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SHI Induced Damage in Electrical Properties of Silicon NPN BJTs

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Abstract: The investigation of radiation damage in Si microelectronic circuitry and devices are being carried out by various research groups globally. In particular the Si Bipolar junction transistors are very sensitive to high energetic radiation. In the present study, radiation response of NPN Bipolar junction transistor (2N3773) has been examined for 60 MeV B^{4+} ion. Key electrical properties like Gummel, dc current gain and capacitance – voltage (C-V) characteristics of 60 MeV B^{4+} ion irradiated transistor were studied before and after irradiation. Ion irradiation and subsequent electrical characterizations were performed at room temperature. Current voltage (I-V) measurements showed the increase in collector current for $V_{BE} \leq 0.4$ V as a function of fluence, which is due to B^{4+} ion induced surface leakage currents. Base current is observed to be more sensitive than collector current and gain appears to be degraded with ion fluence. Also, C-V measurements shows that both built in potential and doping concentration increased significantly after irradiation.

Keywords: Bipolar junction transistors, DC current gain, Swift Heavy Ion radiation effects, Gummel and C-V characteristics.
PACS: 78

INTRODUCTION

Si Microelectronic circuits and devices are widely used in both terrestrial and space applications. Bipolar junction transistors (BJTs) have important applications in analog or mixed-signal integrated circuits (ICs) and bipolar metal oxide semiconductor (BICMOS) circuits, because of their current drive capability, linearity and excellent matching characteristics. Some of these are extensively used in spacecrafts [1]. The radiation effects on bipolar devices produced by protons, neutrons, electrons and gamma rays have been investigated in the past years [2]. However only a few studies are available on irradiation effects of heavy ions for NPN BJTs including the oxygen (O) [3], Lithium (Li) ions [1] and Boron (B) ions [4 - 5]. These investigations are valuable to study the effect of radiation on current transport in these devices.

EXPERIMENTAL DETAILS

The 2N3773 NPN power transistor procured from BEL, Bangalore, India, was used in our study, which is intended for linear amplifiers and inductive switching applications.

The irradiation tests were performed using 15 UD, Tandem accelerator facility, available at Inter University Accelerator Centre (IUAC), New Delhi, India. The decapped and un-biased (all the leads grounded) transistor was exposed to 60MeV Boron (B) ion beam at room temperature inside a chamber at vacuum ~10^{-6}-10^{-7} mbar. The fluence was varied from 1 x 10^{10} to1 x 10^{12} ions cm^{-2}. The ion beam current was maintained at ~1 pnA .To irradiate the sample uniformly, a beam spot of 2 mm^2 area was scanned over a 10 mm × 10 mm area of sample using a magnetic scanner. Electrical characteristics were measured before and after the irradiation using Keithley 2400 source meter and C-V measurements. Using Boonton 7200 capacitance meter interfaced to computer.

RESULTS AND DISCUSSIONS

The NPN transistor 2N3773 was characterized before and after irradiation with various fluences ranging from 1×10^{10} to 1×10^{12} ions cm^{-2}. Fig. 1 illustrates the Gummel characteristics for the device under test.

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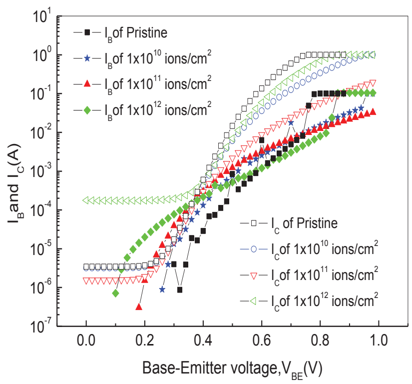

Fig. 1: Variation of Base current and Collector current as a function of Base-Emitter voltage with $V_{CE} = 5$ V

Based on the results from Fig. 1, the change in both collector current and base current can be observed.

The change is higher at lower base-emitter voltages. The collector current was observed to be increased along with the base current. When *npn* Si BJTs are exposed to high-energy ions, the insulating SiO_2 layer is prone to ionization damage. When sufficiently large oxide charge accumulates over the extrinsic base, this leads to significant recombination in the base region. Also it is reported that higher emitter injection efficiency results in the increase in collector current [6].

