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Investigation of enhanced low dose rate sensitivity in SiGe HBTs by ^{60}Co γ irradiation under different biases

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ABSTRACT

This paper evaluates enhanced low dose rate sensitivity (ELDRS) in Silicon–Germanium heterojunction bipolar transistors (SiGe HBTs) which are isolated by LOCOS process. The ^{60}Co gamma irradiations were performed at 80 rad (Si)/s and 0.1 rad (Si)/s respectively in order to investigate dose rate dependence of the SiGe HBT. Devices were set in forward, saturated, cutoff, and all-grounded biases during the irradiation. The degradation mechanism of different dose rate irradiations was analyzed via measurement of forward Gummel mode and inverse Gummel mode both pre- and post- irradiation. The results show that ELDRS exists at forward, saturated, and all-grounded biases irradiations. The dose rate dependences of various irradiated biases are different in the SiGe HBT. The interface-traps both in EB Spacer and LOCOS are the major irradiated damages in the SiGe HBT for the low dose rate irradiation. ELDRS is directly related to the quality, thickness, and shape of oxide layers.

1. Introduction

Silicon-Germanium heterojunction bipolar transistors (SiGe HBTs) technology has been widely used in microelectronics field because of its excellent transistor performance and integratability with complementary metal oxide semiconductor (CMOS) [1]. In addition, SiGe HBT is well suited to be used in space applications on account of the superior cryogenic characteristics, so that it can be installed outside of satellites [2–3].

However, the ICs working in space are inevitably affected by ionizing radiation, especially the devices outside of spacecraft. In that case, the total ionizing dose (TID) radiation effect becomes a significant damage factor that cannot be ignored. Early TID researches involve irradiations at high dose rates (> 50 rad(Si)/s), which are much higher than that in space environments, because using high dose rates for evaluation saves time and resources [4]. Nevertheless, high dose rate (HDR) irradiation may mask some latent dose-rate dependent degradation mechanisms that are induced by low dose rate (LDR) irradiation [9]. In early 1990s, some studies reported that bipolar junction transistors (BJTs) and circuits are susceptible to enhanced low dose rate sensitivity (ELDRS) [5]. To put it simply, bipolar devices show more degradation at LDR irradiation than at HDR irradiation for the same total dose.

Since SiGe HBT is a kind of bipolar device, its ELDRS investigation is very important. The Prof. Niu's group and Prof. Cressler's team first conducted the TID experimental studies for the SiGe HBTs produced by IBM. The results showed that the tolerance of TID radiation in SiGe HBTs was stronger than in conventional Si BJTs [6–8]. Then, experiments of low dose rate irradiations indicate that SiGe HBT did not exhibit ELDRS [9–12]. However, there are still few studies to conduct dose rate impact on degradation mechanism in SiGe HBTs. Moreover, the early studies generally chose all pins grounded or floated, while the effect of various biases on ELDRS for SiGe HBTs was rarely reported [11–13]. In addition, the influences of irradiated defects in various isolation oxide structures on both forward and inverse Gummel modes are less discussed for dose rate dependence.

In this paper, dose rate dependence of TID in the SiGe HBT is investigated by ^{60}Co γ irradiation experiment. SiGe HBTs under different biases are irradiated at high and low dose rates separately in the experiments. The ELDRS mechanism of the SiGe HBT is inferred based on analyzing the forward Gummel characteristics and the inverse Gummel characteristics. The results show that the ELDRS of SiGe HBTs are complicated because of various factors.

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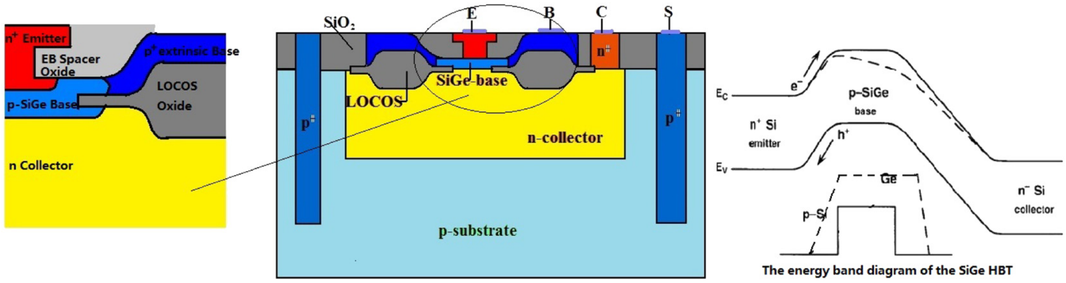

Fig. 1. Schematic of cross section of the SiGe HBT.

