ANALYSIS OF BIPOLAR TRANSISTOR'S $f_T - I_C$ CHARACTERISTICS BY TWO DIMENSIONAL DC AND AC DEVICE SIMULATION

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Abstract

We have developed a two dimensional DC/AC bipolar device simulator. By using it, we have investigated $f_T - I_C$ characteristics of bipolar transistors, and have found some differences between DC and AC results. The differences are due to approximation errors in τ_{EC} of Gummel-Poon's model.

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We have developed a two dimensional bipolar device simulator. It has DC and AC analysis programs. Using our simulator, we have investigated differences of $f_T - I_C$ characteristics derived from DC analysis and AC analysis.

We use the decoupled method given by Gummel [1] for DC analysis. The system of Poisson's equation is solved by the ICCG method and each system of hole and electron current continuity equations is solved by the ILUCGS method.

We use the coupled method for AC analysis. The AC system is obtained by sinusoidal steady state technique. And it is solved by the block-ILUCGS method which is modified to solve complex matrix.

Both of these programs include physical models shown in Table 1.

In DC analysis, the cut-off frequency f_T is calculated by Gummel's method [2]. According to this method, f_T is given by

$$f_T = \left. \frac{1}{2\pi\tau_{EC}} \right|_{f \to 0} \qquad (1)$$

where τ_{EC} is the emitter-to-collector delay time which is given by Gummel-Poon's charge control model as follows [3].

$$\tau_{EC} = \left. \frac{dQ_b}{dI_C} \right|_{V_{CE}=\text{constant}} \qquad (2)$$

· S R H recombination
· Auger recombination
· Impurity concentration, electric field and temperature dependent mobility
· Impurity concentration dependent carrier life time
· Slotboom's band gap narrowing model

Table.1 Physical models included in simulator programs.

On the other hand, in AC analysis, f_T is obtained by extrapolation with -6db/octave curve in $|h_{fe}|$ - f characteristics. Here, h_{fe} is a small signal common emitter current gain.

We analized bipolar transistors having different epi-thicknesses. Fig.1 shows a schematic cross section of the analized transistor. Fig.2 shows the impurity profile of a 2.0-μm-epi transistor. Fig.3 shows the impurity profile of a 1.0-μm-epi transistor. The latter has the same cross section as Fig.1. Results of calculation are shown in Fig.4 and Fig.5.

From Fig.4, we have found the difference between DC analysis and AC analysis. In case of AC analysis, the falloff in f_T at high collector current is much lager than DC analysis. In case of the thinner epitaxial layer (Fig.5), the difference is not as large as that of Fig.4.

These diferences between DC analysis and AC analysis are due to approximation errors in the τ_{EC} of Gummel-Poon's model.

References

[1] H.K.Gummel,"A self-consistent iterative scheme for one-dimensional steady state transistor calculations",IEEE Trans.,Electron Devices, vol.ED-11,pp.455-465,1964

[2] H.K.Gummel,"On the Definition of the Cutoff frequency f_T",Proc.IEEE 57,p.2159,1969

[3] H.K.Gummel and H.C.Poon,"An Integral Charge control Model of Bipolar Transistors",The Bell System Technical Jounal,May-June 1970,p.827

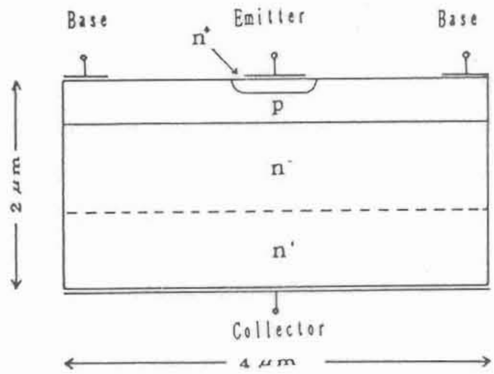

Fig.1 Schematic cross section of an analyzed bipolar transistor.

