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Experimental Study of Fast Neutron Irradiation on Si Transistor

Sung Ho Ahn*, Gwang Min Sun, Hani Baek, Seong Bok Jin, Sy Minh Tuan Hoang
Neutron Utilization Technology Division, Korea Atomic Energy Research Institute,
989-111 Daedeok-daero, Yuseong-gu, Daejeon, 34057, Republic of Korea
**Corresponding author: shahn2@kaeri.re.kr*

1. Introduction

Bipolar junction transistors (BJTs) are applied in many industrial fields. BJT 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].

This study will investigate the electrical characteristics of a p-n-p BJT, such as the base current and collector current for fast neutron irradiation. Fast neutron irradiation can cause displacement damage in the Si bulk [2]. The experimental results show that the base current is increased, and the collector current is decreased, with an increase in the fast neutron irradiation fluence.

2. Experimental Studies

BJT is composed of an emitter, a base, and a collector. In p-n-p 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 [1]. It is clear that the emitter current (i_E) flows into the emitter of a properly biased p-n-p transistor, and that the collector current (i_C) flows out at the collector, since the direction of the hole flow is from the emitter to the collector. Figure 1 shows the hole and electron flows in a p-n-p transistor with a forward-biased emitter junction and reversed-biased collector junction. The hole and electron flows are as follows: (A) injected holes lost to the recombination in the base, (B) holes reaching the reverse-biased collector junction, (C) thermally generated electrons and holes making up the reverse saturation current of the collector junction, (D) electrons supplied by the base contact for a recombination with the holes, and (E) electrons injected across the forward-biased emitter junction. The base current (i_B) is very small because i_E is essentially the hole current, and the collected hole current i_C is almost equal to i_E. The emitter current can be accounted for physically by following three dominant mechanisms. (a) There must be some recombination of injected holes with electrons in the base. The electrons lost to recombination must be resupplied through the base contact. (b) Some electrons are will be injected from n to p in the forward biased emitter junction, even if the emitter is heavily doped compared to the base. These electrons must also be supplied by the base current. (c) Some electrons are swept into the base at the reverse-biased collector junction due to thermal generation in the collector. This small current reduces the base current by supplying electrons to the base. The dominant mechanism in the base current is usually a recombination, and the base current can be often approximated by calculating the recombination rate in the base.

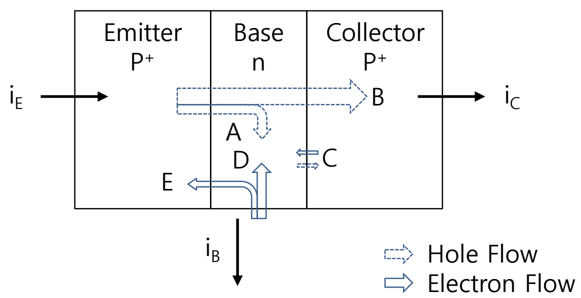

Fig. 1. Hole and electron flows in a p-n-p BJT with forward-biased emitter junction and reversed-biased collector junction.

2.1 Fast Neutron Irradiation Effects on Si BJT

The electron, proton, and fast neutron irradiation methods are used for a performance improvement of the semiconductor devices such as reducing the switching time. The lattice damage arises from the displacement of silicon atoms because of the bombardment by fast neutron irradiation. 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 increasing the fast neutron irradiation fluence. The variations of the base and collector currents after fast neutron irradiation result from an increase in the recombination rate at the base region and an increase in the resistor caused by displacement damage [2][3][4].

2.2 Fast Neutron Irradiation

In this experiment, p-n-p type Si BJTs, used for general purpose application, were applied. Fast neutron irradiation is performed using the MC-50 cyclotron in

KIRAMS (Korea Institute of Radiological & Medical Sciences). The irradiated fast neutron fluence is 5 x 10^{10} n/cm^2.

2.3 Experimental Results

Figure 2 shows the experimental results of the base and collector currents versus the base-emitter voltage for before fast neutron irradiation. Figure 3 shows the experimental results of the base and collector currents versus the base-emitter voltage for after the fast neutron irradiation. Figure 4 shows the base currents versus base-emitter voltage for before and after the fast neutron irradiation.

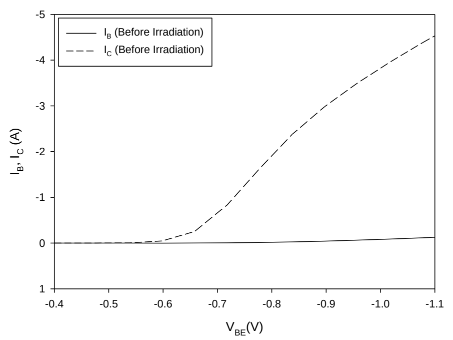

Fig. 2. Base and collector currents versus base-emitter voltage for before fast neutron irradiation.

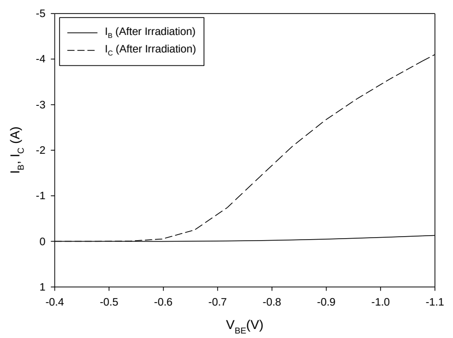

Fig. 3. Base and collector currents versus base-emitter voltage for after fast neutron irradiation.

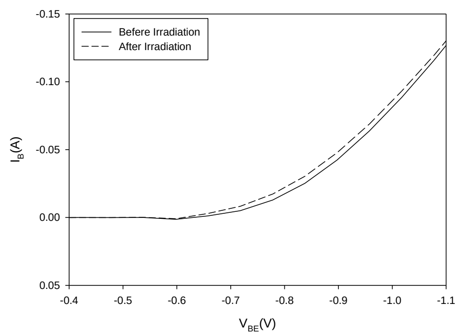

Fig. 4. Base currents versus base-emitter voltage for before and after fast neutron irradiation.

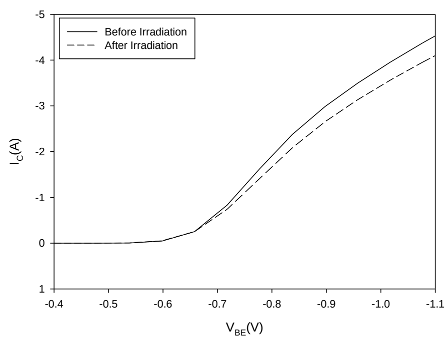

Fig. 5. Collector currents versus base-emitter voltage for before and after fast neutron irradiation.

The base current is increased after fast neutron irradiation, as shown in Figure 4. Figure 5 shows the collector currents versus base-emitter voltage for before and after fast neutron irradiation. The collector current is decreased after fast neutron irradiation as shown in Figure 5. The experimental results indicate that the displacement damage caused by fast neutron irradiation increases the recombination rate of minority carriers and the resistors.

3. Conclusions

In this paper, the electrical characteristics of a p-n-p BJT such as a base current and collector current are investigated for fast neutron irradiation. The experimental results show that the base current is increased and the collector current is decreased after fast neutron irradiation. These results indicate that the displacement damage caused by fast neutron irradiation increases the recombination rate of minority carriers and resistors.

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