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Radiation induced deep level defects in bipolar junction transistors under various bias conditions

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ABSTRACT

Bipolar junction transistor (BJT) is sensitive to ionization and displacement radiation effects in space. In this paper, 35 MeV Si ions were used as irradiation source to research the radiation damage on NPN and PNP bipolar transistors. The changing of electrical parameters of transistors was in situ measured with increasing irradiation fluence of 35 MeV Si ions. Using deep level transient spectroscopy (DLTS), defects in the bipolar junction transistors under various bias conditions are measured after irradiation. Based on the in situ electrical measurement and DLTS spectra, it is clearly that the bias conditions can affect the concentration of deep level defects, and the radiation damage induced by heavy ions.

1. Introduction

Bipolar junction transistors (BJTs) have an important application in these integrated circuits, and are susceptible to ionization and displacement radiation effects in space [1–7]. Heavy ions can induce both the ionization and displacement radiation damage in bipolar transistors, and are suitable to evaluate the space radiation damage comprehensively. However, only a few references are available on the irradiation effects of heavy ions for the BJTs, including the oxygen (O) ions [8], the lithium (Li) ions [9] and the bromine (Br) ions [10–12]. Deep level transient spectroscopy (DLTS) is a very useful tool to analyze the radiation defects, and has been used to detect and characterize the various displacement defects in bipolar transistors [13]. In this paper, an attempt is made to characterize the displacement damage in the NPN and PNP bipolar transistors irradiated by 35 MeV Si ions, based on the DLTS technique.

In space environment, electronic devices are usually under various bias conditions. The bias conditions would affect the electrical characteristics and radiation defects. The radiation damages of bipolar junction transistors irradiated by protons, electrons and Br ions with all terminals grounded was examined in references [14,15]. However, the effects of the bias conditions for the bipolar transistors irradiated by heavy ions were not understood clearly. Therefore, radiation effects on bipolar transistors induced by 35 MeV Si ions with different bias cases were examined in this study.

2. Experimental details

The 3DG130 NPN BJTs and 3CG130 PNP BJTs were used as samples in this study. The thickness is about 600 nm, 1.2 μm, 1.3 μm and 12 μm for the insulating silicon dioxide (SiO_2), the emitter (n^+), the base (p^+) and the epitaxial layer (n^-) of the 3DG130 NPN BJTs, respectively. For the 3CG130 PNP BJT, the thickness is about 600 nm, 1.0 μm, 4.0 μm and 12 μm for the insulating silicon dioxide (SiO_2), the emitter (p^+), the base (n^+) and the epitaxial layer (p^-), respectively. The area of the emitter region is $180 \times 180\ \mu m^2$, and base region is $400 \times 200\ \mu m^2$ for 3DG130 BJT. The area of the emitter region is $200 \times 125\ \mu m^2$, and base region is $250 \times 250\ \mu m^2$ for 3CG130 BJTs. These samples are from a single diffusion lot to minimize uncertainties caused by doping differences. The doping concentration is obtained from the manufacturer and confirmed by current–voltage (C–V) measurements. The collector of 3DG130 NPN BJT was doped with phosphorus to a level of $2.0 \times 10^{15}\ cm^{-3}$, and the base was boron doped to about $1 \times 10^{18}\ cm^{-3}$. For the 3CG130 PNP BJT, the collector was doped with boron to a level of $6.0 \times 10^{15}\ cm^{-3}$, and the base region was phosphorus doped to about $1 \times 10^{18}\ cm^{-3}$. The cross sections of the 3DG130 and 3CG130 BJTs are shown in Fig. 1.

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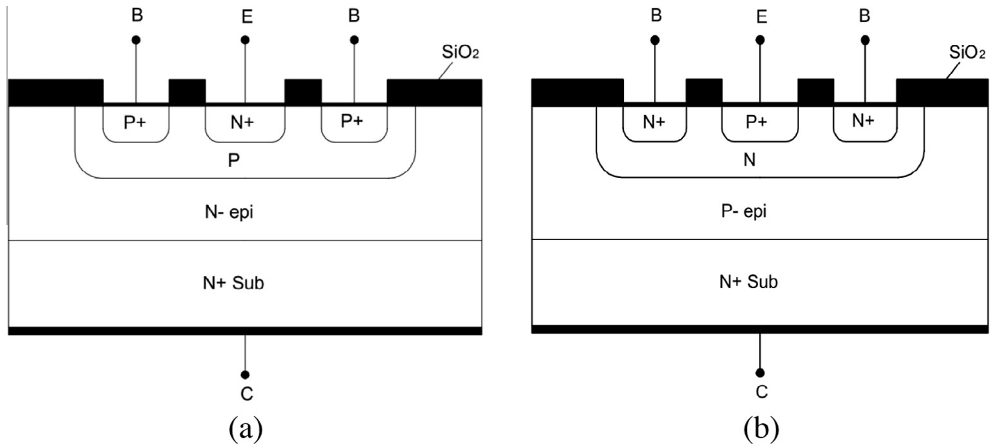

Fig. 1. Cross sections of the bipolar junction transistors: (a) 3DG130 and (b) 3CG130.

