A comparative study of 30MeV boron^{4+} and 60MeV oxygen^{8+} ion irradiated Si NPN BJTs

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A Comparative study of 30MeV Boron^{4+} and 60MeV Oxygen^{8+} ion irradiated Si NPN BJTs

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Abstract. The impact of 30MeV boron^{4+} and 60MeV oxygen^{8+} ion irradiation on electrical characteristics of 2N3773 Si NPN Bipolar junction transistors (BJTs) is reported in the present study. The transistors were decapped and irradiated at room temperature. Gummel characteristics, DC current gain and Capacitance-voltage (C-V) characteristics were studied before and after irradiation at different fluences. DC current gain has decreased significantly in both boron and oxygen ion irradiation. Also the value of capacitance decreased 3-4 times with increase in fluence. Both 30MeV boron ion and 60MeV oxygen ion induced similar extent of degradation in electrical characteristics of the transistor.

Keywords: BJTs, DC current gain, Gummel characteristics, C-V characteristics, nuclear and electronic energy loss.
PACS: 78

INTRODUCTION

Silicon Bipolar junction transistors (BJTs) are still being extensively used in radiation rich environments like space, Large hadron collider (LHC) experiments and other industrial applications. While operating in these kind of environment, the devices suffer severe damage due to passage of high energetic particles through them. Generally these high energetic particles induce both ionization and displacement damage. The SiO_2 insulating layer present inside the transistor is prone to ionization damage [1], on the other hand bulk silicon undergoes displacement damage. Therefore investigation of radiation induced damage in electronic circuitry is very important from both technical as well as fundamental aspect. Previously numerous studies have reported radiation damage on NPN BJTs induced by electrons, protons and gamma rays. Some studies also reported on damage induced by Swift heavy ion (SHI) on NPN BJTs [2-3]. Extensive studies on these devices with different heavy ions with different electronic energy loss (S_e) and nuclear energy loss (S_n) would yield better understanding of interaction of these ions with device as well as the technological limitations. Hence in the present study we have subjected the 2N3773 Si NPN BJTS to 30MeV boron^{4+} and 60MeV oxygen^{8+} ion irradiation. The choice of ion and energy is made such that ratio of S_e and S_n for both the ions is almost same. It is interesting to know that in case of different ions with same ratio of S_e and S_n , whether the degradation extent will be similar or not.

EXPERIMENTAL DETAILS

The commercial NPN power transistor 2N3773 procured from BEL, Bangalore, India, was used in our study. The 2N3773 BJTs are mainly used in linear amplifiers and inductive switching applications. The decapped transistors were exposed to 30MeV boron^{4+} and 60MeV oxygen^{8+} ion irradiation at 15UD Pelletron accelerator at Inter university accelerator center (IUAC), New Delhi, India. The terminals of transistors were grounded during irradiation. The beam current was ~1pnA and vacuum was maintained at ~10^{-6} mbar. Electrical characteristics were performed before and after irradiation using Keithley 2400 source meter and Boonton 7200 capacitance meter. All irradiation

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experiments and electrical measurements were done at room temperature.

RESULTS AND DISCUSSIONS

We compare the effects of 30MeV Boron and 60MeV Oxygen ion irradiation effects on 2N3773 BJTs . The electronic energy loss, nuclear energy loss and range of the ion in silicon target in case of 30MeV Boron and 60MeV Oxygen ion are estimated from SRIM code and tabulated in Table 1. Figure 1 and 2 illustrates the forward gummel characteristics of 30MeV Boron ion and 60MeV Oxygen ion irradiated transistor respectively. From Figure 1. and Figure 2. it is clear that both base current and collector current has changed significantly. When compared to collector current, base current has increased significantly, in both boron and oxygen ion irradiation. Particularly at higher voltages (V_{BE}>0.3 V) the change is apparent.There is a drastic increase in base current and moderate decrease in collector current.

The dc current gain is shown in Figure 3. in which decrease in current gain for both boron and oxygen ion irradiation can be noticed. The drastic increase in base current contributed to decrease in current gain of the transistor. The degradation in current gain may be explained in terms of both ionization and displacement damage induced by 30MeV boron and 60MeV oxygen ion irradiation. The insulating SiO_2 layer present in the emitter-base region of the transistor under goes ionization damage due to high value of electronic energy loss. When high energetic ions pass through the insulating oxide , they create large number of electron-hole pairs and interface traps at Si/SiO_2 interface which results in the increase of base surface current [4]. The nuclear energy loss causes displacement damage leading to bulk damage in base region of the transistor which increase the recombination centers and reduce the minority carrier life time [5]. Hence the dc current gain undergoes severe degradation inn both boron and oxygen ion irradiated transistor. Also it can be noted that, the extent of gain degradation is almost similar in both the cases.

