Student Paper

A Comparison of 10MeV Chlorine and 20MeV Bromine Ion Irradiation Effects on SiGe HBTs for Space Application

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Silicon-germanium heterojunction bipolar transistors (SiGe HBTs), as prime technology for high-speed communication, are being employed in spacecraft and other extreme environment, such as Super Large Hadron Collider [1]. Due to the special device structure, SiGe HBTs have been found to have a built-in multi-Mrad total ionizing dose (TID) tolerance for the ^{60}Co, electron and proton irradiation [2]. However, there are few data available about the irradiation effects of swift heavy ion on SiGe HBTs up to now. In order to understand the high dose effects of the swift heavy ion, in this paper, the SiGe HBTs are exposed to two kinds of heavy ion at room temperature. A comparison of I-V characteristics, neutral base recombination (NBR) and Early effect for SiGe HBTs irradiated by heavy ions are presented in detail.

The devices under test are NPN SiGe HBTs and the detailed device description has been reported in [3]. The transistors were exposed to 10MeV Chlorine (Cl^{3+}) and 20MeV Bromine (Br^{7+}) ion at the room temperature with the equivalent absorbed dose from 300 krad(Si) to 10 Mrad(Si). The ion fluence are varied from 1.3×10^{9} to 4.34×10^{10} cm^{-2} for 10MeV Cl^{3+} and from 9.1×10^{8} to 3 $.0\times10^{10}$ cm^{-2} for 20MeV Br^{7+}, respectively. All the terminals of SiGe HBTs were floating during the irradiation. To avoid the room temperature annealing effects, the irradiated SiGe HBTs were measured within 30 min after irradiation with the Keithley 4200 semiconductor parameter analyzer.

The forward Gummel characteristics for 10MeV Cl^{3+} and 20MeV Br^{7+} ion irradiation are shown in Fig.1(a) and Fig.1(b), respectively. The base currents (I_B) all increase with the ion fluence increasing. The collector current (I_C) for 10MeV Cl^{3+} ion irradiation remains unchanged, while an unexpected increase in I_C appears at low V_{BE} region after 20MeV Br^{7+} ions irradiation. The excess base current ($\Delta I_B=I_{B,post}-I_{B,pre}$) is a result of irradiated-induced ionization damage around the emitter-base spacer oxide and the displacement damage in the neutral base region [2-3]. The generation current in the space charge region of reverse CS junction may be the additional I_C in low V_{BE} region for 20MeV Br^{7+} ions irradiation. Fig.2 shows the ΔI_B and the change in current gain reciprocal ($\Delta(1/\beta)=\Delta(1/\beta_{post})-\Delta(1/\beta_{pre})$) extracted at V_{BE}=0.6V for the two ions irradiation. The ΔI_B for 20MeV Br^{7+} ion is much larger than 10MeV Cl^{3+} ion. The $\Delta(1/\beta)$ varies linearly with the ion fluence, indicating that the displacement damage dominates I_B degradation [2]. The damage factors calculated using Messenger-Spratt equations are 1.89×10^{-11} for 10MeV Cl^{3+} ion and 4.03×10^{-10} for 20MeV Br^{7+} ion, respectively.

Fig.3 shows the neutral base recombination (NBR) for SiGe HBTs irradiated with 10MeV Cl^{3+} and 20MeV Br^{7+} ions. The magnitude of negative slope of the normalized I_B at lower V_{CB} is found to significantly increase after irradiation when compared to the pre-radiation results, indicating a more significant NBR after irradiation. The NBR is a result of irradiation-induced traps in the neutral base and the local traps in CB junction [4]. This suggests that there exists much displacement damage in the SiGe HBT after the two ion irradiation. Compared to the 10MeV Cl^{3+} ions, the 20MeV Br^{7+} ions have a higher NIEL value. Therefore, more serious NBR is observed as expected for 20MeV Br^{7+} ions irradiated SiGe HBTs than those irradiated by 10MeV Cl^{3+} ions.

The output characteristics with fixed V_{BE} of 0.65V for 10MeV Cl^{3+} and 20MeV Br^{7+} ions irradiation are shown in Fig.4(a) and Fig.4(b), respectively. It is found that I_C decreases with the ion fluence increasing. Besides, a significant Early effect appears after irradiation compared with nearly ideal output characteristics of the fresh device, especially for the case of 20MeV Br^{7+} ion irradiation. The extracted Early voltage (V_A) are shown in Fig.5 as a function of ion fluence. It indicates that V_A decreases with the ion fluence increasing, and the 20MeV Br^{7+} ions with higher NIEL lead to a much more serious V_A drop than 10MeV Cl^{3+} ions. The V_A degradation may be a result of the decreased concentration of the ionized impurities in base region due to the impurities passivation induced by the displacement damage [5].

