Relationship between soft error rate in SOI-SRAM
and amount of generated charge by high energy ion probes

Masatoshi Hazama[*1], Satoshi Abo[1], Naoyuki Masuda[1], Fujio Wakaya[1], Shinobu Onoda[2],

Takahiro Makino[2], Toshio Hirao[2], Takeshi Ohshima[2], Toshiaki Iwamatsu[3], Hidekazu Oda[3],

Mikio Takai[1]

1 Center for Quantum Science and Technology under Extreme Conditions, Osaka University, Japan

2 Japan Atomic Energy Agency (JAEA), Japan

3 Renesas Electronics Corporation, Japan
*Email: hazama@nano.cqst.osaka-u.ac.jp

Keywords: silicon-on-insulator (SOI), soft error, floating body effect, body-tie structure,
nuclear microprobe

Abstract

Soft error rates (SERs) in partially depleted (PD) silicon-on-insulator (SOI) static random access memories (SRAMs) with a technology node of 90 nm have been investigated by hydrogen, helium, lithium, beryllium, carbon and oxygen ions, accelerated up to a few tens of MeV using a tandem accelerator. The SERs increased with increasing the amount of the generated charge in the SOI body by a floating body effect, even if the amount of the generated charge was less than the critical charge. The SERs with the generated charge in the SOI body more than the critical charge were almost constant.

1. Introduction

In recent years, a size of a semiconductor device is shrinked for low power consumption and high speed operation. Therefore the amount of charge, inducing soft errors, i.e. critical charge, for an advanced device decreases compared with that for a previous device. In 1970s, active radioisotopes of the package material used for a semiconductor device induced the soft errors [1]. However, in the present time, the cosmic ray is the main factor for the soft error, since the purity of the package material is improved. As the primary cosmic ray from the sun impinges the atmosphere, secondary cosmic rays which include muon, pion, neutron and proton are generated. The main factor for the soft error is a neutron, since a high energy neutron strikes a semiconductor device without energy loss at its flight path. When the neutron strikes a semiconductor device, the neutron induces a nuclear reaction with the device material, resulting in high energy particles and electron-hole pair generations along its track and soft error occurrences. A silicon-on-insulator (SOI) device realizes a low power consumption and high speed operation. In addition, the SOI device can suppress the soft error, since the amount of the generated charge in the SOI body with a separated active area by a buried oxide (BOX) layer from the substrate is less than that in the conventional bulk device. However, even if the amount of the generated charge in the active region is less than the critical charge, the soft errors occur by a floating body effect which appears in the partially depleted (PD) SOI device in the electrically floated active region from the substrate. When a high energy particle irradiates the active silicon region of an n-type SOI-metal-oxide-semiconductor field-effect transistor (MOSFET) with an off state, the generated electrons are moved to the source and drain electrodes. The generated holes are moved to the neutral region which exists at the bottom part in the active silicon region. The accumulated holes in the neutral region make the body potential higher than the normal potential, i.e. floating body effect. The increased body potential by the floating body effect enhances the source-drain current in the n-SOI-MOSFET, resulting in the turning on the transistor with an off state to an on state, even if the amount of

119

the generated charge in the active region by a high energy particle is less than critical charge.

One of the ways to suppress the floating body effect is the use of a body-tie structure. On the body-tie structure, a body electrode is fabricated at the side of the neutral region in the SOI-MOSFET by a partial trench isolation (PTI). The accumulated holes in the neutral region can be retrieved through the body-electrode. However the body-tie structure can't perfectly suppress the floating body effect, since the mobility of an electron is much faster than that of a hole [2].

In this study, hydrogen, helium, lithium, beryllium, carbon and oxygen ions, accelerated up to a few tens of MeV by a tandem accelerator, were irradiated to the body-tie PD SOI-static random access memories (SRAMs) to generate the various amounts of the charge in the SOI body in order to clarify the relationship between the soft error rate and the amount of the generated charge. The generated charge in the SOI body is calculated by "The Stopping and Range of Ions in Matter (SRIM)" simulator [3].

2. Experimental

In this study, the soft error rates (SERs) in the 8 Mbits body-tie PD SOI-SRAM with a technology node 90 nm was investigated by various ion probes. The operating voltages for the SRAM cell and the peripheral circuit in the experimental device were 1.2 V and 2.5 V, respectively. The thicknesses of the SOI and BOX layers were 75 nm and 145 nm, respectively. The gate capacitor was 1.5 fF, resulting in the critical charge of 1.8 fC. The experimental SRAM had 6-MOSFETs (2 p- and 4 n-MOSFETs).

The SERs were calculated as a probability that the soft error occurred by only one ion irradiation to the SRAM chip. The number of irradiated particles to the SOI-SRAM was counted by a solid state detector (SSD) before and after ion irradiation. Avoiding multi ion hits to the single SRAM cell, the irradiation time was determined in order that the number of irradiated particles was less than the number of the SRAM cells.

