(4A-3)

Analysis of Collector Base Junction Avalanch using an Energy Transport Model

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Introduction

The collector doping concentration must be high to prevent the Kirk effect[1], which deteriorates performance at high current density. An increased collector doping concentration strengthens the electric field at the base collector junction, however, abruptly increasing the avalanche multiplication. Avalanche multiplication thus must be evaluated to optimize the collector doping concentration.

Simulation

The impact ionization rate determines avalanche multiplication and is dependent on the carrier energy. The exact carrier energy must be obtained to determine multiplication. We solved energy conservation equations using relaxation time approximation. The modified Scharfetter-Gummel method[2] is used to obtain a self-consistent solution when we make the energy conservation equations discrete.

Ionization Model

We use an empirical impact ionization model[3].

$$\alpha = a\exp(-b / E)$$

E represents electrical field in the drift-diffusion model (DDM) which solves the Poisson and carrier conservation equations. Carrier energy is assumed to be constant ε_0. E represents the effective electrical field in the energy transport model (ETM), which solves the Poisson equation, carrier conservation equations, and energy conservation equations. The effective electrical field is related to carrier energy ε[4],

$$q\tau_W \mu(E) E^2 = \varepsilon - \varepsilon_0$$

The ETM model is more accurate than DDM in obtaining the exact impact ionization ratio, because impact ionization depends strongly on the carrier energy, not the electrical field.

Definition of ξ

Avalanche multiplication decreases the base current (Fig. 1) because the generated carrier (hole in the npn transistor) flows to the base terminal. To evaluate the avalanche multiplication, we used the notation ξ, defined as[5]:

$$\xi(V_{BC}) = \frac{I_B(V_{BC}=0) - I_B(V_{BC})}{I_C(V_{BC}) - (I_B(V_{BC}=0) - I_B(V_{BC}))}$$

ξ corresponds to the number of electron-hole pairs generated by a carrier when it moves through a base-collector junction depletion region. ξ does not depend on the collector currents (Fig. 2). ξ is insensitive to mobility, and the bandgap narrowing model. Thus, ξ is influenced only by the avalanche multiplication.

We assumed the allowable base current to be zero. The critical value of ξ is approximately $1/h_{FE}$. Here, h_{FE} is the current gain at V_{BC}=0.

Comparison with Experiment

Figure3 shows experiment and calculated results. Here, we used an epitaxial base transistor (EBT)[6]. The resistivity of the collector epitaxial region was 0.14 Ωcm. This corresponds to a doping concentration of about 7×10^{16} cm^{-3}. ξ depends strongly on the collector doping concentration (Fig. 3).

The results obtained from DDM are about ten times the experimental, so we can not evaluate the avalanche multiplication using DDM. The results obtained from ETM agree well with the experimental results at doping concentrations of about 7×10^{16} cm^{-3}, because the effective electrical field is lower than the real electrical field (Fig. 4). Thus, ETM is required to evaluate avalanche multiplication.

Figure5 shows ξ versus the collector doping concentration. If the power supply is fixed, the collector doping concentration is obtained from this relationship (Fig. 6). For example, if the power supply is fixed at 3 V, the collector doping concentration should be below 1×10^{17} cm^{-3} to prevent avalanche multiplication.

Conclusion

We evaluated avalanche multiplication using ETM, and the maximum collector concentration, N_C, determined by multiplication. N_C is 1×10^{17} cm^{-3} at a V_{BC} of 3 V.

References

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[3] W. N. Grant et al., Solid-State Electronics, p 1189, 1973
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[5] Pong-Fei Lu et al., IEEE Trans. on Electron Devices, vol. ED-36, p 1182, 1989
[6] K. Suzuki et. al, Symposium on VLSI Technology, p 91, 1989

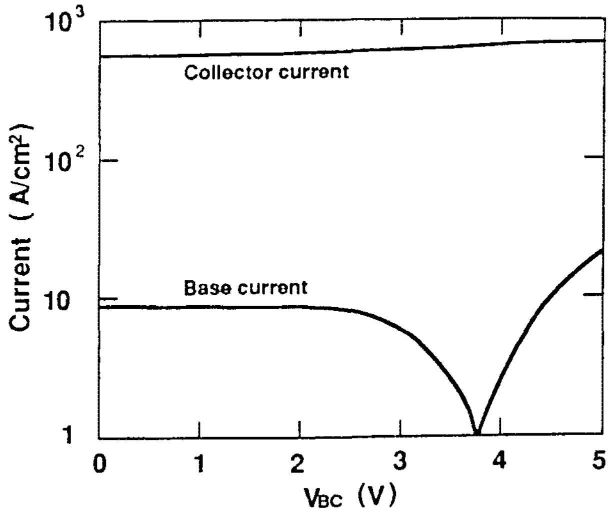

Fig. 1 Dependence of base and collector currents on V_{BC}. The Base current is decreased by the avalanche multiplication.

