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Single Event Effects Induced by 15.14 MeV/u ^{136}Xe Ions*

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Abstract Single event effects induced by 15.14MeV/u ^{136}Xe ions in different batches of $32k \times 8$ bits static random access memory are studied. The incident angle dependences of the cross sections for single event upset and single event latchup are presented. The SEE cross sections are plotted versus energy loss instead of linear energy transfer value in sensitive region. The depth of sensitive volume and thickness of "dead" layer above the sensitive volume are estimated.

Key words single event upset, single event latchup, SRAM

1 Introduction

Single event effect (SEE) induced by energetic proton and heavy ion in VLSIs is a harmful ionization radiation effect for microelectronics used in space. These effects, including single event upset (SEU), single event latchup (SEL), single event burnout (SEB), etc., result from the charge produced by a single particle crossing a sensitive region in the device. SEEs have become very serious as the device feature size is reduced. It has been verified from the spaceflight practice that SEE induced by cosmic ray is one of the important sources of anomalies and malfunctions of spacecraft system. Various artificial satellites of many counties including P.R.China have suffered harmfulness from SEE. Accelerator testing on ground is an economic and effective way for research on SEE and the most of heavy ion SEU and SEL data are obtained from accelerator testing[1,2].

Heavy ions research facility in Lanzhou (HIRFL) is the first medium-energy heavy ion accelerators in China. Various ions delivered by HIRFL from several hundred MeV to several GeV cover a wide span of linear energy transfer (LET) value, so it is very fit for studying fundamental mechanisms responsible for SEE and measuring soft error susceptibility of devices. In recent years, some important SEE experiments have been accomplished at HIRFL, such as the verification of five SEE research instruments on board SJ-5 satellite[3—5]. Because of high energy, heavy ions from HIRFL still have long enough range to cross through sensitive region when the LET values are kept at high levels. So it is particularly convenient to SEE study of ICs which have deep sensitive region or are covered with polyimide film. A new SEE simulation equipment (SEESE) set up on the beam line of HIRFL provides good experimental condition and ion beam parameter monitoring. In this paper,

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SEEs induced by 15.14MeV/u ^{136}Xe ions in different batches of 32k × 8 bits static random access memory (SRAM) IDT71256 were studied. The dependence of SEU and SEL cross sections on incidence angles is obtained. The performance of new SEESE was checked during the experiment.

2 Experimental

The experiment was carried out with SEESE at HIRFL. SEESE containing the devices under test (DUTs) and particle detectors is shown in Fig. 1. At entrance to the target chamber, an attenuator having aluminum foils of eight kind of different thickness can be available for lowering ion energy. A scintillation detector consisting of photomultiple tube, 50μm-thick BC400 scintillation foil and elliptic reflection cover was regarded as non-interceptive flux detector, which gives the ion fluence falling on DUT. If necessary, ion energy can be measured by a 3.5mm-thick Si(Li) detector and homogeneity of ion beam distribution can be monitored by a position sensitive detector, which are located on the rotary sector disk. The DUTs were mounted on the sample holder, which can make vertical and rotational movement. The DUTs can be translated into the beam and rotated to desired angles relative to beam under the vacuum.

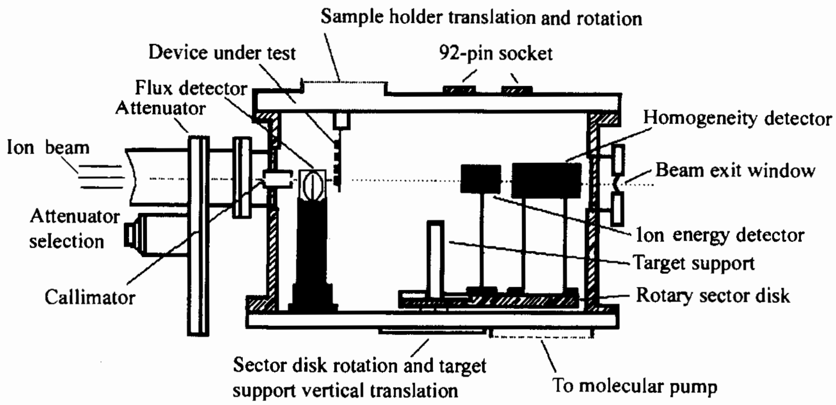

Fig. 1. Schematic presentation of SEE simulation equipment.