The SER was calculated by comparing the memorized values before and after ion irradiation. To clarify the relationship between the amount of the generated charge and the SERs, it was necessary to generate the various amounts of charge in the SOI body. Therefore, hydrogen, helium, lithium, beryllium, carbon and oxygen ions, accelerated from 0.525 to 18 MeV by the tandem accelerator, were irradiated to the SOI-SRAM.

3. Results and Discussion

Fig. 1 shows the amount of the generated charge in the SOI body as a function of incident energy of hydrogen, helium, lithium, beryllium, carbon and oxygen ions calculated by SRIM simulator. The horizontal dotted line shows the critical charge (1.8 fC). The various amounts of charge (0 ~ 5.5 fC) can be generated in the SOI body using various ions
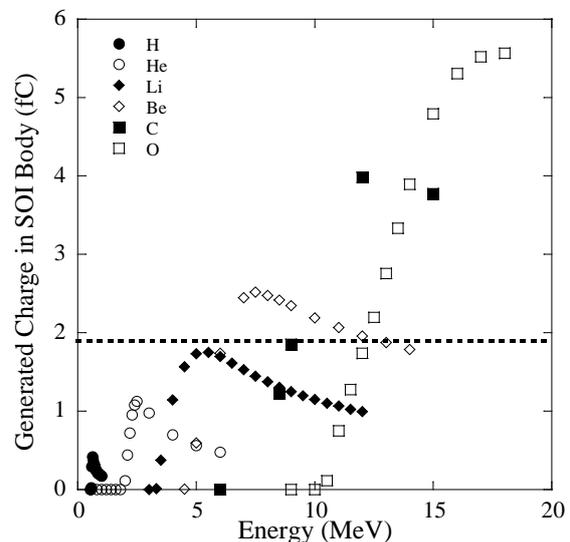
Fig. 1 The amount of the generated charge in the SOI body as a function of incident energy of H, He, Li, Be, C, and O ions calculated by SRIM simulator. The horizontal dotted line shows the critical charge of 1.8 fC.

accelerated to various energies. The generated charges were started to increase with energies of 0.55, 1.8, 3.3, 4.5, 6.0 and 10 MeV for hydrogen, helium, lithium, beryllium, carbon and oxygen ions, respectively. When the ion energies were less than these energies, the ions stop at the top passivation and wiring layers above the SOI-MOSFET, resulting in no charge generation in the SOI body.

Fig. 2 shows the soft error maps in the SOI-SRAM by Li ion irradiation with energies ranging from 3.0 to 11.9 MeV. The points show the SRAM cells where the soft errors occurred. No soft error occurred by 3.0 MeV Li ion irradiation, since the Li ions did not reach the SOI body. The uniform points show that the particles irradiated the SOI-SRAM uniformly above 3.0 MeV Li ion irradiation. Table. 1 shows the parameters include the energies, the number of particles and the number of soft errors by Li ion irradiation. It is necessary to clarify the probability to induce soft errors by single ion irradiation, since the number of the irradiated particles was not constant.

Fig. 3 shows SERs by hydrogen, helium, lithium, beryllium, carbon and oxygen ion probes for the PD SOI-SRAM with a technology node of 90 nm as a function of incident energy. The SERs started to increase with energies of 0.525, 2.0, 3.5, 4.5, 8.5 and 10.5 MeV for hydrogen, helium, lithium, beryllium, carbon and oxygen ions, respectively. The energies for charge generation (Fig. 1) and the SERs (Fig. 3) were almost the same for each incident ion, though the difference of the thickness of the top passivation and the wiring layers between the devices in the simulator and in the experiment exists.

Fig.4 shows the relationship between the SERs and the amount of the generated charge in the SOI body. The vertical dotted line shows the critical charge of 1.8 fC. The soft errors occurred by the floating body effect, even if the amount of the generated charge in the SOI body was less than the critical charge of 1.8 fC. When the amount of the generated charge in the SOI body was less than the critical charge, the SERs increased with
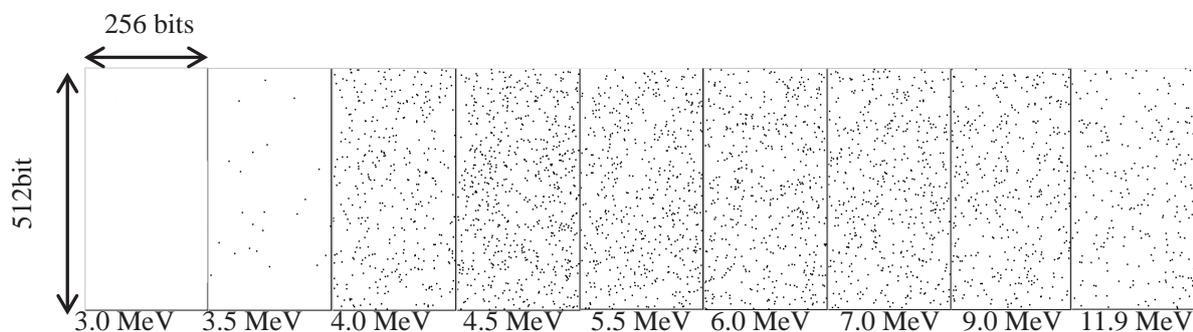
Fig. 2   Soft error maps in the SOI-SRAM by Li ions irradiation

with energies ranging from 3.0 to 11.9 MeV.

