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Low temperature radiation response of SiGe HBTs

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Abstract. Radiation degradation rate of base current in SiGe HBTs was experimentally investigated using X-ray irradiation source with Cu anode at room and low temperatures. The dependences of base and collector current on the emitter-base voltage of the transistors were measured during radiation impact and presented for different total dose levels and irradiation conditions.

1. Introduction

SiGe HBTs are widely used in modern high-frequency electronic devices due to low cost and compatibility with convention silicon technology. There a lot of different applications of high-frequency devices based on SiGe transistors. Excellent balance of electrical performance and compatibility properties of SiGe technology provides a wide range of possibilities for applications of SiGe devices in special operation conditions such as front-end-electronics of particle accelerators or data communication equipment of space-crafts. The common property of both cases is radiation impact during operation. For accelerator applications, it is high energy slowing-down radiation [1]. In the space environment, the main reason of radiation damage of electronics is the impact of protons and electrons from radiation belts of the Earth [2], which can be simulated in laboratory conditions by Co-60 or X-ray sources [3].

As in conventional silicon devices, the radiation impact leads to accumulation of interface traps at the interface of chip substrate and a passivation layer in SiGe transistors. The interface traps act as recombination centers and increases surface component of base current [4]. The increase of base current reduces current gain of the transistors and leads to parametric and functional failures of semiconductor microelectronic devices.

Unlike accelerator applications, the operation temperature of electronic devices during space mission varies in a wide range. The most typical for temperature values for space applications are near the low limit of the operation temperature range. It was experimentally obtained, that low-temperature irradiation reduces the degradation rate of conventional silicon devices [5]. Since it increases failure total dose level, we can consider this feature as very useful. The main purpose of this work is to investigate the degradation rate in SiGe transistors for room and low temperature irradiation.

2. Experimental equipment

As in conventional silicone devices, main electrical performance characteristics of SiGe transistors are the dependences of base and collector current on emitter-base voltage at a fixed bias of the collector junction. Using this data, we can determine the current gain for any emitter junction bias. To perform set different values of emitter junction bias and to measure base and collector currents during



irradiation an experimental installation was used. The structure diagram of the installation is presented in Fig.1.

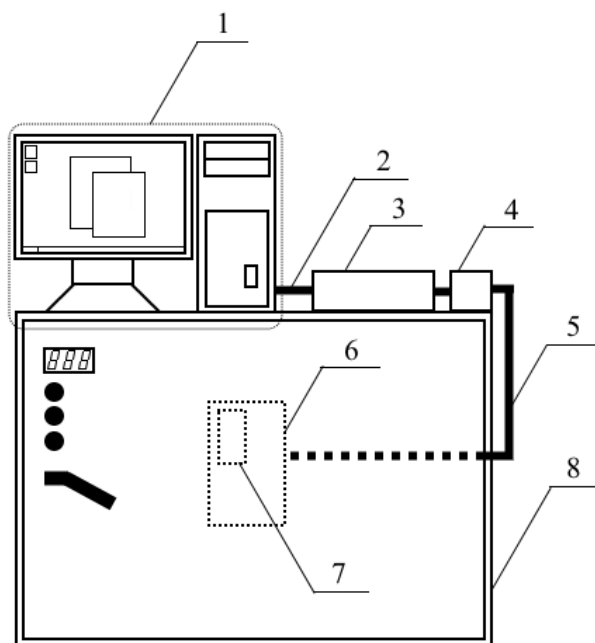


Figure 1. Structure diagram of the experimental installation.

To perform measurements during irradiation, a SiGe-transistor is soldered into printed circuit board (7) with a resistive temperature sensor. The board (7) is in good thermal contact with the active surface of temperature control device (6), the base of thermoelectric modules (Peltier elements). The temperature control device and the board with SiGe-transistor are located in X-ray chamber (8), which involves X-ray source with Cu-anode. The energy of the X-ray beam is 8 keV. The temperature control device and the board with SiGe-transistor are connected with measure (3) and control (4) devices respectively by cable (5). General control and the user interface are provided by the computer (1) through cable (2).

