INTERNATIONAL RESEARCH JOURNAL OF ENGINEERING AND TECHNOLOGY (IRJET) E-ISSN: 2395-0056
VOLUME: 07, SPECIAL ISSUE | JUNE 2020 WWW.IRJET.NET P-ISSN: 2395-0072
International Conference on Recent Trends in Science & Technology-2020 (ICRTST - 2020)
Organised by: ATME College of Engineering, Mysuru, INDIA

Swift Heavy Ion Irradiation Studies on SiGe HBTs at Low Temperature

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Abstract— Total dose effects of 50MeV lithium ion irradiation on 200GHz Silicon-Germanium heterojunction bipolar transistors (SiGe HBT) in the dose ranging from 1 to 30Mrad were examined at low temperature (150K). The HBTs were subjected to 50MeV lithium ion with typical beam current of 1pnA at 150K and 300K. The pre- and post-irradiation dc electrical characteristics were studied. Low temperature irradiation results were compared with room temperature (300K) results systematically in the same dose range. The radiation caused generation-recombination trapped carriers increases the base current (I_B) of HBTs and is proportional to total dose. However, The HBTs irradiated at 150K show lesser degradation when compared to devices irradiated at 300K.

Keywords- SiGe HBT, ion irradiation, low temperature

1. INTRODUCTION

The bandgap engineered SiGe HBT BI-CMOS technology has come out as fundamental building block for many extreme environment electronic (EEE) applications including; at cryogenic temperatures (e.g., liquid helium temperature, 4K), at elevated temperatures (e.g., up to 300°C) and in radiation-harsh environment. It is well known that, due to band-gap engineering, the performance of the SiGe HBTs is superior at cryogenic temperature (an operational region traditionally forbidden to conventional BJTs) than that at 300K [1]. The attractive cryogenic properties and high temperature capabilities of SiGe HBTs can enable their extension into various emergent possibilities [2]. From conventional Si CMOS and Si BJTs, one cannot expect better performance above 125°C and below -50°C due to the reliability concerns like substrate leakage and freez-out issues. Therefore, SiGe HBTs are potential candidate for various EEE applications operational at low temperatures to temperatures as elevated as 300°C. Because of these advantages of SiGe HBTs, the space communities are considering using these devices in space exploration programs. In space, the electronic systems have to working in harsh environments such as, under irradiation and at low and temperatures. The conventional method is that to shield the electronics using "warm box" which secures them from temperature variations, radiation exposure and helps for their reliable operation. Unfortunately, such warm boxes are power hungry, bulky and heavy [1]. The applicability of SiGe HBTs will eliminate the need of warm boxes. Along with this, electronic systems should be ionizing radiation tolerant [3-6]. For such applications, one must demonstrate the reliability of SiGe HBTs under the exposure to very high radiation dose levels, while operating in wide temperature range. Hence, experimental characterizations and reliability testing of HBTs at extreme temperature are needed. However, previously, gamma and proton irradiation effects on 1st generation SiGe HBTs at 77 K have been studied [6, 7]. The literatures on ion irradiation studies on SiGe HBTs at low temperatures are not available. Therefore, for the first time, systematic investigations on the effects of 50MeV lithium ion irradiation on SiGe HBTs at both low temperature and room temperatures are presented.

2. EXPERIMENT

The 200GHz SiGe HBTs procured from IBM, USA are employed for this study. The HBTs with emitter area (A_E), 0.12x2μm², 0.12x4μm² and 0.12x8μm² were chosen for irradiation. The devices were subjected to 50MeV lithium ion in 15UD 16MV Pelletron Accelerator at Inter University Accelerator Centre (IUAC), New Delhi, India. All terminals of transistors were grounded while lithium ion irradiation. The irradiation was carried out at temperatures 150K and 300K with dose range from 1 to 30Mrad. In order to achieve low temperature of 150K, liquid nitrogen poured in to a ladder. The SiGe HBTs were placed on the copper strip on the ladder in order to reduce temperature gradient and temperature of the device was measured using temperature sensor during the ion irradiation. In order to measure the accurate temperature, PT100 temperature sensor was mounted on the ceramic package. The typical beam current throughout the irradiation was 1pnA. The I-V characteristics were taken at 300K. The I-V characteristics of the irradiated and pre-irradiated devices were carried out by using Keithley 2636A dual source meter. The different DC parameters namely, Gummel characteristics, normalized base current (I_{Bpost}/I_{Bpre}), current gain (h_{FE}), avalanche multiplication (M-1) and the output characteristic (I_C-V_{CE}) were performed and results of HBTs with A_E = 0.12x2.0μm² were present in this work. The HBTs with other A_E are also shown similar behaviour.

