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Heavy ion micro-beam study of single-event transient (SET) in SiGe heterjunction bipolar transistor

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Silicon-germainum heterojunction bipolar transistor (SiGe HBT) has been demonstrated to be suitable in extreme environment because of its superior temperature characteristics which can operate from 43 K to 400 K [1]. In addition, outstanding hardness to both total ionizing dose (TID) radiation and displacement damage make SiGe HBT technology particularly attractive for space applications [2]. However, it was shown that SiGe HBTs are vulnerable to single event effects (SEEs) [3].

In the last decade, the mechanism of the SEE of SiGe HBT was investigated via TCAD simulation method by a mass of studies. And the representation of SEE was explored by the broad beam heavy-ion tests, for instance, some single event upsets (SEU) of SiGe HBT circuits had been performed by broad beam heavy-ion irradiation [4]. But the SEE sensitive volume can be accurately defined only by the micro-beam heavy ion tests. Furthermore, the micro-beam heavy ion irradiation can observe the actual transient phenomena and the mechanism of single event transient (SET) well.

SiGe HBT under test. For this work, the KT9041 SiGe HBTs are employed in the irradiation experiment. The device is similar to vertical NPN Si BJT. But the base region is constituted by gradient SiGe in the SiGe HBT. The thickness of intrinsic base is 0.08 μm. And the heavy doping process is used in the region of the base and the emitter to reduce the area resistance. The lightly doped concentrations of collector and substrate are 6×10^{15} and 1×10^{14} cm^{-3}, respectively. Most importantly, there is a collector/substrate (C/S) junction with very large area about 100 μm × 100 μm, which is the most typical structure in this SiGe HBT. In addition, the local oxidation of silicon (LOCOS) isolation process is employed in the SiGe HBT, but the deep trench isolation (DTI) is not used.

Experiment details. The heavy ion micro-beam experiment for the SiGe HBT was conducted on the test platform of the L30^0 terminal of the HI-13 tandem accelerator in China institute of atomic energy. The spot size of ions micro-beam is less than 2.7 μm × 4.1 μm. In order to penetrate the whole device and into the sensitive volumes resulting in SET, the 110 MeV chlorine ion was selected in the irradiation test. And the LET is almost constant about 12 MeV·cm^2/mg within the SiGe HBT, also as verified using SRIM calculation. The heavy ion

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tests were performed in vacuum at normal incidence with heavy ion irradiation from the topside of the SiGe HBT [5]. Different from the traditional IBIC method to use charge sensitive amplifier, this experiment employs an oscilloscope, which bandwidth is 4 GHz, to directly measure current transients induced by ion striking. The amplitude and pulse width of the SET signal is very small but the environmental noise maybe large, so that the real signal is not easily captured by the oscilloscope. Consequently, a testing circuit is designed as follow. First, two resistors which values are 100 kΩ are respectively connected with input ports of base and emitter to prevent leakage current breakdown. Second, two inductances about 10 μH are used to remove noise from the power supply at power ports of base and collector. Third, two capacitors of 0.1 μF are placed between the output ports and the terminals of base and collector to collect high frequency transient signals. The C/S junction is biased at −3 V, the base and emitter are biased at 0 V. So the worst bias is formed for SEEs.

Results and discussion. Figure 1(a) shows characteristic of SETs induced by heavy-ion at collector and base terminals when the ion micro-beam strikes at the center of the SiGe HBT. The peak values of transient currents are about 1 mA and 0.3 mA for collector and base respectively. And the pulse width of transient current is about 6 ns. As heavy ions strike into the SiGe HBT, a large number of e-h pairs will ionized along path of ions. Therefore, the terminal currents sharply increase within a few picoseconds. Then, the electrostatic potential of the depletion layer is broken by the plasma track. Thus, the vast carriers are collected by the electrodes via drift and diffusion mechanism within a few nanoseconds. The collected charges of collector and base respectively are about 1.5 pC and 0.6 pC as shown in Figure 1(b).

After the irradiation experiment, we also compare the experimental results with our previous simulation results. The SEE model of the SiGe HBT is built by Sentaurus TCAD tools. The ions characteristics and bias conditions are the same as those of the heavy ion micro-beam experiment.