15.14MeV/u ^{136}Xe ions used in this work are the heaviest ion accelerated by HIRFL. This work is the first experiment with Xe ions at Institute of Modern Physics. The two kind of energy of Xe ions were used to irradiate the DUT, one was directly from HIRFL and another one was that degraded by 51μm-thick aluminum absorber. The ion energies at the surface of DUT, their LET values at the surface of DUT and their ranges in silicon are given in Table 1 for two cases. Ion flux was kept at order of $10^2/(cm^2 \cdot s)$ during the irradiation by adjusting the beam intensity from accelerator and scanning the ion beam.

Table 1. **^{136}Xe ion used in irradiation of DUT.**

Ion	Energy after attenuator /MeV	Energy loss in scintillation foil /MeV	Energy at surface of die /MeV	LET at surface of die /($MeV \cdot mg^{-1} \cdot cm^2$)	Range in Si /μm
Un-degraded	2059	326	1733	50.74	132.2
Degraded	1400	381	1019	58.30	75.6

In this study, the DUTs were IDT71256S100DB(…) and IDT71256S100DB(9624). 32k × 8 bits SRAM IDT71256 utilizing NMOS resistive-load RAM cells with full CMOS peripheral circuitry has been widely used in space electronics systems and is a typical device in domain of SEE research. Packaged DUTs were delidded and its whole memory was loaded with a constant test pattern "5A" before irradiation. The computer was interfaced to the RS-232 line to remotely control start/stop commands, collect test data, and perform real time test status summary. From both the upset number occurred due to the irradiation and the ion fluence, the SEU cross section could be derived for each DUT.

3 Results and discussions

The two devices studied in present work were irradiated by the ^{136}Xe beam at the incidence angle of 0°, 30°, 45°, 60° and 70° with respect to the normal to the device face, respectively. The results show that both SEUs and SELs were observed in the two DUTs during the irradiation with un-degraded ions. As SEL happened, a series of continual-address error were recorded and the operation current of circuit board on which the DUT was mounted rised steeply. But only SEU and no SEL were detected in the two DUTs during the irradiation with degraded ions. The SEU cross sections as a function of the incidence angle are given in Fig.2 for two DUTs.

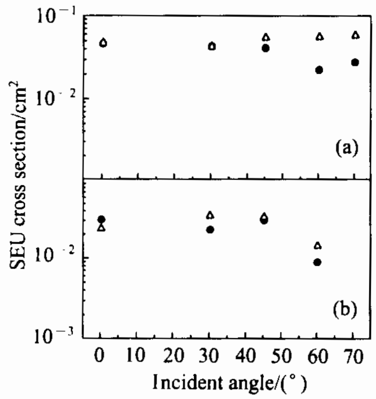

Fig.2. The SEU cross sections of two IDT71256 as a function of incidence angle (a) irradiated with un-degraded ions; (b) irradiated with degraded ions. • 1# DUT, Δ2# DUT.

It can be seen from Fig.2 that SEU cross section not distinctly varies with the incidence angle for the irradiation with un-degraded ions. The maximums of SEU cross section obtained for two DUTs are $4.62 \times 10^{-2}\,cm^2$ and $5.76 \times 10^{-2}\,cm^2$, respectively. But for the irradiation with degraded ions, SEU cross section is a little smaller than that for the irradiation with un-degraded ions and decreases with increasing the angle at large angles. The dependence of SEU cross section on incidence angle is attributable to the decrease in effective range. The difference in SEU cross sections at angle smaller than 30° for two energies could be due to the contribution of charge generated in the next layer[6].

The SEL cross sections as a function of incidence angle are given in Fig.3 for two DUTs. Though the maximums of SEL cross sections obtained are different, the dependences of cross sections on angle are similar for two DUTs. It can be seen from Fig.3 that SEL cross section increases with increasing incidence angle and the peak of SEL cross section appeared between incidence angle of 45° and 60°, then the SEL cross section droppes. The maximums of SEL cross sections obtained for two DUTs are $7.47 \times 10^{-4}\,cm^2$ and $2.84 \times 10^{-4}\,cm^2$, and are 1.62 % and 0.493 % of their corresponding SEU cross sections, respectively.