3. Result and Discussion

The forward and inverse Gummel characteristics of irradiated SiGe HBTs at 150K and 300K and measured at 300K are shown in Figures 1 to 4 respectively.

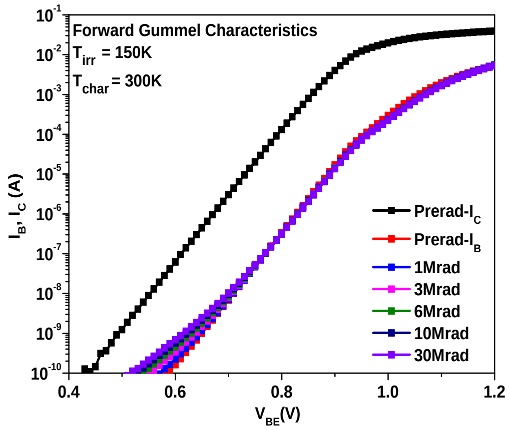

Fig.1. Forward Gummel characteristics of SiGe HBT irradiated at 150K and measured at 300K.

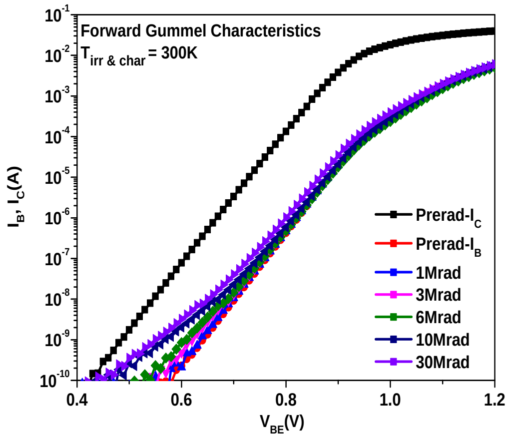

Fig.2. Forward Gummel characteristics of SiGe HBT irradiated and measured at 300K.

The both forward and inverse mode I_B of the ion irradiated SiGe HBTs increases as ion dose increases at both temperatures. However, the I_C was remained same even after irradiation at both 150K and 300K. Hence, only the pre-rad I_C is shown in figures. The increase in I_B is due to ion induced generation-recombination (G-R) traps in the periphery of Emitter-Base (E-B) spacer and Shallow Trench Isolation (STI) oxides. From the figures it is observed that the ion irradiation at low temperature cause less degradation in both forward and inverse mode I_B when compared to irradiation at 300K. At low temperature ion induces less ionization and displacement damages in oxides as well as in bulk of the device [8, 9].

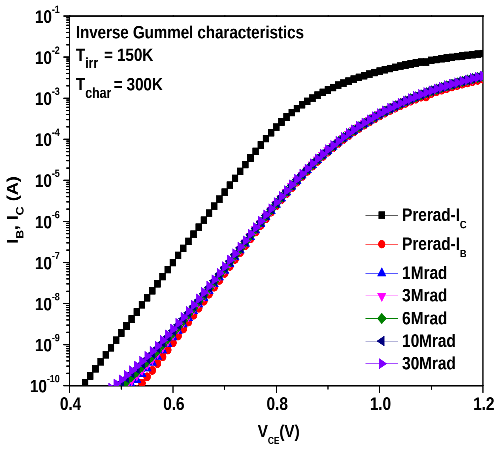

Fig.3. Inverse Gummel characteristics of SiGe HBT irradiated at 150K & 300K and measured at 300K.

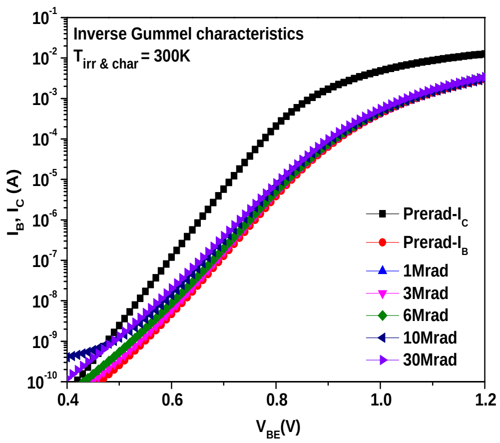

Fig.4. Inverse Gummel characteristics of SiGe HBT irradiated and measured at 300K.

