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Boron ion interaction with pnp bipolar power transistor and displacement damage effects on its electrical characteristics

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Abstract

Bipolar junction transistors used in switching and amplification applications is examined for their electrical performance after irradiation with 60 MeV boron ions of different fluence. Unirradiated device base current is 5.97×10^{-5} A while it is 9.03×10^{-4} A after irradiation with a fluence of 1×10^{12} ions/cm^2. For unirradiated device collector current is 1.22×10^{-3} A and is 7.31×10^{-4} A after irradiation to a fluence of 1×10^{12} ions/cm^2. Base current increases whereas collector current decreases after irradiation with a fluence of 1×10^{12} ions/cm^2. The magnitude of decrease in collector current is approximately same as that of the increase in base current, showing the leakage of the collector current due to irradiation. The output collector gain of the unirradiated transistor is 20.5 after irradiation to a fluence of 1×10^{12} ions/cm^2 it has reduced to 0.81. The capacitance measurements for base-emitter junction show that for the unirradiated and irradiated samples, linearity of the curves indicate uniformity of shallow doping concentration. The built in potential (Vbi) for unirradiated device is 2.69 V and after irradiation it is 2.52V. The device is also studied for activation energy, trap concentration and capture cross-section of deep levels are studied using deep-level transient spectroscopy (DLTS) technique. Majority carrier trap level is observed with energy Ev+0.784 eV.

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Keywords: Radiation Hardness, Silicon, Linear Energy Transfer, Displacement Damage;

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1. Introduction

BJT's have important applications in analog and mixed – signal IC's and BICMOS (Bipolar Complementary Metal Oxide Semiconductor) circuits because of their current drive capability, linearity, and excellent matching characteristics Dinesh et.al. (2008). Ionizing radiation may cause failures in integrated devices (ICs) due to gain degradation of individual devices. Extensive research has been carried out in exploring the effect of radiation-induced damage at the surface of the device.

A comparison of ionizing radiation induced gain degradation in a lateral, substrate and vertical pnp bipolar junction transistors is reported by Schmidt et.al (1995) and Schrimpf et. al. (1995). They have concluded that the effect of ionizing radiation on lateral and substrate pnp structures are different from the effects on vertical pnp structure. Of the three pnps, the lateral pnp suffers the most current gain degradation while the vertical pnp suffers the least current gain degradation due to ionizing radiation. But the heavy ion irradiation effects need to be studied on pnp BJTs as they are important. There are little reports on TID and D_d due to heavy ion irradiations on BJTs. Radiation induced changes in bipolar device characteristics are caused by generation of net positive oxide trapped charge, and an increase in surface recombination velocity due to formation of interface traps. It is also important to study the defects present deep inside the device. Detailed analysis is needed for large spectrum of devices in order to develop radiation hard model.

Wei et.al reported that, base current of irradiated bipolar devices increased with increase in ion fluence and the collector current decreased. This results in a decrease in the current gain ($\beta=I_C/I_B$) Wu et.al.

The operation of BJT devices may depend on the particle energy deposition mechanisms by ionization and non-ionization processes Dinesh et.al. (2008). The radiation-induced damage and its effect on device parameters mainly depend on particle type, energy and fluence, also it may depend on the device technology. Hence the irradiation effect of B-ion impact on BJTs may show significant variations in their characteristics, when compared to Li-ion. There are evidences that the existence of boron ion in galactic cosmic ray (GCR). BJTs are commonly employed in many fields including particle physics experiments, nuclear medicine and space Claude Leroy et.al., (2007). The particle interactions in the bulk or active part of the silicon devices are responsible for the gain degradation resulting from the absorbed dose. Both the ionizing and non-ionizing energy-loss contributes to the absorbed dose (figure 1, S_e and S_n of the table 1).

Vertical npn transistors exhibit very significant gain degradation, particularly when they are irradiated at low dose rates. In contrast, vertical pnp transistors are relatively hard to ionizing radiation Nowlin et.al., (1992) and Kosier et.al., (1995). Several mechanisms have been proposed which may cause the current gain degradation viz., (1) depletion of the p-type emitter, (2) recombination at the base surface, (3) electron injection into the emitter and (4) surface hole depletion. However, due to competing nature of these mechanisms, it is rather difficult to identify the dominant mechanism. On the other hand, there are relatively less reports on the displacement damage effects in discrete BJTs. Literature reports several npn type transistors have been investigated in the literature for current gain degradation based on these arguments Kulakar et.al., (2003). In general, the pnp type transistors are also expected to exhibit the same type of degradation. However, it appears that there is little experimental evidence to support this. Dale et al. (1988) have studied the high energy electron induced gain degradation in terms of displacement of atoms. Burke (1986), Summers et al. (1986, 1987) and Xapsos et al. (1994) have studied the displacement damage produced by high energy electrons and neutrons. In this work an attempt is made to access the radiation response of vertical discrete pnp transistor 2N6052 manufactured indigenously by Bharath electronics Ltd (BEL) India. Also the objective of this investigation is to reveal the mechanisms due to ionizing and non-ionizing energy deposition and hence degradation of current gain of the pnp BJT.