New Materials and Devices Designed by a New Concept C – P1

3-D Simulation of Angled Strike Heavy-Ion Induced Charge Collection in SiGe HBTs

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Abstract

This paper presents 3-D simulation of angled strike heavy ion induced charge collection in Silicon-Germanium Heterojunction Bipolar Transistors (SiGe HBTs). We select several different striking angles at various typical ion strike positions. The charge collection mechanism for each terminal is identified based on analysis of the device structure and simulation results. Angled strike ions induced charge collection present complex situation. With the change of striking angle, the longer the length of the ions track in sensitive volume, the more charge is collected. STI will prevent a part of diffused charge that charge collection reduces.

1. Introduction

In recent years, SiGe HBTs have become a strong contender in space applications because of outstanding low-temperature performance. For space applications, SiGe HBTs have demonstrated excellent hardness to both total ionizing dose radiation and displacement damage without radiation hardening. However, results of testing and simulations have shown that single-event effects are restrictions of space applications in SiGe HBTs [1]-[3].

Heavy ions in space strike electronic components in any possible angles. This work simulates the charge collection for angled strikes in SiGe HBTs [4]-[6]. We verify the sensitive volume of the SEE, and explore the mechanism of charge collection for angled strike through the analysis of device structure and simulation results.

2. Device structure

The SiGe HBT used for simulation is similar to the traditional NPN vertical bipolar transistor as shown in Fig.2. The difference is that the base region is constituted by gradient SiGe in SiGe HBT. Active region is formed using shallow trench isolation (STI) in the base around. This SiGe HBT has a heavily doped extrinsic base to decrease base resistance and collector-base capacitance [7]-[9]. Other structures include a lightly doped p-type substrate and a polysilicon emitter. An n^+ buried layer is provided for the lead-out collector contact, and the outermost ring as heavy boron-doped substrate contact.

3. single-event effects device 3D simulation

3.1 structure simulation

The structure model of 3-D SiGe HBT is structured based on device formation and process information. For accurate SEE simulation, it is important to built appropriate grid for device structure. In this work, the more mesh in the base and near the ion tracks, and less mesh in other regions. Fig. 2 shows the 3-D view of device and mesh. Fig. 3 shows the 2-D cross section which cut the simulated 3-D structure in central of z coordinate axis.

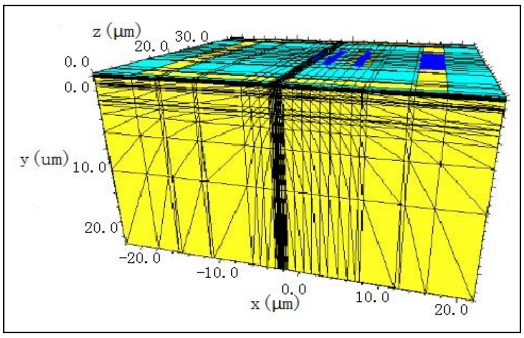

Fig. 1, 3-D view of device

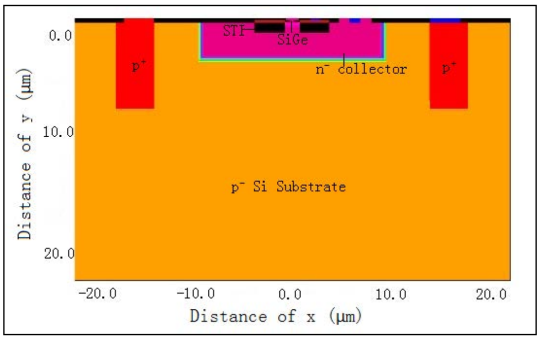

Fig. 2, 2-D view of the intrinsic portion of the device

3.2 Single-event effects simulation

The physical models for simulation include Phillips unified mobility, SRH recombination, Auger recombination, velocity saturation, and band gap narrowing (BGN). In the simulation, the substrate is biased at -5V, and all other terminals are biased at 0V. This is the worst bias situation in SiGe HBTs that would form a reverse biased pn junction in collector/substrate(C/S) junction. In order to investigate the worst case that ions traverse the entire device, we simulate charge deposition throughout the entire simulated structure. Thus, we chose a 0.2 *pC/μm* charge deposition, which is equivalent to an LET=20*MeV/cm²/mg*.