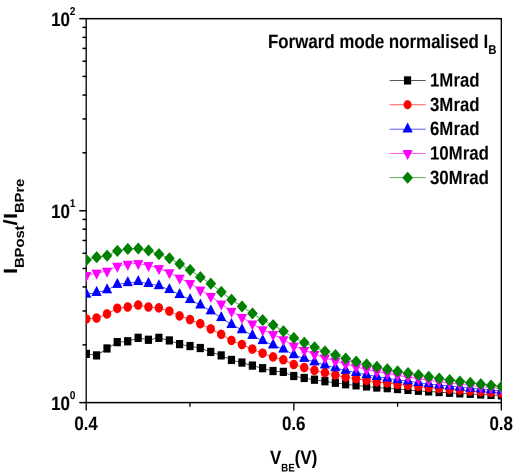

Fig.5. Forward normalized I_B of SiGe HBT irradiated at 150K and measured at 300K.

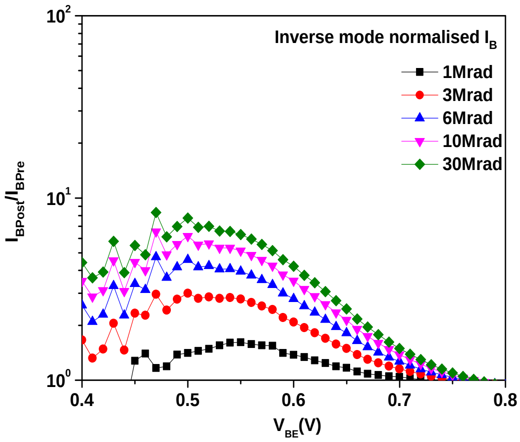

Fig.6. Inverse normalized I_B of SiGe HBT irradiated at 150K and measured at 300K.

The post-irradiation forward and inverse normalized I_B for ion irradiated SiGe HBTs at 150K and characterized at 300K are shown in Figures 5 and 6 respectively. The normalised I_B increases with increase in radiation dose since the ion induced G-R trapped carriers increases with ion dose. The inverse mode normalized I_B is more, therefore ion induce more G/R trapped charges in STI oxide than EB spacer oxide. Hence, the damage production is more reliant on on perimeter to area (P/A) ratio of the EB spacer and STI oxides than irradiation temperature.

Figure 7 depicts the variation in forward-mode h_{FE} for SiGe HBTs irradiated at 150K and measured 300K. The h_{FE} of the ion irradiated SiGe HBT decreases, due to the increase in forward I_B. The normalised peak h_{FE} for ion irradiated SiGe HBTs is depicts in Figure 8. The SiGe HBT irradiated at 150K shows less decrease in peak h_{FE} than SiGe HBTs characterized at 300K. After the 30Mrad(Si) of total dose, degradation in peak h_{FE} is around 15% at 150K is and around 35% at 300K irradiation. Hence, ion irradiation at low temperature induces fewer damages when compared to at 300K.

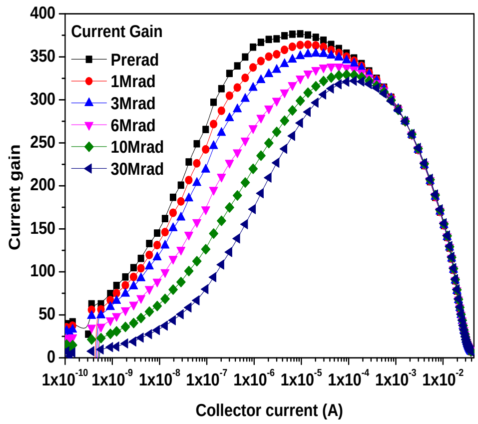

Fig.7. The variation in h_{FE} of SiGe HBT irradiated at 150K and measured at 300K.

Figure 9 reveals the M-1 factor for the SiGe HBT irradiated at 150K and measured 300K. It can be seen that there is negligible changes in M-1 at lower V_{CB} values after irradiation. Hence, ion irradiation at low temperature induces less impact on local junction electric fields. The same behavior was observed for the SiGe HBT irradiated by 50MeV lithium ions at 300K.

