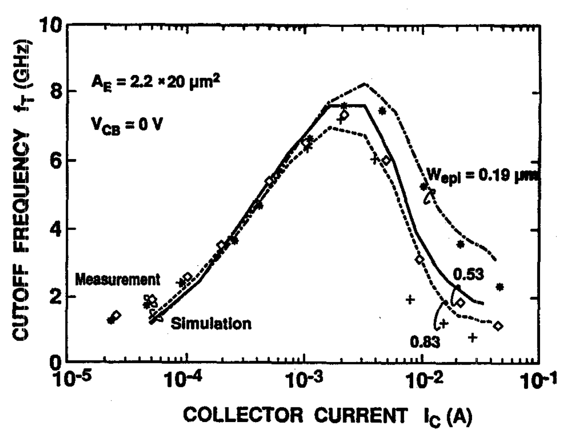

Fig. 4 Comparison between simulations and measurements.