

The comparison of radiation hardness of heterojunction SiGe and conventional silicon bipolar transistors

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Abstract. The results of the X-ray radiation impact on heterojunction SiGe and conventional silicon bipolar transistors are presented. Oxide thickness over the emitter-base junction depletion region determines the radiation hardness of the bipolar transistors. In this article, the estimation of the rate of radiation degradation of electrical parameters for conventional silicon devices and SiGe-transistors is performed.

1. Introduction

Nowadays in modern data acquisition and processing systems are used high-frequency bipolar transistors, made with SiGe technology. These devices have series of advantages in comparison with conventional silicon transistors, that is explained in [1]. Firstly, the implantation of germanium atoms into silicon crystal structure, which concentration increases in the direction from emitter junction to the collector, creates accelerating electric field, which increases the frequency performance of the transistor significantly. Secondly, the dopant of Germanium leads to a local decrease of the bandgap, which results in the increase of emitter efficiency and current gain of the transistors. Third, SiGe-transistors appear to have good compatibility with common silicon technology, low noise level, and high radiation hardness.

To estimate the effect of construction and technology on radiation hardness, a number of radiation experiments were performed in this work with SiGe and conventional bipolar transistors.

2. Bipolar transistors radiation tests

A static current gain that is considered in the article is a radiation-sensitive parameter which is called β and equal to a ratio of collector current to base current. Under the impact of ionizing radiation, positively-charged traps accumulate in the oxide (SiO_2). They interact with electrons from substrate and converts to interface traps that can further act as recombination centers. It results in an increase of surface recombination current that in its turn raises base current I_b [2]. Since SiGe-transistors usually have a vertical structure, the charge carriers do not reach the subsurface area on their way from the emitter to collector, and so the collector current does not change during irradiation. Generally, the drift of the parameters and characteristics of integrated circuits (in the article this will be base current I_b and static current gain of the transistor β) is called degradation. The radiation degradation of a static current gain of the bipolar transistor is determined by a radiation-induced increasing of the base current, which usually depends linearly on the total dose [3-6].

Two types of transistors were selected to compare radiation hardness: SiGe-transistors SGN8343Z and silicon 2N2222A. The irradiation was performed with the 8 keV X-ray source at the dose rate of 10 rad(SiO_2)/s. The dependencies of collector and base current on the voltage that was applied to



the emitter junction at the zero offset of the collector junction have been measured during the irradiation process. These dependencies are shown in Fig. 1 and Fig. 2 for different total dose levels. The dependencies of static current gain on the emitter-base voltage are shown in Fig. 3 and Fig. 4. Irradiation and measurement processes were held at $(25 \pm 0,1)^\circ\text{C}$. The temperature stabilization system was used to control the temperature during the experiment. Its theory of operation is described in [6].