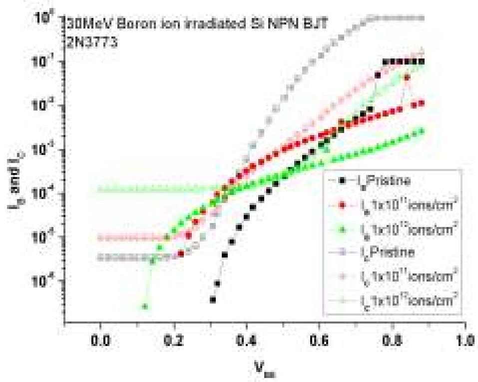

Figure 1. Forward gummel characteristics of 30 MeV Boron ion irradiated 2N3773 Si NPN BJTs

The output I_{CE} versus V_{CE} characteristics is shown in Figure 4 for boron and oxygen ion irradiated transistors. It is evident from the figure that the collector saturation current decrease at lower fluence in both cases but moderately increase at higher

TABLE 1. SRIM Calculations for 30MeV Boron and 60MeV Oxygen ion Si target

Ion/energy	Range (µm)	Electronic energy loss (S_e) KeV/ µm	Nuclear energy loss (S_n) KeV/ µm	Ratio (S_e)/ (S_n)
Boron 30MeV	42.79	5.289×10^{2}	3.373×10^{-1}	1.568×10^{3}
Oxygen 60MeV	47.33	9.864×10^{2}	6.315×10^{-1}	1.561×10^{3}

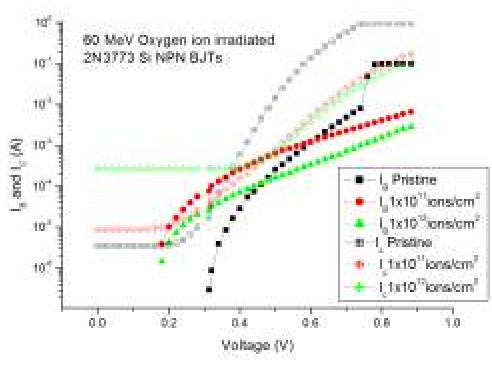

Figure 2. Forward gummel characteristics of 60 MeV oxygen ion irradiated 2N3773 Si NPN BJTs

fluence. Initially the decrease in current is attributed to reduction in minority carrier lifetime because of 30MeV boron and 60MeV oxygen ion induced displacements, vacancies and their complexes. The variation of capacitance along with the applied reverse

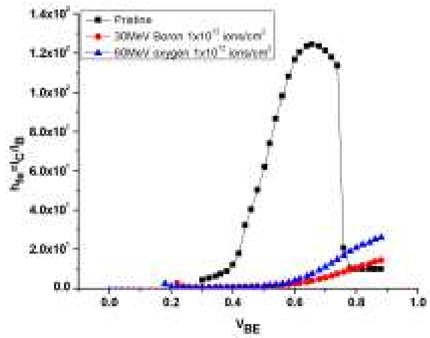

Figure 3. Current gain versus V_{BE} 30 MeV boron and 60 MeV oxygen ion irradiated 2N3773 Si NPN BJTs

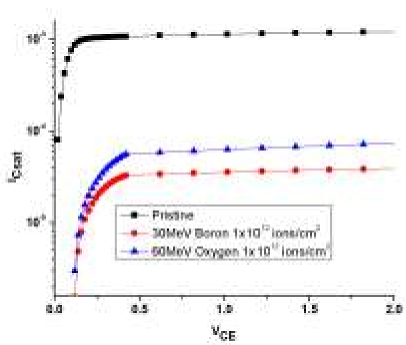

Figure 4. Output collector current characteristics at I_B= 50μA before and after 30MeV Boron and 60MeV Oxygen ion irradiated 2N3773 Si NPN BJTs

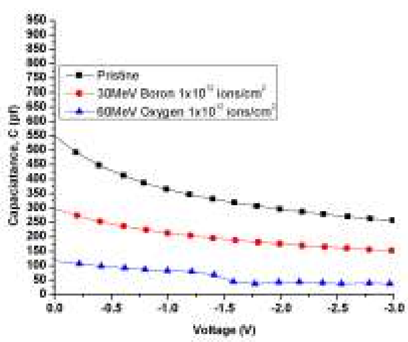

Figure 5. Capacitance-voltage characteristics of 30 MeV boron and 60MeV Oxygen ion irradiated 2N3773 Si NPN BJTs

bias voltage in emitter-base configuration is as shown in the Figure 6. The value of capacitance at zero bias voltage is 550pf for unirradiated transistor and it reduces to 300pf and 125pf for 30MeV boron and 60MeV oxygen ion irradiated transistors for the fluence of 1×10^{12} ions/cm^2. The capacitance –voltage characteristics show clear degradation as the bias voltage is increased. The reduction in carrier density may have caused the decrease in capacitance [6].

CONCLUSION

The commercial BJTS 2N3773 has been subjected to 30MeV boron and 60MeV oxygen ion irradiation at different fluences. The electrical degradation observed in both the cases was almost similar. Both ionization and displacement damage induced defects and their complexes were responsible for the observed degradation.

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