4. Result and Discussion

4.1 Charge Collection Mechanism and Sensitive Volume

Strike ions induce a large number of electron-hole pairs along the ion track so that potential equipotential lines along the ion track distort to the substrate to form a funnel potential. A part of charge is collected by drift in the funnel field. Subsequently, collector and substrate collect a part of charge because of diffusion effect. Holes are collected through substrate and base. Electrons are collected through collector and emitter. Fig. 4(a)-(c) show the charge collection by base, collector and substrate as a function of the x-coordinate of striking location. The z-coordinate is fixed at the centre of device. The area within the shallow trench isolation is affirmed the sensitive volume for base. Collector and substrate charge collection are sensitive in and nearby the C/S junction. Charge collection of emitter is negligible.

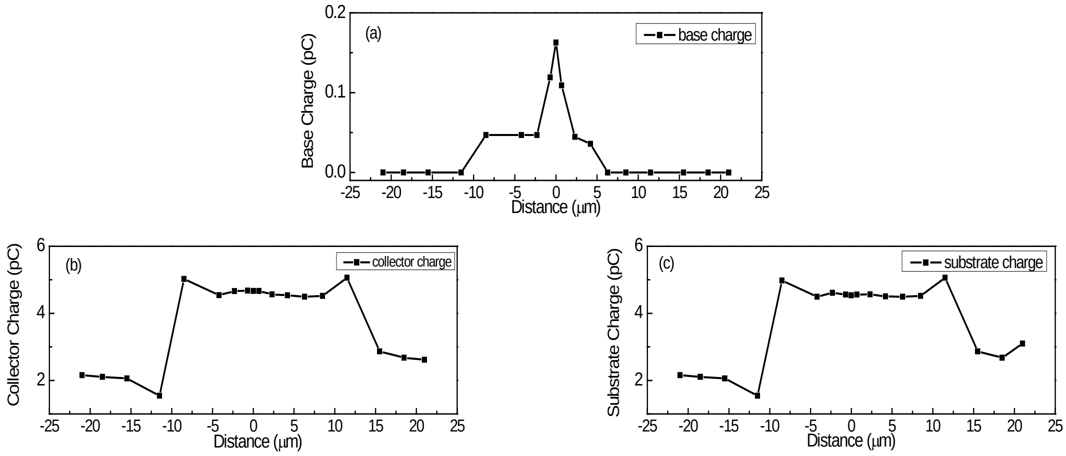

Fig. 4, Charge collected by base (a), collector (b) and substrate(c) as a function of the x-coordinate of strike location

4.2 Angled Strike Track Selection

In ground modeling experiment, angled strike is usually more complicated to achieve. However, it is relatively simple that computer simulate angle strike. Hence the computer simulation is an effective method to research angle strike. According to the different areas, different materials, different junction, as well as different length in specific structure of ions track, we chose eight kinds strike paths, as shown in Fig. 5.

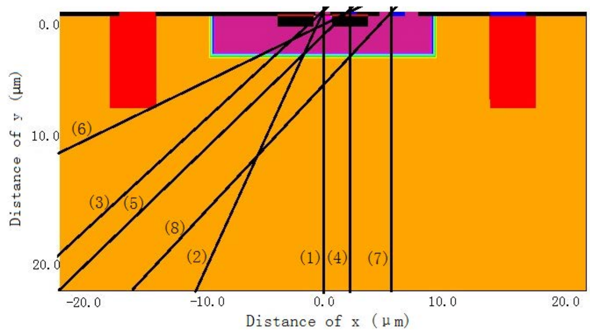

Fig. 5, Angled strike paths in simulation

4.3 Ion Angled Strike Dependence

Each terminal of the charge collection is closely related to the position and angle of strike ions. Angle dependency of charge collection can be obtained through the analysis of transient current, charge collection and device structure. Table I shows the charge collection of angled strike. Fig.6-Fig. 9 show transient terminal current as function of time of several typical position and angle.