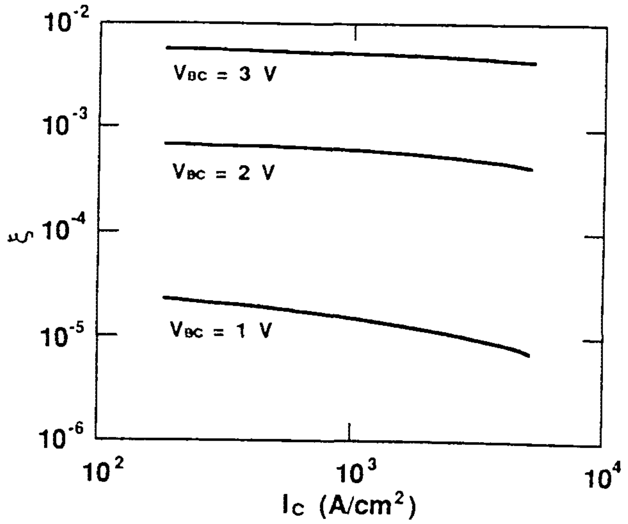

Fig. 2 ξ as a function of collector currents. ξ does not depend on the collector current.

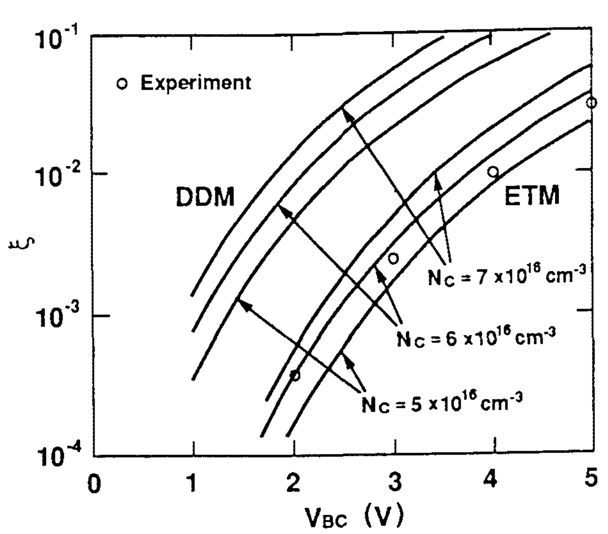

Fig. 3 ξ as a function of V_{BC}. o refers to experimental results and (-) calculation results. The results obtained from ETM agree well with experimental results.

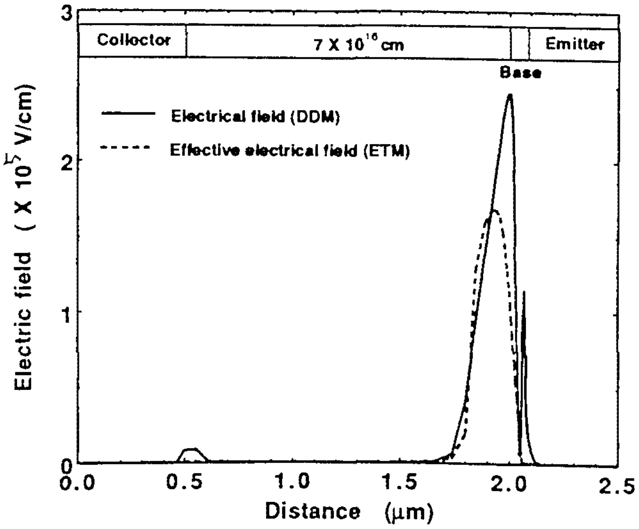

Fig. 4 Comparison of the electrical field and effective electrical field. The effective electrical field is lower than the electrical field.

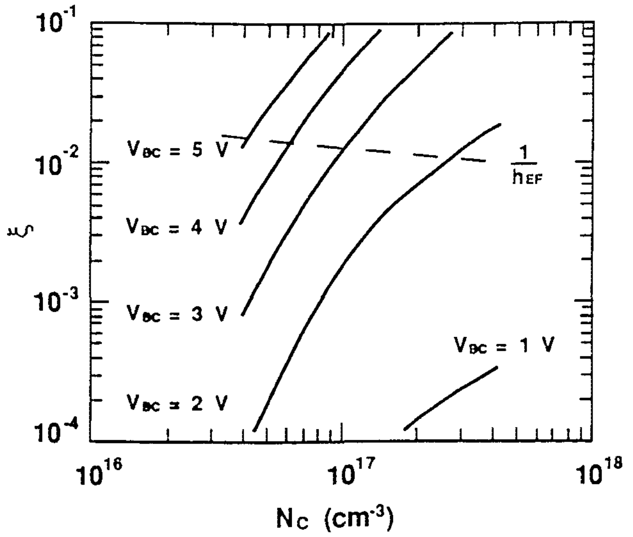

Fig. 5 ξ as a function of the collector doping concentration.

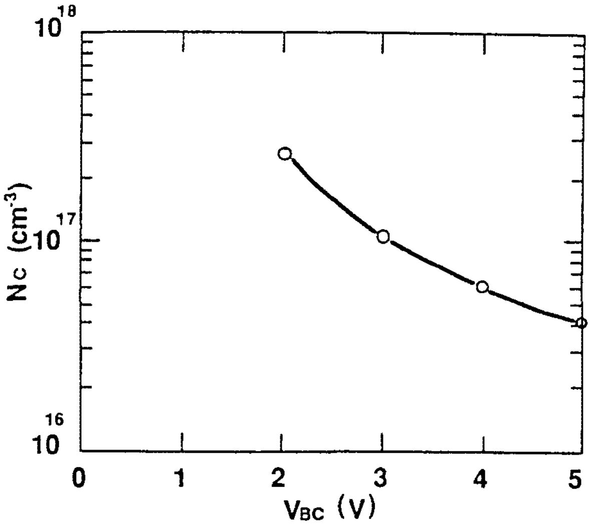

Fig. 6 Critical collector doping concentration as a function of V_{BC}.