As seen from the Figures 1(a) and (b), the SETs of collectors in the simulation and test are similar: the peak values of transient currents respectively are 0.9 mA of test and 1.5 mA of simulation, and collected charges are 1.5 pC of test and 2.0 pC of simulation, which differences are less than double. And both in irradiation test and simulation, the rising time of transient currents are about a few picoseconds, and the pulse widths are 6 ns. The details of drift and diffusion of ionized charges within the SiGe HBT can be observed by simulation in our previous work [6]. However, the SET of base is slightly different between simulation and test: the peak values of transient currents are 0.3 mA of test and 1.5 mA of simulation, and collected charges are 0.7 pC of test and 0.2 pC of simulation, which differences are about triple but still less than an order of magnitude. For time characteristics, the rising time of transient currents are the same for test and simulation, so the drift of carriers is consistent for test and simulation. But the diffusion times are 500 ps of simulation and 6 ns of test. These differences may be caused by the ideal state of simulation and the test environment. In view of the complex equipment in the heavy ion test, using prober system is impossible. Thus, a test circuit needs to be employed to capture the small SET pulse. However, a little electrical interference may be brought in the electronic component of the test circuit by the complex electromagnetic environment produced by the accelerator equipment. Thus, the tiny signal of base SET may be affected.

Figures 1(c) and (d) compare the transient currents and charge collection of collector and base at different power voltages. For the collector, the amplitude of transient cur-rent increases but the pulse width is almost constant with the voltage rising. Moreover, the amount of collected charges gradually increase and finally tend to saturated as voltage rising. The reason is that the range of “funnel” electrostatic potential rises to the maximum with the voltage rise. For the base, the transient currents and charge collection hardly change with power voltage increased, because the grounded base terminal is not influenced by the applied voltage.

In the heavy ion micro-beam irradiation test, the whole topside of the SiGe HBT was irradiated point by point. Figures 1(e) and (f) respectively show the charge collection of collector and base as a function of the striking location obtained by simulation and experiment. Both of simulation and experiment indicate that the charge collection of col-lector is sensitive in and nearby the C/S junction. Since there is no DTI structure in this SiGe HBT, the potential of C/S junction is affected when the ions strike into the area near the C/S junction, resulting in the sensitive areas of charge collection is larger. The area within the STI is affirmed the sensitive volume for base. According to the results of the heavy ion micro-beam test, the simulation model is verified reasonable in our pervious works [6, 7].