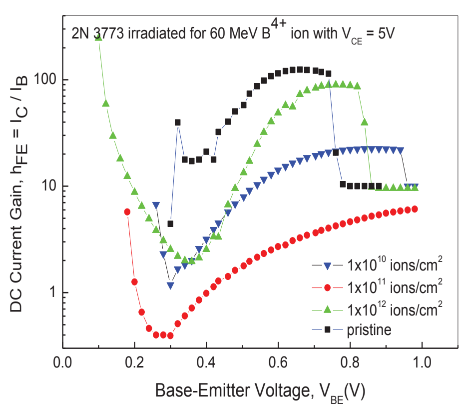

Fig. 2: Variation of DC current gain as a function of base emitter voltage V_{BE} at $I_B = 0.5\mu A$

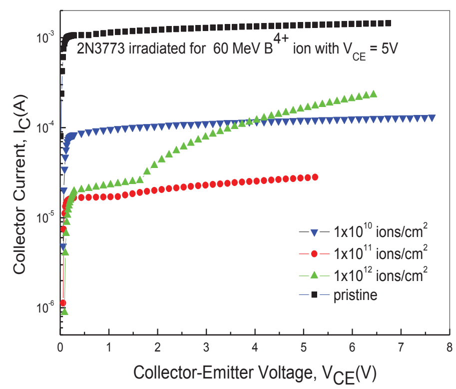

Fig. 3: Variation of collector current as a function of collector-emitter voltage, V_{CE} at $I_B = 0.5\mu A$

The common emitter gain $h_{FE} = I_C / I_B$ versus I_C is as shown in Fig. 2. It can be observed that current gain degrades substantially with increasing fluence especially at lower base emitter voltage. The decrease in current gain is mainly due to considerable increase in base current.

The $I_C - V_{CE}$ characteristics are shown in Fig. 3 .It is clear that at a given collector emitter voltage saturated collector current (I_C) decreases with increasing fluence. The MeV ions are capable of producing defects like vacancies, interstitials and divacancies in collector region which reduces the minority carrier lifetime. These MeV ion induced defects are responsible for the increase in the collector series resistance and there by reducing the I_C.

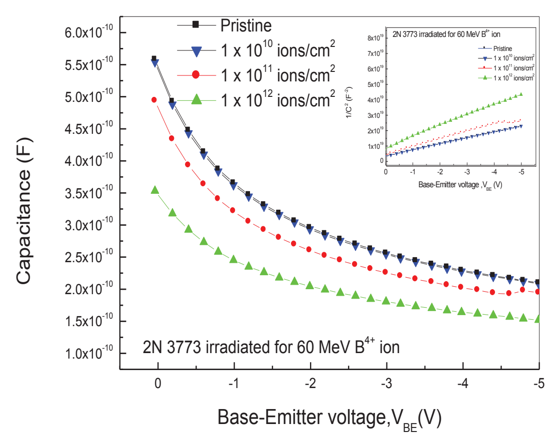

Fig. 4: Variation of capacitance with Base-Emitter voltage, V_{BE} .
Inset shows the variation of $(1/c^2)$ with V_{BE}.

Fig. 4 illustrates the variation of capacitance with base-emitter voltage which indicates the decrease in capacitance with increase in ion fluence. This degradation may be attributed due to partial loss of charge carriers in the base collector junction of the transistor upon Boron ion irradiation. Inset in Fig. 4 gives the variation of ($1/C^2$) with base -emitter voltage. It is evident that the value of doping concentration increases from 3.855×10^{18} cm^{-3} for pristine to 6.924×10^{18} cm^{-3} at 1×10^{12} ions/cm^2. Also built in potential increases from 3.61293×10^{18} V for pristine to 9.53622×10^{18} V at 1×10^{12} ions/cm^2.

CONCLUSION

The 60 MeV B^{4+} ion irradiation effects on electrical characteristics of 2N3773 NPN transistor were studied for different ion fluences. The base current I_B of the irradiated transistor was increased with increase in the fluence. The DC current gain was observed to be degraded especially at lower base-emitter voltage. The Collector saturation current was found be decreased after irradiation with the increase in fluence. From the C-V measurements the built in potential, as well as doping concentration was observed to be increased considerably along with the increase in ion fluence. Generation-recombination centers created by Boron ion beam in the emitter- base region may be the main reason for the degradation in electrical characteristics of the transistor.

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