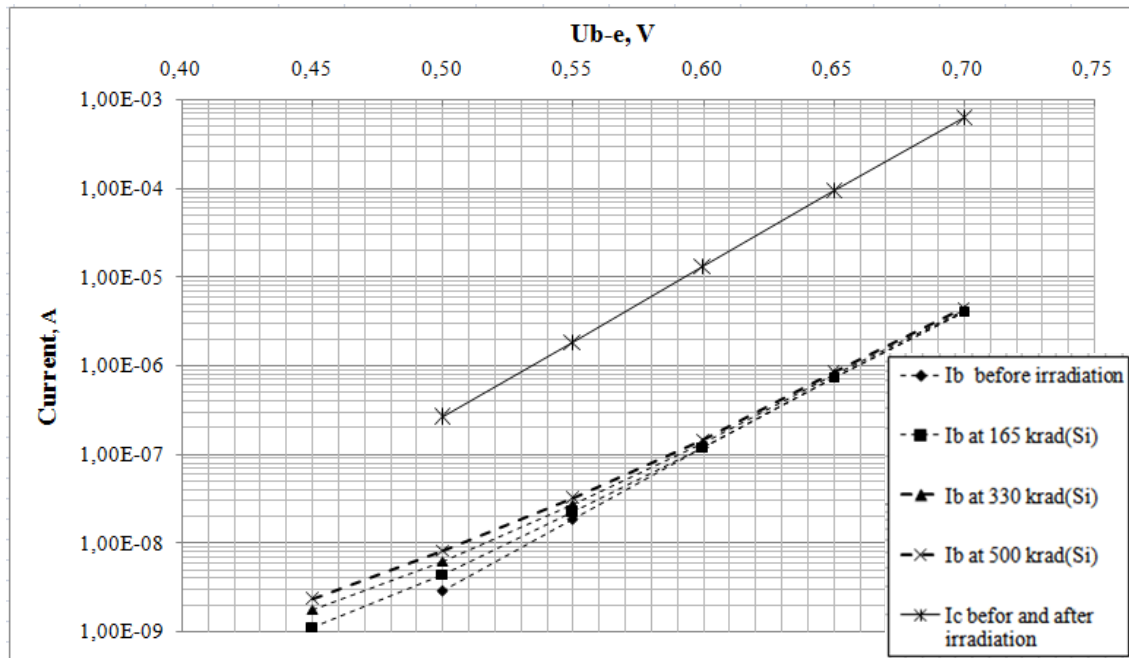


Figure 1. The dependence of the base current I_b and the collector current I_k on the voltage emitter-base at zero offsets of collector junction for the SiGe transistors SGN8343Z before irradiation and for different value of total dose.

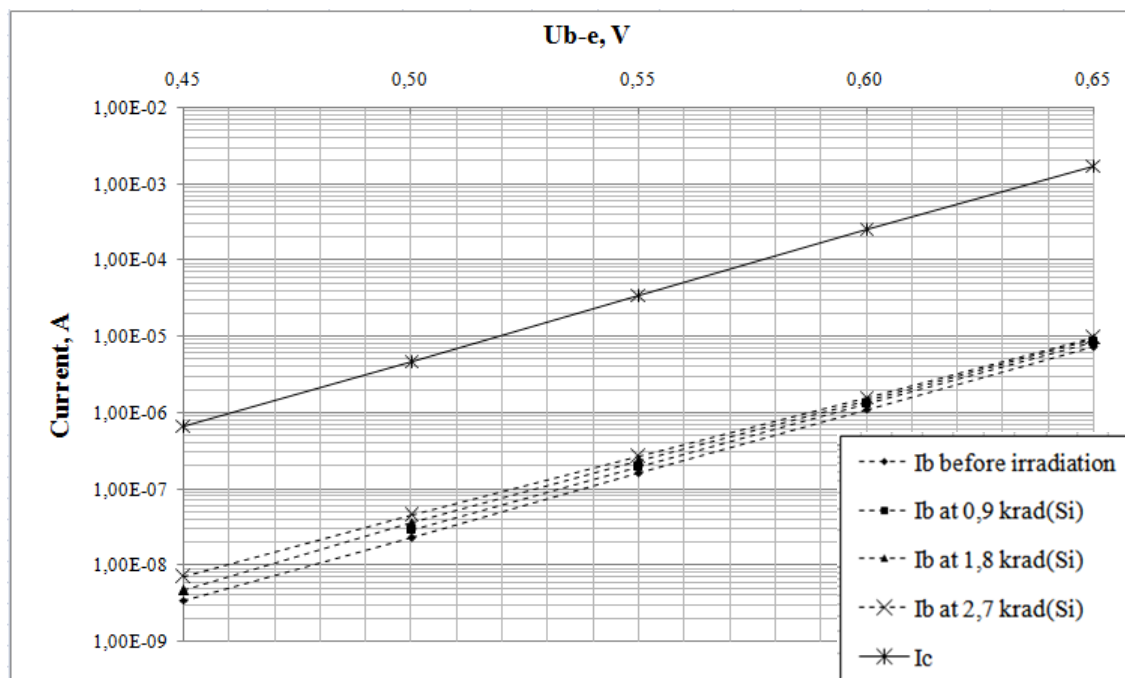


Figure 2. The dependence of the base current I_b and the collector current I_k on the voltage emitter-base at zero offsets of collector junction for the silicon transistors 2N2222A before irradiation and for different value of total dose.

