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Experimental Study of Gamma Irradiation on Bipolar Junction Transistor

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1. Introduction

Bipolar Junction Transistor (BJT) is useful in amplifiers because the current at the emitter and collector are controllable by the relatively small base current. The ionizing radiation degrades the electrical performances in BJT devices. Ionizing radiation degradation is mainly caused by excess charge trapped on or near the surfaces of their insulating layers and interfaces. These phenomena reduce the minority carrier lifetime and decrease the current gain in the BJTs [1]. This study investigates the current characteristics of a pnp Si BJT through the gamma irradiation experiments.

2. Experimental Study

In this section, the current characteristics of a pnp BJT and the effects of ionizing radiation on BJTs are examined. And the gamma irradiation effects on the currents of BJT are investigated through the experiments.

2.1 Ionizing Radiation Effects on BJTs

BJT is composed of an emitter, a base, and a collector. In pnp BJT, the forward-biased junction that injects holes into the center n-region is called the emitter junction, and the reverse-biased junction that collects the injected holes is called the collector junction. If the saturation current at the collector region is neglected, the collector current is made up entirely of those holes injected at the emitter that are not lost to recombination in the base region. It is clear that the emitter current flows into the emitter of a properly biased pnp transistor, and that the collector current flows out at the collector, because the direction of the hole flow is from the emitter to the collector [2].

The amount of ionizing radiation degrades the electrical performances in BJT devices [1]. Radiation-induced degradation of BJT is mainly due to two operation : an increase in the net positive charge trapped in the oxide overlaying the device, and an increase of traps located near the Si-SiO_2 interface, with energy levels near mid-gap [3][4]. These two phenomena change the carrier balance all along the device surface and the near the interface, and as a result modify the electrical characteristics of the transistor. These two phenomena have different effects in the npn transistors and the pnp transistors. For the npn devices, the trapped positive charge in the oxide covering the device spreads the emitter-base depletion region into the lightly-doped portion of the base, modifying the carrier balance, causing an increase in the recombination current. Radiation-induced interface traps also increase the base current, acting as recombination centers near the emitter-base depletion region. Since ionizing radiation introduces charge in the oxide at the surface of the device, the base current component related to the surface effects is crucial. The trapped oxide charge alters the space charge region at the surface of the device. For pnp transistors, the positive charge in the oxide depletes the p-type emitter and accumulates the n-type base. The trapped positive charges accumulated the base near the surface, moderate the increased recombination caused by the radiation-induced interface traps in the pnp transistors.

2.2 Experimental Results

General purpose pnp Si BJTs were used for the gamma irradiation experiments. The maximum ratings of the BJT are given in Table I. The pnp Si BJTs were irradiated by the gamma ray of 700 Gy (50 Gy/h) with the package state to evaluate the performances at the gamma ray range irradiated on different devices [5].

Table I: Maximum ratings of PNT BJT at 25 °C

Characteristic	Symbol	Rating
Collector-Base Voltage	V_{CBO}	-100 V
Emitter-Collector Voltage	V_{CEO}	-100 V
Emitter-Base Voltage	V_{EBO}	-5 V
Collector Current	I_C	-5 A
Base Current	I_B	-0.5 A

Fig. 1 shows the base current versus the base-emitter voltage (V_{BE}) for gamma irradiation. Fig. 2 shows the variation amount of the base current between before and after gamma irradiation. I_{B1} is the measured base current after gamma irradiation and I_{B0} is the measured base current before irradiation. It is shown in Fig. 1 and 2 that the base current is increased with gamma irradiation. This means that recombination is increased in the base region by the radiation-induced interface traps and effects on increasing of base current.

Fig. 3 shows the base-to-collector current amplification ratio (β) for gamma irradiation. Fig. 4 shows the variation amount of β between before and after gamma irradiation. β_1 is the measured base-to-collector current amplification ratio after gamma irradiation and β_0 is the measured base-to-collector current amplification ratio before irradiation. It is shown in Fig. 3 and 4 that β is decreased with gamma irradiation. This means that β is decreased by the increased recombination in the base region caused by gamma irradiation.