The experimental installation has followed performance parameters:

- available voltage range: $-10.0\text{ V} \dots 10.0\text{ V}$
- absolute voltage accuracy: $\pm 1.0\text{ mV}$
- available current range: $\pm 0.1\text{ nA} \dots \pm 100\text{ mA}$
- relative current accuracy: $\pm 1\%$
- available temperature control and stabilization range: $-40^{\circ}\text{C} \dots +125^{\circ}\text{C}$
- absolute temperature stabilization accuracy: $\pm 0.1^{\circ}\text{C}$
- available range of irradiation dose rates: $1.0 \cdot 10^{-3}\text{ rad(Si)/s} \dots 50\text{ rad(Si)/s}$

3. Experimental results and discussion

For experimental investigations, a sample of commercial available BFU768F SiGe transistor was selected. The BFU768F are NPN wideband silicon germanium radiofrequency bipolar transistors manufactured by NXP Semiconductor in the plastic SOT343F package.

The dependences of base and collector currents of the transistor were measured at various emitter-base voltage values and zero collector junction bias. The dependence of current gain on emitter junction bias was calculated using measured data. The measurements were performed at $(25.0 \pm 0.1)^{\circ}\text{C}$. The irradiation of the sample was performed at 10 rad(Si)/s by X-ray source with Cu-anode in three steps. During the first step, the temperature of the sample was 25°C . The second and the third irradiation steps were performed at -40°C . After each step, the measurements were performed at

(25.0 ± 0.1) $^{\circ}\text{C}$. The dependences of base current and collector current on total dose are presented in Fig.2 during the first step, after the second step and after the third step of the irradiation. The dependence of base and collector current measured at (25.0 ± 0.1) $^{\circ}\text{C}$ on emitter-base voltage before irradiation and after each irradiation step and corresponding current gain data are presented in Fig.3.

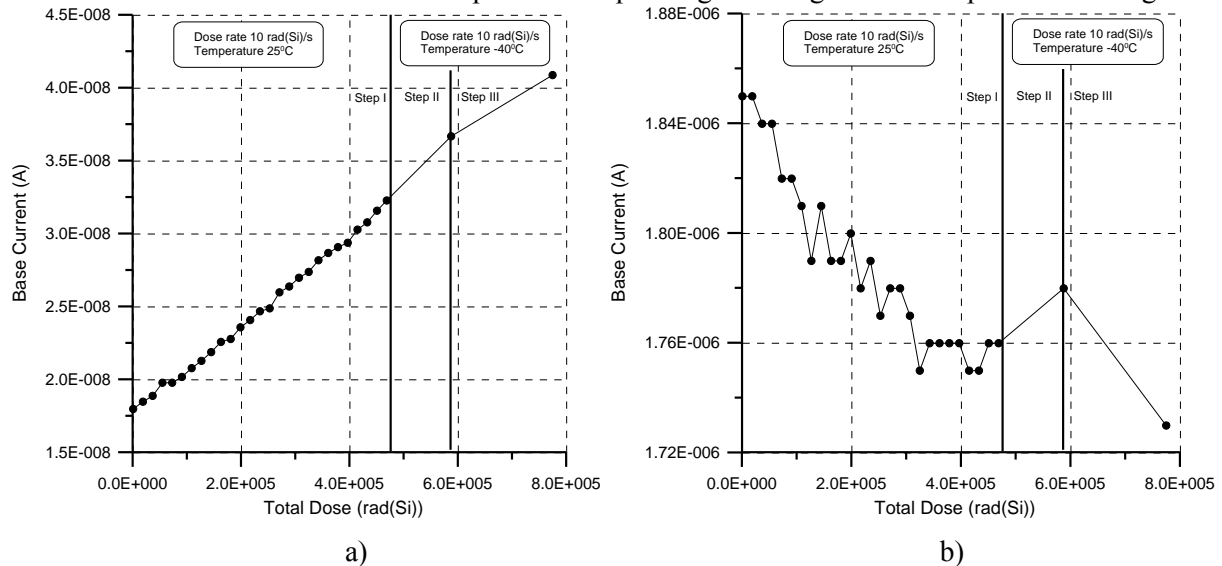


Figure 2. Dependence of base current on total dose during irradiation steps (a); Dependence of collector current on total dose during irradiation steps for BFU768F SiGe-transistor.