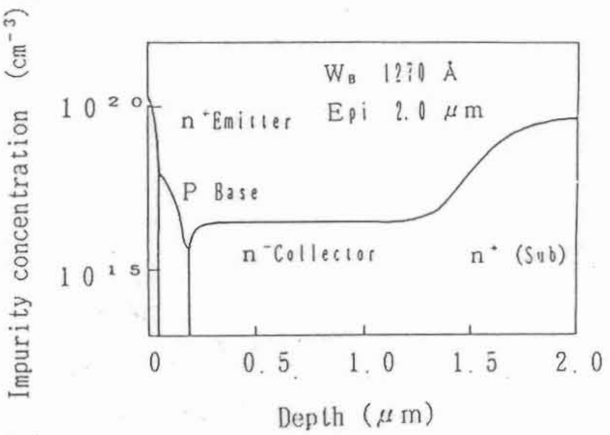

Fig.2 Impurity profile of a 2.0-μm-epi transistor.

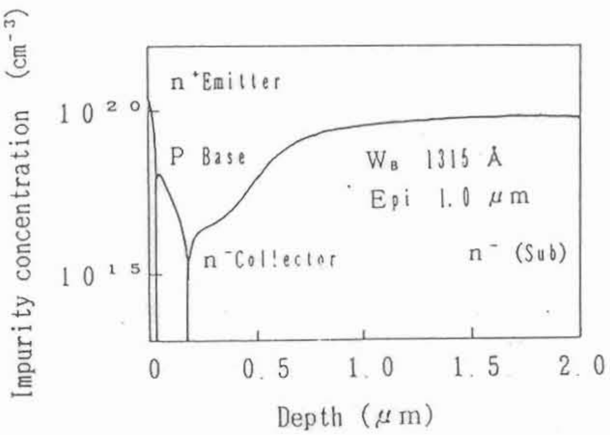

Fig.3 Impurity profile of a 1.0-μm-epi transistor.

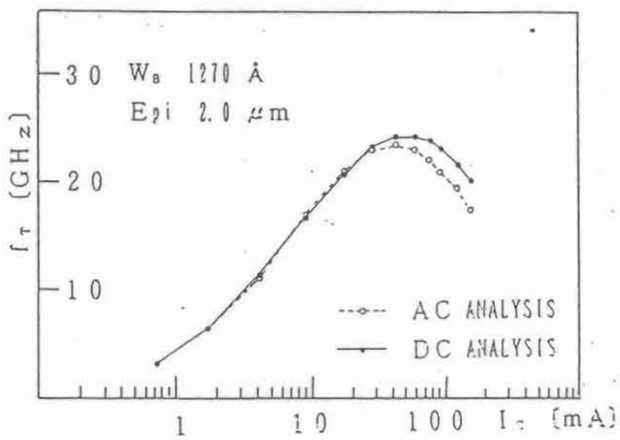

Fig.4 $f_T - I_c$ characteristics of a 2.0-μm-epi transistor.

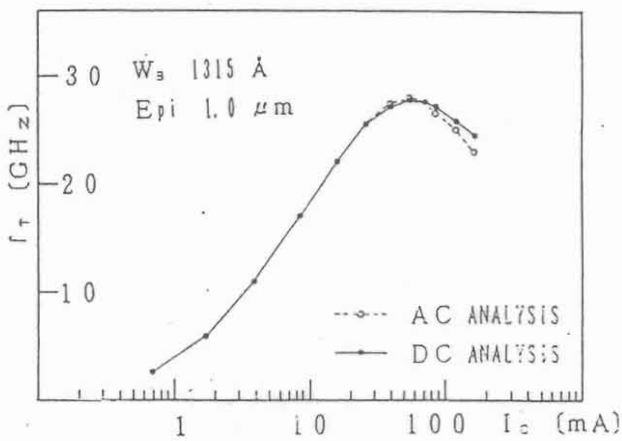

Fig.5 $f_T - I_c$ characteristics of a 1.0-μm-epi transistor.