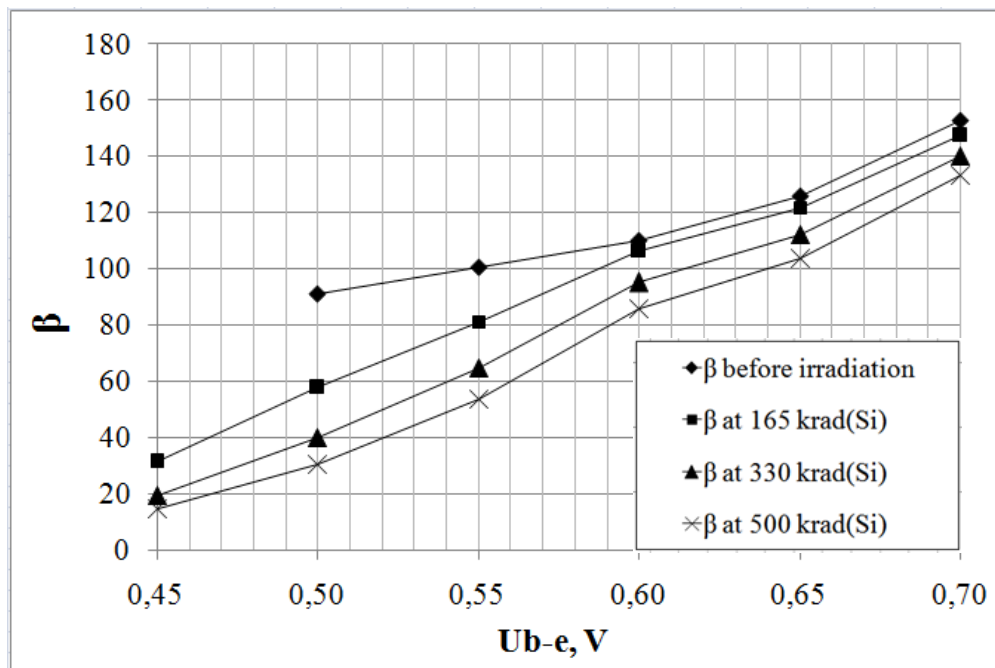


Figure 3. The dependence of the static current gain of the transistor on the voltage emitter-base at zero offsets of collector junction for the SiGe transistors SGN8343Z before irradiation and for different value of total dose.

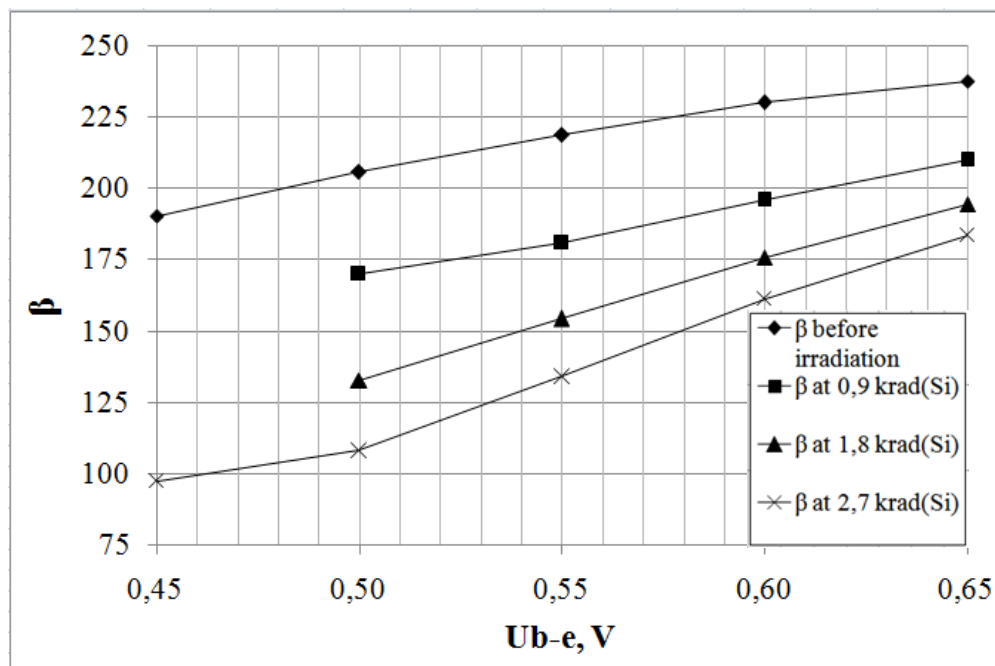


Figure 4. The dependence of the static current gain of the transistor on the voltage emitter-base at zero offsets of collector junction for the silicon transistors 2N2222A before irradiation and for different value of total dose.