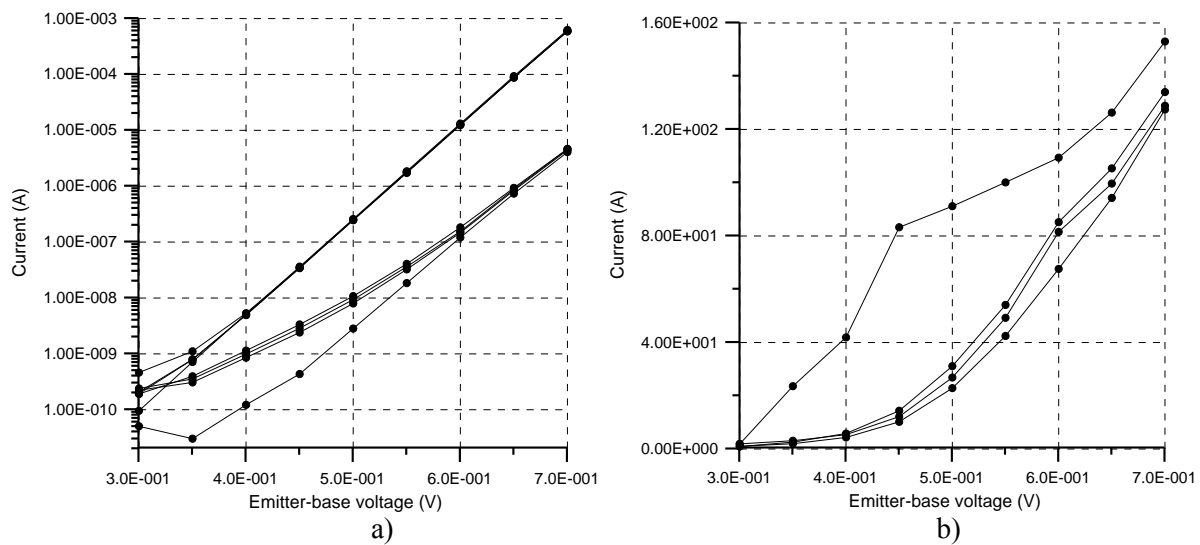


Figure 3. Dependence of base and collector current measured at (25.0 ± 0.1) $^{\circ}\text{C}$ on emitter-base voltage before irradiation and after each irradiation step (a) and corresponding current gain data (b) for BFU768F SiGe-transistor.

From Fig.2 and Fig.3 it is clear, that, as in conventional silicon transistors, current gain radiation degradation is connected with radiation-induced an increase of base current because collector current doesn't depend on the total dose significantly for all the emitter-base voltage range. From Fig.4 we can see, that, unlike conventional silicone transistors, the decreasing of the irradiation temperature down to -40°C doesn't lead to decreasing of the radiation degradation rate. It can be explained by decreased oxide thickness over emitter-base junction in comparison with conventional silicon structure. Typical cross section of the SiGe bipolar structure is presented in Fig.4.

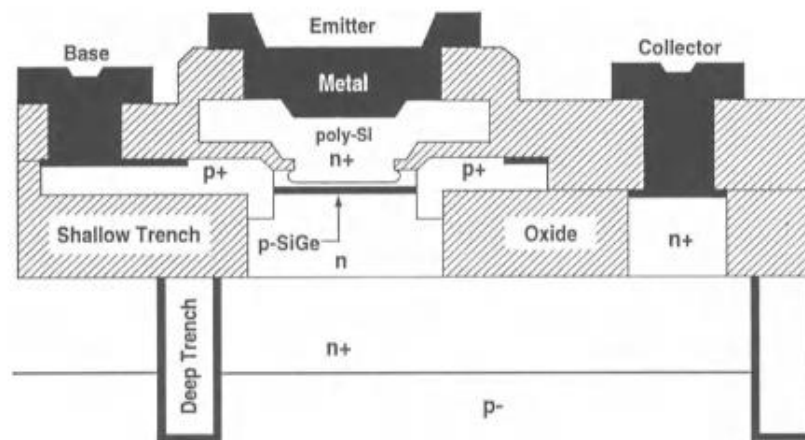


Figure 4. Typical cross section of SiGe bipolar structure [1].

4. Conclusion

As in conventional silicon transistors, the main reason of current gain degradation during radiation impact is increasing of surface component of the base current. Unlike silicon devices, the decreasing of irradiation temperature doesn't decrease the rate of the radiation degradation of SiGe bipolar transistors. It can be explained by decreased oxide thickness over emitter-base junction in comparison with conventional silicon structure. To affect the radiation degradation rate of SiGe device, it is necessary to decrease irradiation temperature down to the low limit of operation temperature range.

5. References

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