In this study, the irradiation effects of two kinds of swift heavy ions are investigated and compared for SiGe HBTs. The current gain and Early voltage are found to degrade and a non-negligible NBR appears after irradiation. The heavy ions with high NIEL have a large ability to produce the displacement damage, therefore, more degradation are observed for higher NIEL ion irradiated SiGe HBT when compared to that irradiated with lower NIEL ion. All these data provide a radiation hardened foundation for SiGe HBTs in extreme environment applications.

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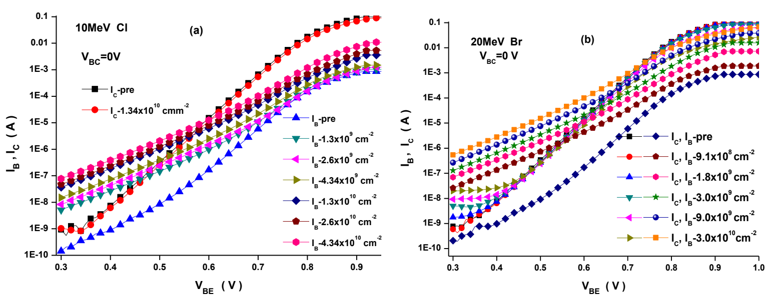

Fig.1 Forward Gummel characteristics for (a) 10MeV Cl^{3+} and (b) 20MeV Br^{7+} ion irradiated SiGe HBTs

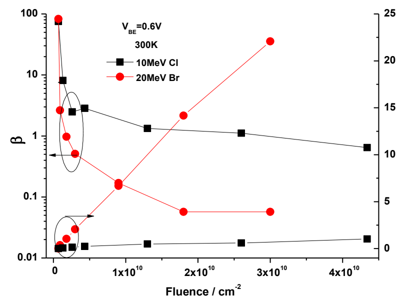

Fig.2 Current gain β and the change of 1/β for Br^{7+} and Cl^{3+} irradiation

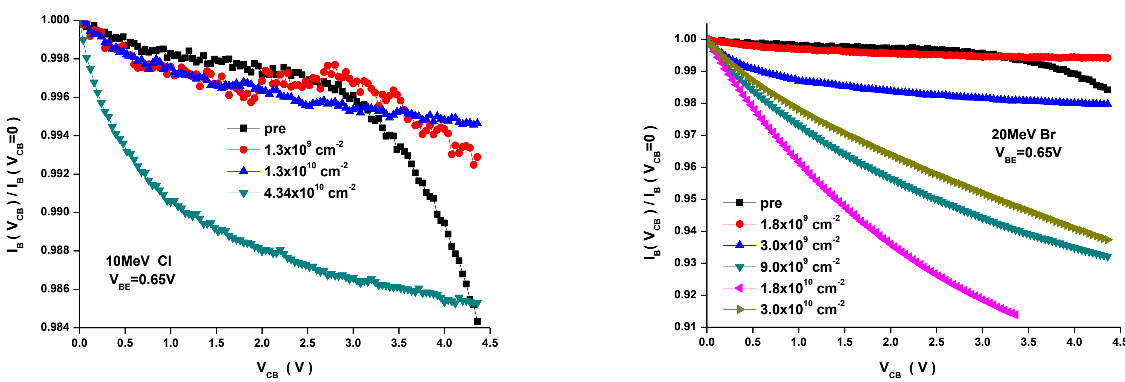

Fig.3 NBR for SiGe HBTs irradiated by (a) 10MeV Cl^{3+} and (b) 20MeV Br^{7+} ions.

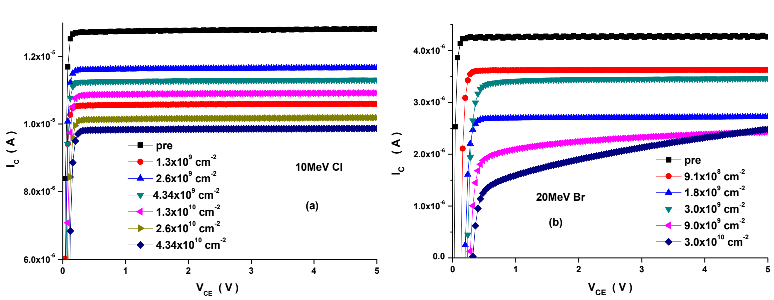

Fig.4 The output characteristics at fixed V_{BE} of 0.65V before and after (a) 10MeV Cl^{3+} and (b) 20MeV Br^{7+} irradiation.

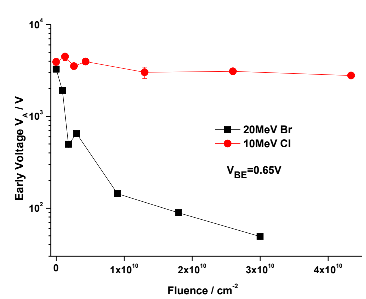

Fig.5 The extracted Early voltage V_A after Cl^{3+} and Br^{7+} irradiation