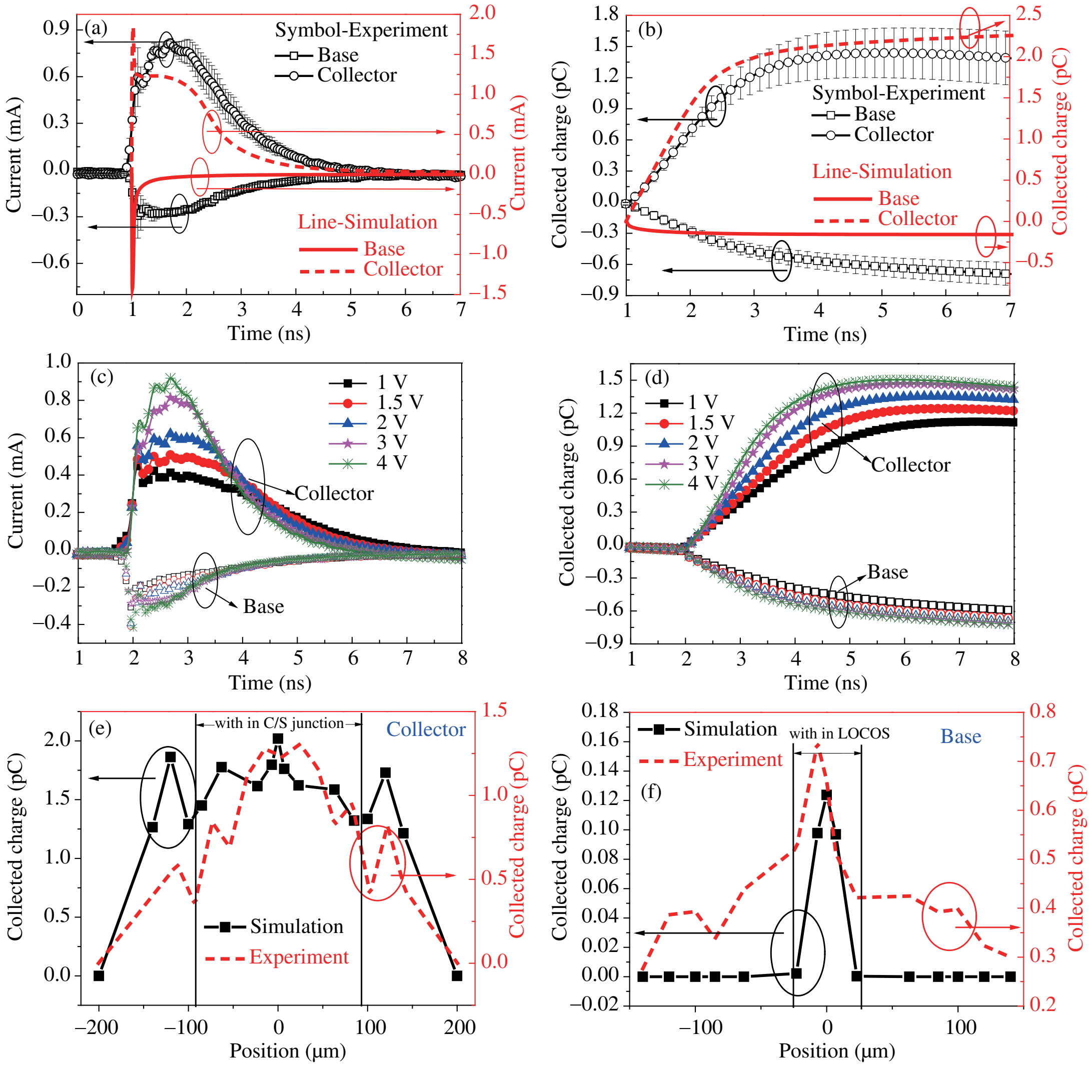

Figure 1 (Color online) The irradiation test results of the SiGe HBT. (a) The transient currents as function of time by micro-beam heavy-ion test and simulation; (b) the collected charges as function of time by micro-beam heavy-ion test and simulation; (c) the transient currents at different power voltages in irradiation test; (d) the collected charges at different power voltages in irradiation test; (e) comparing the SEE sensitive volume of charge collection at collector by test and simulation; (f) comparing the SEE sensitive volume of charge collection at base by test and simulation.

Conclusion. The domestic SiGe HBT is irradiated by heavy ion micro-beam in our work. First, the mechanism of SET and the influence of power voltage are investigated. Then, the SEE sensitive volume of the SiGe HBT is confirmed. In addition, the experimental results are compared with the simulation results.

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References

1 Cressler J D, Niu G F. Silicon-Germanium Heterojunction Bipolar Transistors. Boston: Artech House, 2003. 22–30

2 Cressler J D. Radiation effects in SiGe technology. IEEE Trans Nucl Sci, 2013, 60: 1992–2014

3 Xu Z Y, Niu G F, Luo L, et al. Charge collection and SEU in SiGe HBT current mode logic operating at cryogenic temperatures. IEEE Trans Nucl Sci, 2010, 57: 3206–3211

4 Varadharajaperumal M. 3D simulation of SEU in SiGe HBTS and radiation hardening by design. Dissertation for Ph.D. Degree. Alabama: Auburn University, 2010. 89–93

5 Fleetwood Z E, Lourenco N E, Ildefonso A, et al. Using TCAD modeling to compare heavy-ion and laser-induced single event transients in SiGe HBTs. IEEE Trans Nucl Sci, 2017, 64: 398–405

6 Zhang J X, Guo H X, Wen L, et al. 3-D simulation of angled strike heavy-ion induced charge collection in silicon-germanium heterojunction bipolar transistors. J Semicond, 2014, 35: 044003

7 Zhang J X, He C H, Guo H X, et al. 3-D simulation study of single event effects of SiGe heterojunction bipolar transistor in extreme environment. Microelectron Reliab, 2015, 55: 1180–1186