The comparison of radiation degradation of base current ΔI_b for different transistors was performed at the emitter-base voltage 0.55 V. The relative increase of base current $\Delta I_b/I_{b_0}$ for SiGe-transistors and silicon devices against its value before the irradiation is shown in Fig. 5. It is easy to see that the radiation degradation of the base current ΔI_b of SiGe-transistors is 2 orders of magnitude less than in silicon transistors.

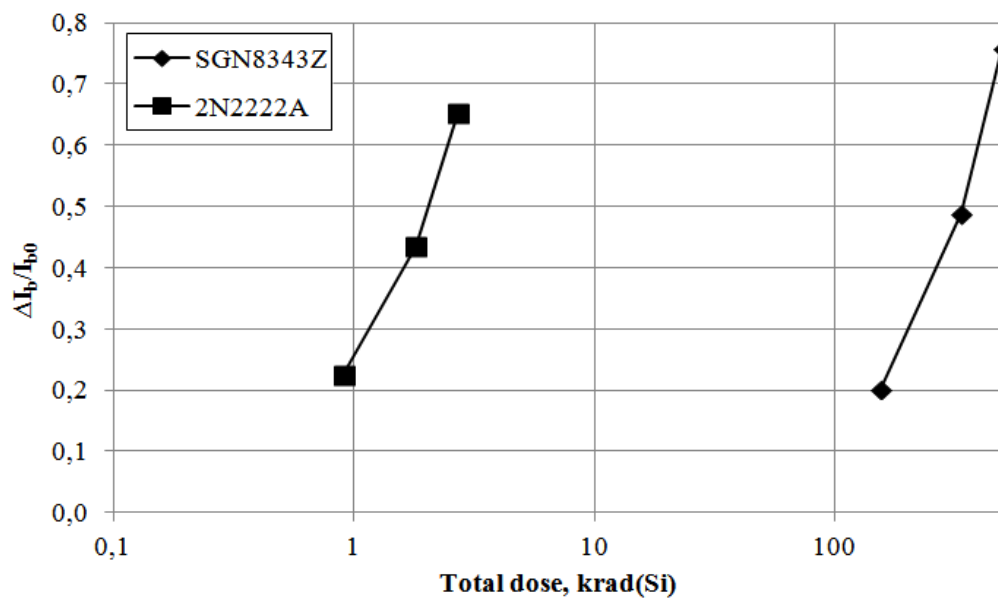


Figure 5. Total dose dependence of relative difference of input bias current of the SiGe transistor SGN8343Z and conventional silicon transistors 2N2222A (I_{b0} - the value of the base current before irradiation).

3. Physical reasons of increased radiation hardness of the SiGe-transistors

According to the series of work, the main reason of bipolar SiGe-transistors radiation degradation is the formation of positively-charged traps in the oxide with the following conversion to the interface traps. Their build up results in the increase of base current and decrease of a static current gain of the transistor [4-6]. Electron-hole pairs can be most effectively separated during irradiation above the emitter junction border by the edge electric field. There are a number of works that describe the correlation of the dimensions of depleted area and bipolar devices radiation degradation rate [7].

A standard cross-section that shows the structure of bipolar SiGe-transistor is shown in Fig. 6. Above the emitter junction side boundary at the passive area, a thin layer of SiO_2 oxide is located. The layer is many times thinner than the corresponding protective layer in conventional silicon transistors. As shown in Fig. 7, the protective layer in silicon transistors is usually located over the emitter junction on the surface of the silicon substrate.

