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Current Amplification Characteristics of BJT on Fast Neutron Irradiation

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1. Introduction

BJT (Bipolar Junction Transistor) is a three-terminal device with an important feature in that the current through two terminals can be controlled by small changes we make in the current or voltage at the third terminal. This control feature allows us to amplify small AC signals or to switch the device from an on state and off state and back. These two operations, amplification and switching, are the basis of a host of electronic functions [1]. Fast neutron irradiation incurs lattice damage in bulk Si [2]. The recombination rate of minority carriers and register are increased by the lattice damage. This study will investigate the current amplification characteristics of a pnp Si BJT through fast neutron irradiation experiments.

2. Amplification Characteristics of BJT

2.1 Current characteristic of BJT

A BJT is useful in amplifiers because the current at the emitter and collector are controllable by the relatively small base current. In a PNP BJT, the forward-biased emitter junction injects holes into the center n-region, and the reverse-biased collector junction collects the injected holes, as shown in Figure 1 [1].

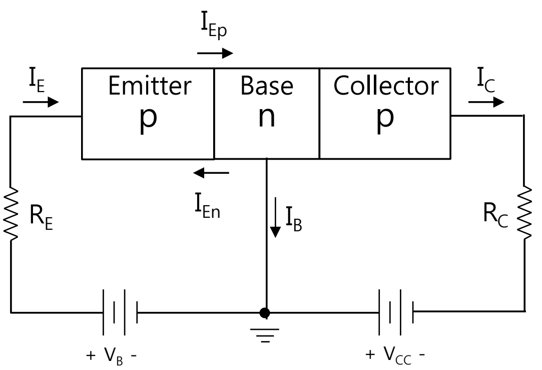

Fig. 1. pnp BJT with forward-biased emitter junction and reversed-biased collector junction.

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. Thus, I_C is proportional to the hole component of the emitter current I_{Ep} :

$$I_C = BI_{Ep}, \tag{1}$$

where B is the base transport factor, that is, injected holes that make it across the base to the collector [1]. The total emitter current (I_E) is made up of the hole component (I_{Ep}) and an electron component (I_{En}), owing to electrons injected from the base to the emitter. The emitter injection efficiency (γ) is

$$\gamma = \frac{I_{Ep}}{I_{En}+I_{Ep}}. \tag{2}$$

The current transfer ratio (α), which represents the emitter-to-collector current amplification is

$$\alpha = \frac{I_C}{I_E} = \frac{BI_{Ep}}{I_{En}+I_{Ep}} = B\gamma. \tag{3}$$

There is no real amplification between these currents, because α is smaller than unity.

In accordance with the base current, the rates at which electrons are lost from the base by injection across the emitter junction (I_{En}) and the rate of electron recombination with holes in the base region are considered. In each case, the lost electrons must be supplied through the base current (I_B). If the fraction of injected holes making it across the base without recombination is B, then it follows that $(1-B)$ is the fraction recombining in the base region. Thus the base current is

$$I_B = I_{En} + (1-B)I_{Ep} \tag{4}$$

neglecting the collector saturation current. The base-to-collector current amplification ratio (β) is found from (1) and (4) :

$$\beta = \frac{I_C}{I_B} = \frac{BI_{Ep}}{I_{En}+(1-B)I_{Ep}} = \frac{B\gamma}{1-B\gamma} = \frac{\alpha}{1-\alpha} \tag{5}$$

If the base transit factor (B) is small because B is less than unity, the base-to-collector current amplification ratio is small as well.

2.2 Fast Neutron Irradiation Effects

Fast neutron irradiation incurs the lattice damage owing to the displacement of silicon atoms. This lattice damage introduces a deep level in the silicon band gap, which acts as a recombination center [2]. A uniformity of damage can be obtained from the fast neutron irradiation method. The electrical characteristics of the Si transistor such as the base current and collector current are varied with an increase in the fast neutron irradiation fluence [3][4]. The variations of the base and collector currents owing to the fast neutron irradiation result from an increase in the recombination rate at the base region and an increase in the resistor caused by lattice damage.