The irradiation tests were performed using the EN Tandem Accelerator in the State Key Laboratory of Nuclear Physics and Technology, Peking University, China. To prevent the incident particle energy loss generated in the device package, the device needed to be decapped during the radiation process. 35 MeV Si ions have an incident range of 12.5 μm in the BJT, and can penetrate the sensitive region of the BJTs. Therefore, 35 MeV Si ions are chosen as an irradiation source in the BJTs in this investigation.

In order to research the degradation of bipolar transistors irradiated by 35 MeV Si ions under various bias conditions, the following cases were performed:

(1) V_{BE} (V_{EB} for PNP BJTs) = V_{BC} = 0 V, all terminals grounded,
(2) V_{BE} (V_{EB} for PNP BJTs) = 0.7 V, V_{BC} = 0 V,
(3) V_{BE} (V_{EB} for PNP BJTs) = −4 V, V_{BC} = 0 V.

The irradiation and measurements were performed at room temperature. Different electrical parameters of the BJTs were measured in-situ using a semiconductor characterization system that consists of KEITHLEY 4200-SCS. Deep level defects were measured using a PhysTech HERA-DLTS (High Energy Resolution Analysis Deep Level Transient Spectroscopy) system for the bipolar transistors after irradiations, respectively.

3. Experimental results and discussion

3.1. Gummel characteristics

Figs. 2 and 3 show the variations of collector current (I_C) and base current (I_B) with V_{BE} or V_{EB} for the 3DG130 and 3CG130 transistors irradiated by 35 MeV Si ions with different fluences, respectively. During the radiation process, all terminals of the BJTs are grounded ($V_E = V_B = V_C = 0$ V).

Based on the results from Figs. 2 and 3, it is shown that the collector current (I_C) keeps invariably with the increasing fluence, while the base current (I_B) increases. These phenomena indicate that the base current (I_B) is more sensitive to the radiation damage caused by 35 MeV Si ions, while the collector current is only slightly affected by irradiation at any given base–emitter voltage value (V_{BE}). As a consequence, for these fluences, the gain degradation is mostly affected by the behavior of the base current.

3.2. Current gain degradation

Based on the above results, the current gain ($\beta = I_C/I_B$) is mostly affected by the behavior of the base current, and the collector current is only slightly affected by irradiation. Based on the

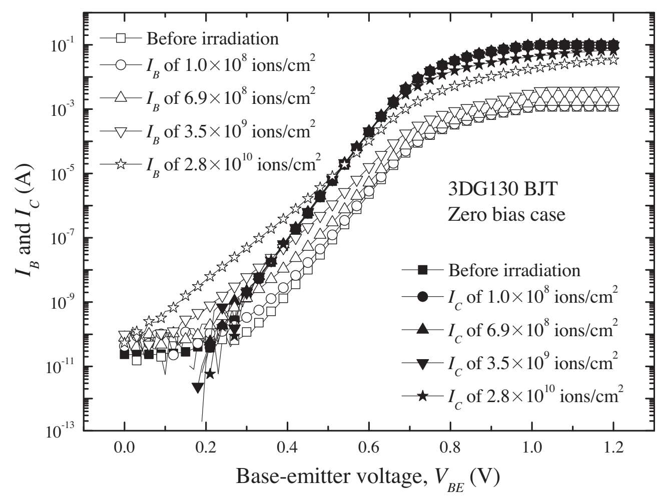

Fig. 2. Variations of collector current (I_C) and base current (I_B) with base–emitter voltage (V_{BE}) for the 3DG130 irradiated by 35 MeV Si ions with different fluences ($V_{BE} = V_{BC} = 0$ V).

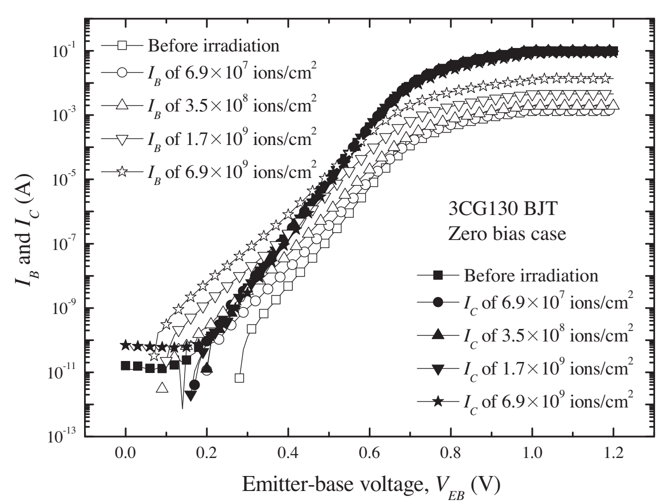

Fig. 3. Variations of collector current (I_C) and base current (I_B) with emitter–base voltage (V_{EB}) for the 3CG130 irradiated by 35 MeV Si ions with different fluences ($V_{EB} = V_{BC} = 0$ V).

Messenger–Spratt equation [16], the change in the reciprocal of the gain variation ($\Delta(1/\beta)$) can be defined as the value after irradiation subtracting its initial one. The Messenger–Spratt equation is