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Difference of soft error rates in SOI SRAM induced by various high energy ion species

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ABSTRACT

Soft error rates in silicon-on-insulator (SOI) static random access memories (SRAMs) with a technology node of 90 nm have been investigated by beryllium and carbon ion probes. The soft error rates induced by beryllium and carbon probes started to increase with probe energies of 5.0 and 8.5 MeV, in which probes slightly penetrated the over-layer, and were saturated with energies at and above 7.0 and 9.0 MeV, in which the generated charge in the SOI body was more than the critical charge. The soft error rates in the SOI SRAMs by various ion probes were also compared with the generated charge in the SOI body. The soft error rates induced by hydrogen and helium ion probes were 1–2 orders of magnitude lower than those by beryllium, carbon and oxygen ion probes. The soft error rates depend not only on the generated charge in the SOI body but also on the incident ion species.

1. Introduction

A soft error or bitstate upset due to an excess carrier generation by high energy particle incidence becomes a serious problem in shrunk semiconductor devices. In a conventional bulk metal oxide semiconductor field effect transistor (MOSFET), generated carriers along to the entire particle track are flow to source and drain electrodes, resulting in the soft error. On the contrary, a silicon-on-insulator (SOI) device has an advantage over the conventional bulk device for the soft error [1,2], in which the channel region is insulated from the silicon substrate by a buried oxide (BOX) layer and few excess carriers generated in the SOI body are flow to the source and drain electrodes [1–5]. However, in a n-channel SOI MOSFET, some generated charge in the SOI body are kept in the channel region and increase the SOI body potential, resulting in an abnormal current (i.e., floating body effect) and the soft error [1]. One of the simplest ways to suppress the floating body effect is use of a body-tie structure, in which the channel region is connected to the source electrode through the partial trench isolation (PTI) [6]. The body electrode extracts the generated excess carriers from the channel region and suppresses the floating body effect [6–9]. Ion probes are used for an accelerated test of radiation hardness errors since species, energy, location and fluxes of incident particles were easily controlled by using ion probes.

The soft errors in the SOI static random access memories (SRAMs) with a technology node of 180 and 90 nm were investigated by hydrogen, helium and oxygen ion probes in our recently studies [10–13]. The soft error rates depended on the generated charge in the SOI body and were saturated in the case of more excess carriers generated in the SOI body than the critical charge.

In this study, the soft error rates were investigated by beryllium ion probes with energies ranging from 4.0 to 10.0 MeV and carbon ion probes with energies ranging from 6.0 to 12.0 MeV. The soft error rates by hydrogen, helium, beryllium, carbon and oxygen ion probes were also compared based on the generated charge in the SOI body.

2. Experimental

A SOI SRAM test element group (TEG) chip with a technology node of 90 nm was used for an accelerated test of radiation hardness in this study. The memory cell with a size of 1.25 μm^2, including 4 n-channel and 2 p-channel MOSFETs, was used in this study. The voltages of input/output signals and MOSFETs drives were 2.5 and 1.2 V, respectively. The critical charge for SOI SRAMs was 1.8 fC, which was calculated charge between the gate electrode and the SOI body with the designed structure and on-state voltage of the SOI MOSFET. However, the actual critical charge of the SOI SRAMs should be lower than the calculated one. Because the abnormal drain current in the SOI MOSFET is enhanced by the floating body effect. The thicknesses of the SOI body and the BOX

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layers were 75 and 145 nm, respectively. The memory capacity of the SRAM chip was 8 Mbits. The over-layer consisted by four copper metal, silicon nitride and polyimide passivation layers without plastic mould. The SOI SRAM had the body-tie structure fabricated by the PTI for suppressing the floating body effect [6].

The beryllium ion probes with energies of 4.0–10.0 MeV and the carbon ion probes with energies of 6.0–12.0 MeV were used in the accelerated test in this study. The SOI SRAM TEG chips were mounted to the evaluated chamber in Takasaki Ion Accelerators for Advanced Radiation Application (TIARA) in Japan Atomic Energy Agency (JAEA). The fluxes of ions were monitored by a solid state detector before the acceleration test. The minimum and maximum fluxes were 2500 and 25 counts per second, respectively. The beam size of the beryllium ion probes was $2.0 \times 2.0\,cm^2$, which was larger than the SRAM chip size. The beam spot sizes of the carbon ion probe were less than 1 μm. The scanned areas of the carbon ion probes were calculated from the secondary electron images. The irradiation time was adjusted for less than 1 beryllium or carbon ion hit to 1 SRAM cell from the flux and the scanned area to avoid double bitstate upset in the same memory cell. The excess carriers generated in the SOI body were calculated by SRIM code [14]. In our previous study, the soft errors occurred with proton probe energy of 525 keV in 90 nm node SOI SRAM [11]. However, the calculated penetration depth by SRIM code was shallower than the over-layer thicknesses. Thus an atomic thickness of the over-layer should be thinner than the physical thickness obtained by the scanning electron microscope (SEM) since the deposition technique affects the concentration of the over-layer. Therefore, the excess carriers generated in the SOI body were simulated with designed and 25% thinner over-layer thicknesses.