Table I, The simulated charge collection of angled strike

Charge collection (C) / Position and angle	Base	Collector	Emitter	Substrate
(1) x=0μm-0°	-1.62851E-13	4.66546E-12	3.45768E-14	-4.53719E-12
(2) x=0μm-30°	-1.78975E-13	5.12988E-12	3.32266E-14	-4.98413E-12
(3) x=0μm-45°	-1.74344E-13	5.69374E-12	2.73509E-14	-5.54675E-12
(4) x=1.2μm-0°	-1.72978E-14	4.59674E-12	1.11523E-17	-4.57945E-12
(5) x=1.2μm-45°	-1.67557E-13	6.05033E-12	7.57121E-16	-5.88354E-12
(6) x=1.2μm-60°	-2.65368E-13	4.81177E-12	6.33744E-15	-4.55274E-12
(7) x=7μm-0°	1.65496E-17	4.47693E-12	3.39524E-19	-4.47695E-12
(8) x=7μm-45°	-2.1268E-16	6.12464E-12	-3.58287E-18	-6.12442E-12

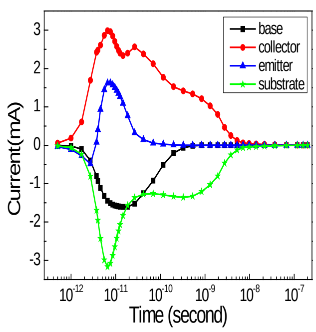

Fig.6, Transient terminal current for ions strike from x=0μm at 30°

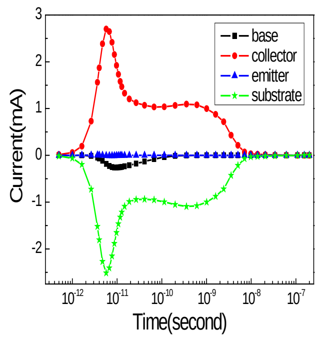

Fig.7, Transient terminal current for ions strike from x=1.2μm at 0°

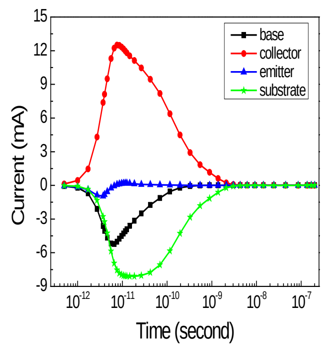

Fig.8, Transient terminal current for ions strike from x=1.2μm at 45°

The transient current of striking ions from x=0μm at 0° and 45° are very similar to the incidence at x=30° as shown in Fig. 6. Ions pass through the active region of the device, each transient terminal current generates a pulse crest because of drift effect. Then, collector and substrate current slowly change to 0 due to diffusion. Compared the first three rows of data in table I found that base charge collection for 0° is least. Ions track length of angled strike is longer than the length of normal strike in base. Thus, angled strike collects more charge. Base charge collection for 45° is less than 30° because STI prevent a part of collected charge by diffusion. This further verified that the region of STI surrounding is the sensitive volume for base charge collection. The ions track length become longer in collector and substrate due to increase of strike angle, so collector and substrate collect more charge, as shown in table 1.

Fig. 7-Fig.8 compare the transient current when ions strike device at x=1.2μm for 0°, and 45°. The graph of 60° is similar to the graph of 45°. For 45° and 60°, base current has a pulse, while it has not for 0°. In addition, the data of x=1.2μm in the table 1 shows that the base charge collection

for 60° is more than 45° than 0°. The reason is that ions pass through the inside of STI where sensitive area of base at 45° and 60°, and the ions track length is longer for 60° than 45° in base. Collector and substrate charge collection for 45° than 60° than 0°. The ions track of 45° is located in STI so that a part of charge cannot diffuse to the collector and substrate contact.

Transient current of strike ions from x=7μm at 0° and 45° is similar to the Fig.7. Base current is almost zero because ions do not pass through the base region. The collector and substrate charge collection for 45° is greatly more than 0°. As previously mentioned, the ions track length through device is greatly longer for 45° than 0°.

5. Conclusion

We have presented a simulation of angled strike ions induced charge collection in SiGe HBTs, and get the conclusions as follow. Whether the location of ions enter device, as long as ions track pass through the sensitive volume, it will cause vast charge collection. With the change of striking angle, the longer the length of the ions track in sensitive volume, the more charge is collected. STI prevents a part of diffused charge.

Acknowledgments

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