Table. 1   The energies, the number of particles and the number of errors
by Li ion irradiation to the SOI-SRAM.

Energy(MeV)	3.0	3.5	4.0	4.5	5.5	6.0	7.0	9.0	11.9
Particles	113816	57409	10885	12917	13804	15318	14772	14709	24428
Errors	0	23	378	652	537	491	488	407	254

121

increasing the amount of the generated charge in the SOI body. When the amount of the generated charge in the SOI body was more than the critical charge, the SER was almost constant. The SERs for hydrogen and helium ions were 2 orders of magnitude lower than those for lithium, beryllium, carbon and oxygen ions, when the amount of the generated charge was less than the critical charge. The reason of that would be the difference of the nuclear stopping power for each ion.

4. Conclusion

The SERs in a SOI-SRAM with a technology node of 90 nm were investigated by hydrogen, helium, lithium, beryllium, carbon and oxygen ions, accelerated up to a few tens of MeV by a tandem accelerator. When the amount of the generated charge in the SOI body was more than the critical charge, the SERs were almost constant. When the amount of the generated charge in the SOI body was less than the critical charge, the SERs increased with increasing the amount of the generated charge in the SOI body. Even if the amount of the generated charge is less than the critical charge, the floating body effect induces soft errors by enhancing the source-drain current and increasing the body potential.

References

[1] J. Ziegler, IBM J. RES. DEVELOP. VOL 40 NO. 1
JANUARY 1996.

[2] Satoshi Abo, Naoyuki Masuda, Fujio Wakaya, Shinobu Onoda, Takahiro Makino, Toshio Hirao,Takeshi Ohshima, Toshiaki Iwamatsu, Hidekazu Oda, and Mikio Takai, proceedings of the 9th International Workshop on Radiation Effects on Semiconductor Devices for Space Applications (9th RASEDA) (2010) 72.

[3] J. Ziegler, The Stopping and Range of Ions in Matter (SRIM2008) <http://www.srim.org>.
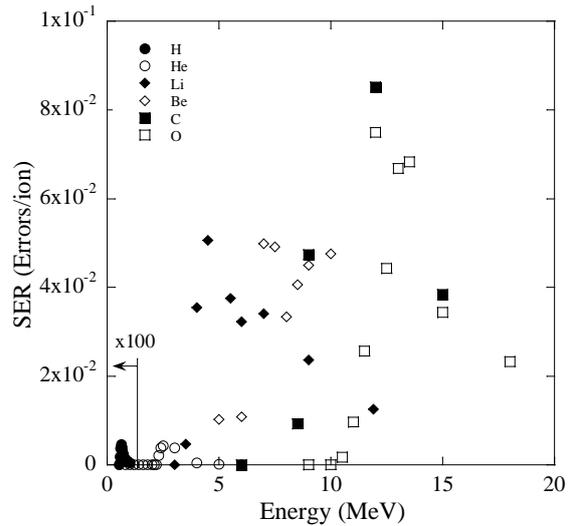
Fig. 3   SERs by H, He, Li, Be, C and O ion probes for 90 nm node PD SOI-SRAM as a function of incident energy.
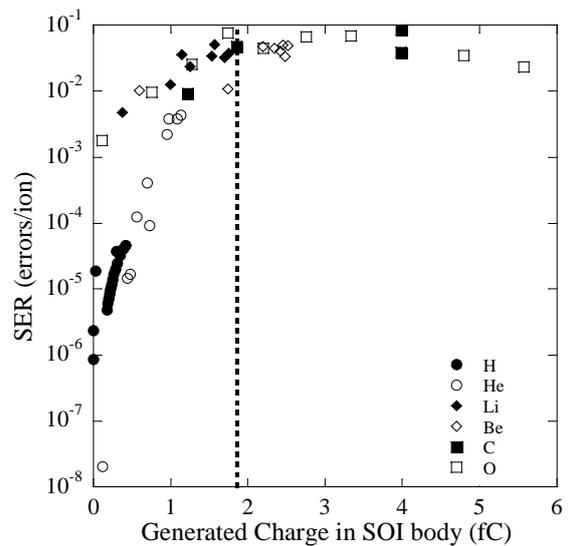
Fig. 4   SERs as a function of amount of generated charge in the SOI body by using H, He, Li, Be, C and O ion probes for 90 nm node PD SOI-SRAM. The vertical dotted line shows the critical charge of 1.8 fC.

122