The soft error rates by beryllium and carbon ion probes were also compared with those by hydrogen, helium and oxygen ion probes in our previous studies [11–13] based on the generated charge in the SOI body.

3. Results and discussion

Fig. 1 shows the soft error rates in the SOI SRAM as a function of beryllium ion energy. No soft error occurred in the SOI SRAM by the 4.0 MeV beryllium ion probe, in which beryllium ions should be shielded by the over-layer. The soft error rates started to increase with beryllium ion energy of 5.0 MeV and were saturated at approximately 0.05 errors/ion with beryllium ion energies at and above 7.0 MeV. A decrease of the soft error rates with beryllium ion energies of 6.0, 8.0 and 8.5 were presumably due to the fluctuation of the ion fluxes. Fig. 2 shows the generated charge in the SOI body as a function of beryllium ion energy with designed and 25% thinner over-layer thicknesses simulated by SRIM code. The amount of the generated charges in the SOI body by the beryllium ion probes with energies of 5.0 and 6.0 MeV was lower than the critical charge of the 90 nm node SRAM. Thus, the soft errors for the SOI SRAM shown in Fig. 1 by the beryllium ion probes with energies of 5.0 and 6.0 MeV occurred by the floating body effect due to the generated excess carriers in the channel regions. The amount of the generated charges in the SOI body in the SOI SRAM by the beryllium ion probes with energies at and above 7.0 MeV was higher than the critical charge of the 90 nm node SRAM. Thus, the soft errors for the SOI SRAM shown in Fig. 1 by the beryllium ion probes with energies at and above 7.0 MeV occurred by both the floating body effect and the generated excess carriers.

Fig. 3 shows the soft error rates in the SOI SRAM as a function of carbon ion energy. No soft error occurred in the SOI SRAM by the 6.0 MeV carbon ion probe, in which carbon ions should be shielded by the over-layer. The soft error rates started to increase with carbon ion energy of 8.5 MeV and were saturated at approximately 0.08 errors/ion with the carbon ion energies at and above 9.0 MeV. Fig. 4 shows the generated charge in the SOI body as a function of carbon ion energy with designed and 25% thinner over-layer thicknesses simulated by SRIM code. The amount of the generated charges in the SOI body by the carbon ion probes with an energy of 8.5 MeV was lower than the critical charge of the 90 nm node SRAM. Thus, the soft errors for the SOI SRAM shown in Fig. 3 by the carbon ion probes with an energy of 8.5 MeV occurred by the floating body effect due to the generated excess carriers in the channel regions. The soft errors for the SOI SRAM shown in Fig. 3 by the carbon ion probes with an energy of 9.0 MeV was almost the same as that with an energy of 12.0 MeV, even though the generated charge in the SOI body was less than the critical charge of the 90 nm node SRAM. This contradiction might be due to the difference of the thickness and composition of the over-layer in the simulated and real devices. The generated charge in the SOI body by the 9.0 MeV carbon ion probe should be more than the critical charge of the 90 nm node SRAM.

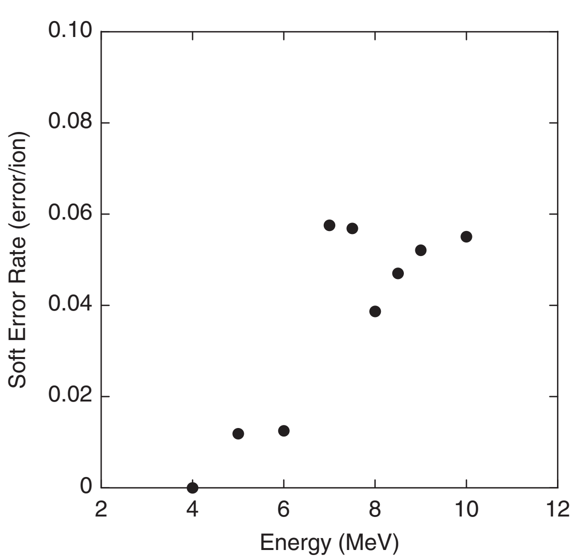

Fig. 1. Soft error rates in the SOI SRAM as a function of beryllium ion energy.

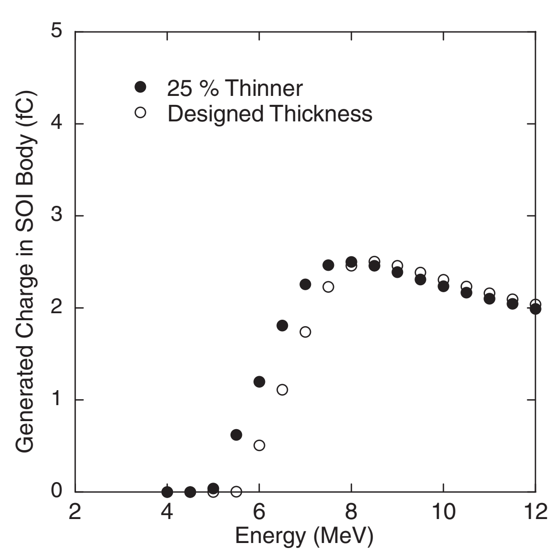

Fig. 2. Generated charges in the SOI body as a function of beryllium ion energy with the designed and 25% thinner over-layer thicknesses.