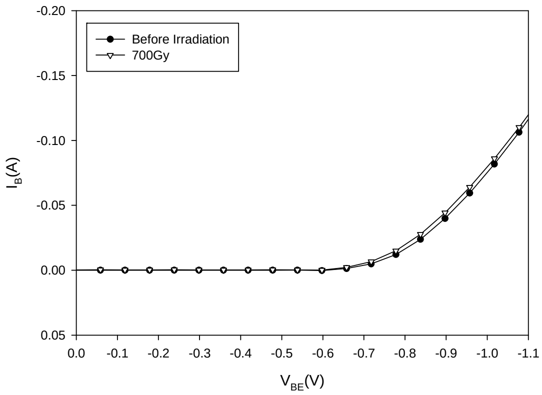

Fig. 1. Base current versus base-emitter voltage for gamma irradiation.

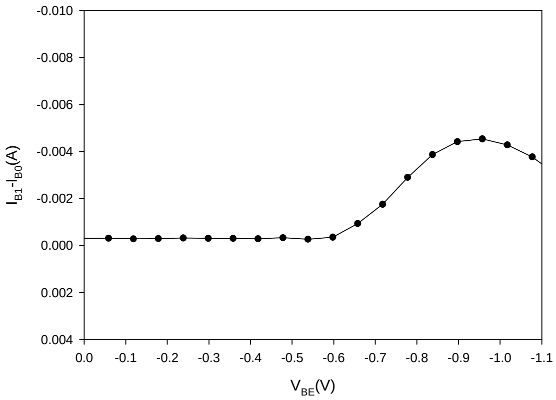

Fig. 2. Variation amount of base current for gamma irradiation.

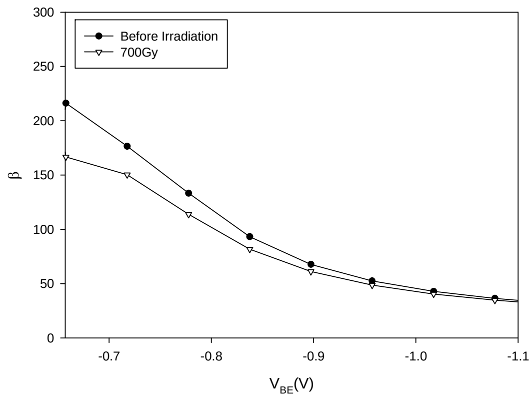

Fig. 3. Base-to-collector current amplification ratio versus collector-emitter voltage for gamma irradiation.

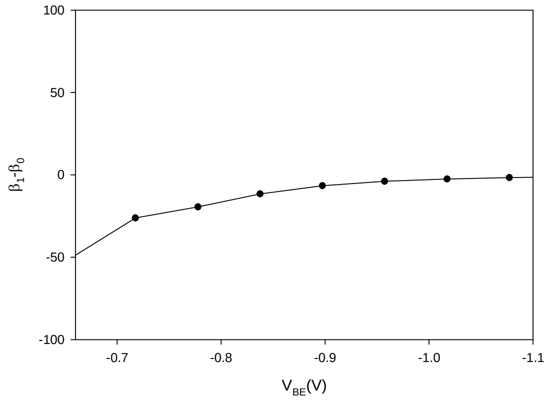

Fig. 4. Variation amount of base-to-collector current amplification ratio for gamma irradiation.

3. Conclusions

The ionizing radiation degrades the electrical performances in BJT devices. The electrical performance degradation of BJT is mainly due to an increase in the net positive charge trapped in the oxide, and an increase of traps located near the Si-SiO_2 interface. In this paper, the current characteristics of a pnp Si BJT were investigated for gamma irradiation. The experimental results show that the base current is increased and the base-to-collector current amplification ratio is decreased with gamma irradiation. These are due to the increased recombination in the base region caused by gamma irradiation.

ACKNOWLEDGEMENT

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