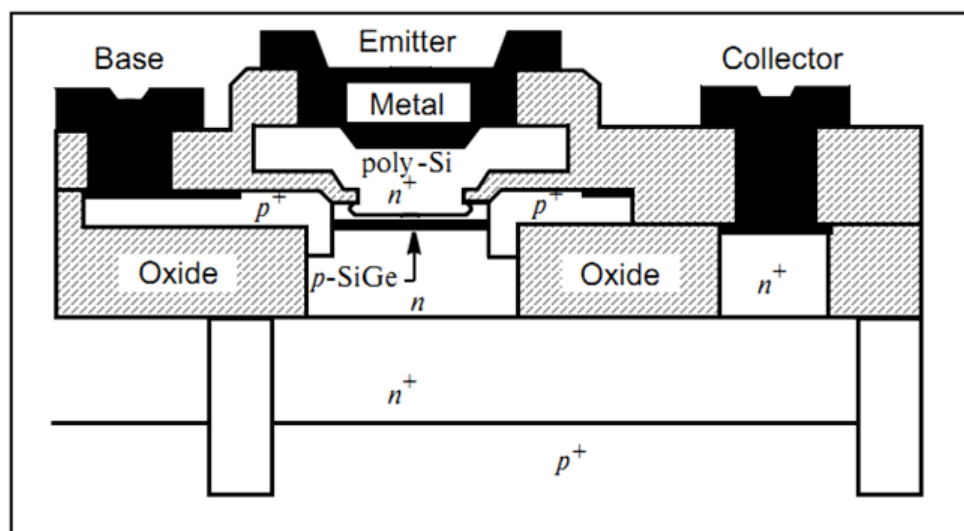


Figure 6. The cross-section that shows the structure of bipolar SiGe-transistor [1]

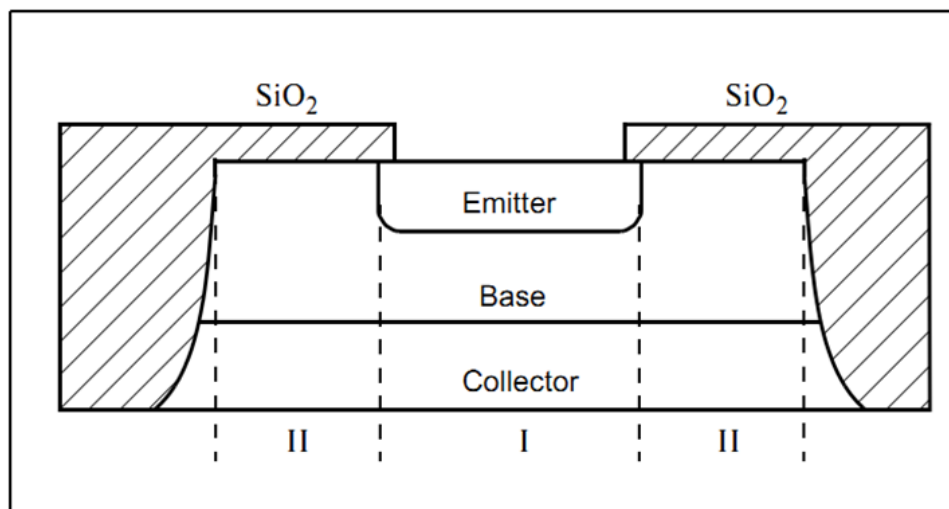


Figure 7. The cross-section that shows the structure of conventional silicon transistor [1]

Positively charged traps are formed on the whole oxide layer during the irradiation. As a result, a lot more holes are accumulated in thick oxides rather than in thin ones. It explains a dependence of the rate of radiation degradation of the base current on the oxide thickness above the depleted emitter junction area.

From the analysis of obtained experimental results (fig. 5), it is clear that the degradation rate of SiGe transistor base current lower than in conventional silicon devices by two orders of magnitude. It approximately corresponds to the ratio of oxide thickness over emitter depletion regions in SiGe and conventional silicon transistors.

4. Conclusion

In this work an experimental comparing of the radiation hardness of SiGe transistors and silicon devices were performed. It was obtained that base currents radiation degradation rate and current gain decreasing of SiGe-transistors are approximately two orders of magnitude less. High radiation hardness of SiGe devices is connected with a small thickness of SiO₂ oxide layer above the depleted emitter junction area. It should be noted that it is also possible to use this technological method in silicon transistors in order to increase their radiation hardness.

Acknowledgements

This work was supported by the Competitiveness Program of NRNU MEPhI.

References

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