2.3 Experimental Results

The MC-50 cyclotron in KIRAMS (Korea Institute of Radiological & Medical Sciences) is used for fast neutron irradiation of BJT. The pnp Si BJTs were irradiated with the package states. The irradiated fast neutron fluences is 5 x 10^{10} n/cm^2.

Figure 2 shows the base-to-collector current amplification ratio (β) versus the base-emitter voltage (V_{BE}) for before and after fast neutron irradiations. The displacement damage caused by fast neutron irradiation increases the resistor and the recombination rate of injected holes with electrons in the base region. In addition, the electrons lost to recombination in the base region must be resupplied through the base contact. Thus the base current is increased and the collector current is decreased. Finally β is decreased with increasing of fast neutron irradiation.

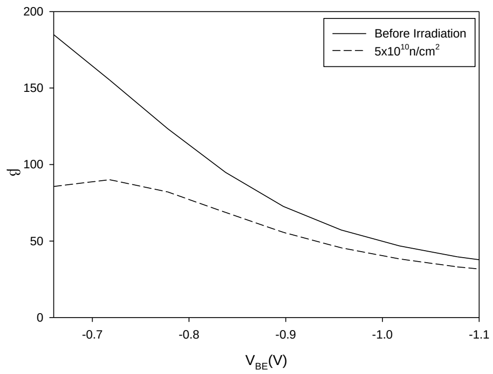

Fig. 2. Base-to-collector current amplification ratio versus base-emitter voltage for before and after fast neutron irradiation.

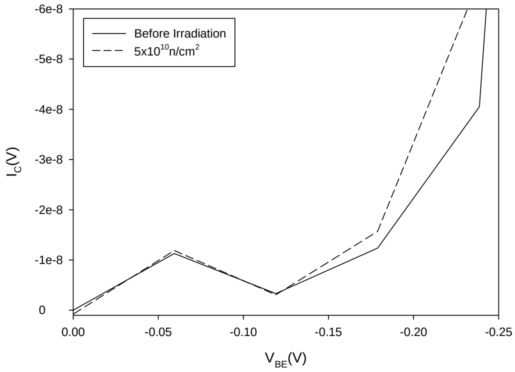

Fig. 3. Leakage current versus base-emitter voltage for before and after fast neutron irradiation.

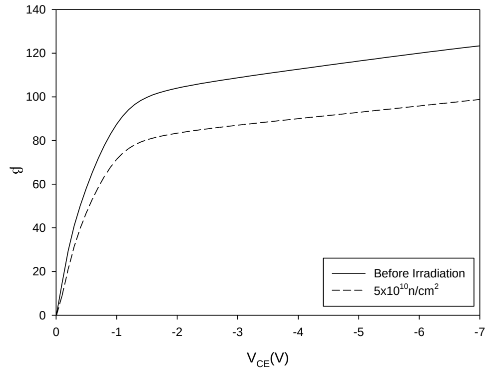

Fig. 4. Base-to-collector current amplification ratio versus collector-emitter voltage for before and after fast neutron irradiation.

Figure 3 shows the leakage collector current versus base-emitter voltage for before and after fast neutron irradiation. This result indicates that the displacement damage caused by fast neutron irradiation increases the leakage current. Figure 4 shows that β versus collector-emitter voltage (V_{CE}) for before and after fast neutron irradiation. This result indicates that the displacement damage caused by fast neutron irradiation decreases β versus V_{CE}.

3. Conclusions

In this paper, the current amplification characteristics of a pnp Si BJT were investigated for fast neutron irradiation. The experimental results show that base-to-collector current amplification ratio is decreased with an increase in the fast neutron irradiation. These indicate that the lattice damage caused by fast neutron irradiation increases the recombination rate of minority carriers and resistor.

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