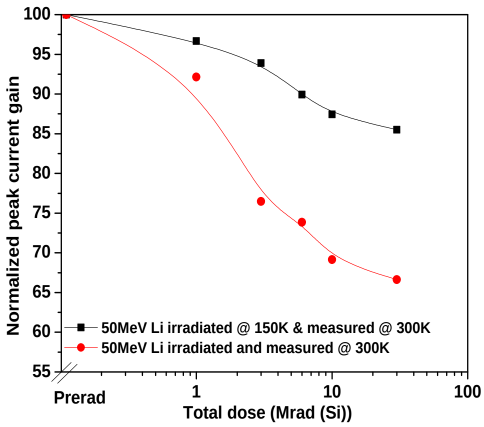

Fig.8. The normalised h_{FE} as a function of dose.

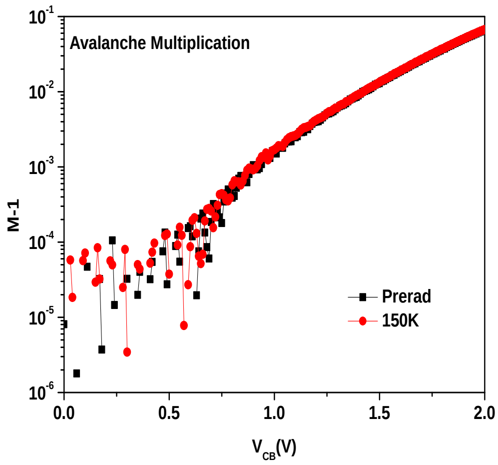

Fig.9. M-1 factor for SiGe HBT irradiated at 150K and measured at 300K.

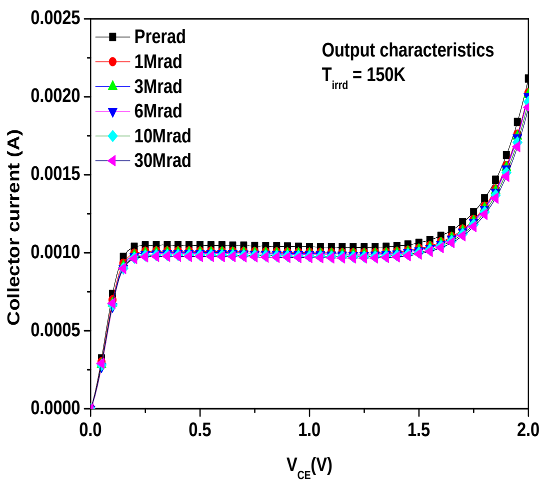

Fig.10. Output characteristics of SiGe HBT irradiated at 150K and measured at 300K.

The output characteristics of ion irradiated devices at 150K and 300K are shown in Figure 10 and 11 respectively. From the figures, it can be observed that I_C at saturation and active region found to be slightly decreased after 30Mrad of total dose at 150K and significantly at 300K. Therefore, ion induced degradation at collector region is very less at 150K than 300K. Hence, irradiation temperature plays very important role in damage production.

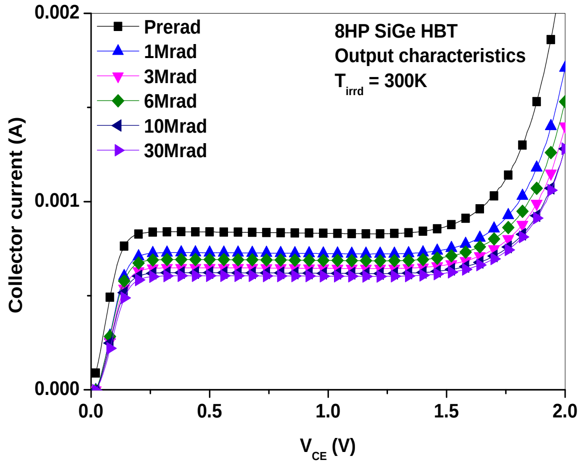

Fig.11. Output characteristics for SiGe HBT irradiated and measured at 300K.

4. CONCLUSION

The 3rd generation SiGe HBTs were irradiated with 50MeV lithium ion up to 30Mrad of total dose at 150K and 300K. The important parameters such as IB, hFE and ICsat were found to degraded after ion irradiation at both temperatures. From this investigation, it is observed that ambient temperature plays important role in damage mechanism. SiGe HBTs shows significant radiation hardness at low temperature. Even after room temperature irradiation all the characteristics are acceptable and device is working satisfactorily.

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