2. Experiment details

2.1. Device structure

The SiGe HBTs used in the experiment are manufactured based on conventional npn BJT process which usually grows an oxide layer above EB junction to form an EB Spacer that has the effect of passivation. And the LOCOS process is used so that a thin oxide layer is formed at BC junction by the characteristic bird's beak. The basic structure of the SiGe HBT is shown in Fig. 1. The base is constituted by gradient SiGe in the SiGe HBT. The content of Ge gradually changes from 0% at Emitter/Base (E/B) junction and Base/Collector (B/C) junction to 14% in the intrinsic base that forms grading heterojunctions, and maintains 14% in the base. The doping concentration of base region is higher about $1 \times 10^{19}\,cm^{-3}$, and the thickness of base is thin, approximately 0.08 µm. An epitaxial base region of p-type polysilicon is grown on the LOCOS isolation which is located in internal collector. The width of the emitter window is 0.4 µm. The doping concentration of collector and substrate are low, about $6 \times 10^{15}\,cm^{-3}$ and $7 \times 10^{14}\,cm^{-3}$ respectively. A ring wall of heavily doped boron leads out substrate contact near the edge of the device.

2.2. Experimental method of irradiation

The gamma irradiations were performed using ^{60}Co γ-ray sources. In order to explore the dose rate dependence, the high dose rate of 80 rad (Si)/s and the low dose rate of 0.1 rad (Si)/s were selected in irradiation experiments. Both HDR and LDR irradiation accumulated to the same total dose of 1 Mrad (Si). The irradiated devices of HDR were annealed at room temperature after the irradiations. The annealing time was 2774 h which equals the time of LDR irradiation so as to distinguish between time dependent effects (TDE) and ELDRS effects.

In view of various electric fields formed at pn junctions and common operating modes of transistors, four typical bias conditions were set during the irradiation: (E is emitter, B is base, and C is collector) (1) forward bias: $V_{BE} = 0.8$ V, $V_{BC} = -1.8$ V; (2) saturated bias: $V_{BE} = 0.8$ V, $V_{BC} = 0.4$ V; (3) cutoff bias: $V_{BE} = 0$ V, $V_{BC} = -2$ V; (4) all-grounded bias: $V_E = V_B = V_C = 0$ V.

2.3. Measurement

The offline test method was used in the experiment. The forward and inverse Gummel characteristics were measured with KETHLEY4200 semiconductor parameter tester when the total dose respectively accumulated to 50, 100, 200, 300, 500, 800, and 1000 krad (Si). Irradiation experiments and parameter tests were performed at room temperature, and each test completed in 20 min after irradiations stop. During the 2774 h of annealing, the Gummel characteristics are also measured at different times. In the forward Gummel tests, the base-collector voltage (V_{BC}) set 0 V, and the base-emitter voltage (V_{BE}) was swept from 0 V to 1.2 V. Base and collector currents were measured. In the inverse Gummel tests, the base-emitter voltage (V_{BE}) set 0 V, and the base-collector voltage (V_{BC}) was swept from 0 V to 1.2 V. Base and emitter currents were measured.

A total number of 32 SiGe HBTs were irradiated by ^{60}Co γ in the experiments. 16 devices were exposed HDR irradiation at 80 rad (Si)/s, while the other half of the devices were irradiated at LDR of 0.1 rad (Si)/s. That is to say, four devices were used for each bias in the experiment.

3. Experiment results and discussion

The excellent current gain both in forward and inverse Gummel modes are presented in the SiGe HBT on account of the bandgap grading by Ge doping in the base region. Therefore, both forward and inverse Gummel characteristics are tested and studied in the irradiation experiments. Fig. 2(a) and (b) shows the forward Gummel characteristics in the pre- and post-irradiation under forward bias at LDR and HDR respectively. The inverse Gummel characteristics under forward bias at LDR and HDR are recorded in Fig. 3(a) and (b). The curves of other biases irradiations are similar to the Figs. 2 and 3. The collector current (I_C) of inverse Gummel mode is larger than the emitter current

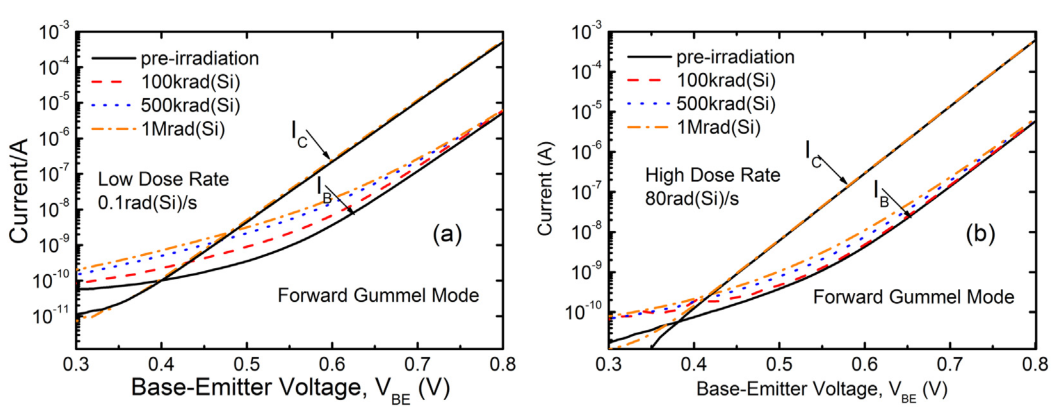

Fig. 2. Forward Gummel characteristics in the pre- and post-irradiation under forward bias, (a) LDR (b) HDR.