As is well known, the LET of the ions and their ranges in silicon are two important parameters for SEU and SEL sensitivities. The situation becomes complicated because there is thick polyimide coverage on the surface of device IDT71256. In the case of tilted beam, the coverage make decrease in ion energy and effective range. It is important that LET of ion at surface can not characterize the actual energy deposited in sensitive region . In order to estimate coverage thickness , we calculated

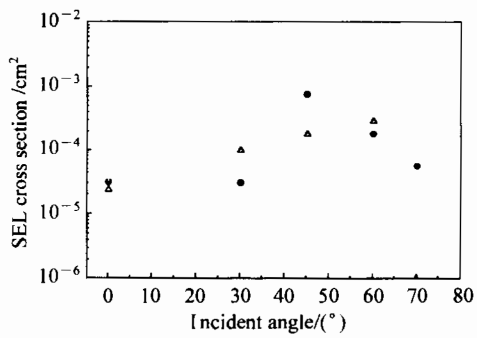

Fig.3. The SEU cross sections of two IDT71256 as a function of incidence angle. • 1# DUT, Δ2# DUT.

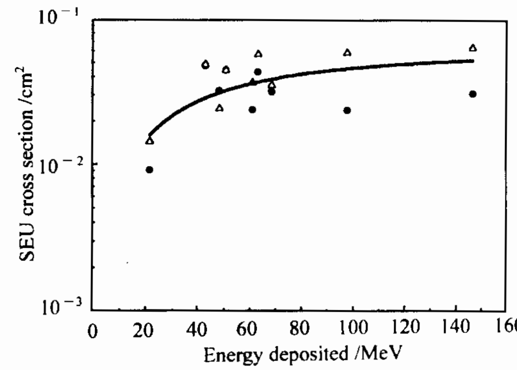

Fig.4. The SEU cross section versus the energy deposited curve for $h = 48\mu m$, $d = 3.5\mu m$. • 1# DUT, Δ2# DUT.

the energy deposited in sensitive region for a series of given h and d, as done by R. Ecoffet et al[7]. h is the thickness of top layer over sensitive region including Si dead layer and polyimide coverage, which is considered as polyimide equivalent thickness. d is the thickness of sensitive region, which is considered to be made out of silicon. The result shows that $h = 48\mu m$ and $d = 3.5\mu m$ as a best set of values for the final shape for the SEU cross section versus energy deposited curve. The corresponding SEU cross section curve and the Weibull function associated to the best fit are represented in Fig.4. Similarly, the result for SEL cross section is given in Fig.5, in which $h = 48\mu m$ and $d = 15\mu m$ are chosen. It should be noted that it is difficult to determinate the threshold LET of SEU by means of this method, because Xe used in this experiment is the ion of high LET and the critical charge or energy to induce SEU in device IDT71256 is relatively small.

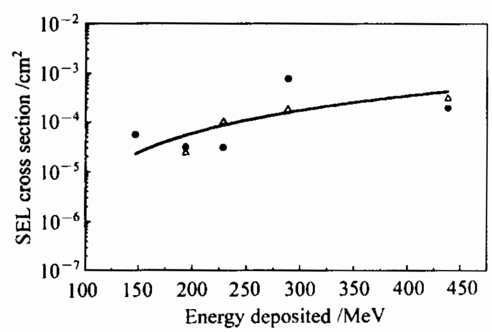

Fig.5. The SEU cross section versus the energy deposited curve for $h = 48\mu m$, $d = 15\mu m$. • 1# DUT, Δ2# DUT.

4 Conclusions

The saturation cross sections of SEU and SEL induced by 15.14MeV/u ^{136}Xe ions in 32k × 8 bits SRAM IDT71256 have been obtained. The cross section of SEU is about two orders of magnitude higher than that of SEL. The cross sections show some difference for different batches of devices. By means of measuring the dependence of SEU and SEL cross sections on incidence angles, the information on thickness of coverage and depth of sensitive region can be obtained. Although this work is preliminary, the potential of HIRFL and SEESE in SEE study of ICs, especially that has deep sensitive region or are covered with polyimide film, are obvious.

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15.14 MeV/u ^{136}Xe 离子引起的单粒子效应*

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摘要 研究了15.14MeV/u ^{136}Xe离子在不同批次的32k×8bits静态存储器中所引起的单粒子效应.获得了单粒子翻转和单粒子闭锁截面与入射角度的依赖关系.将单粒子效应截面与灵敏区中沉积的能量相联系,而不是线性能量转移(LET)值.估计了灵敏体积的深度和死层的厚度.

关键词 单粒子翻转 单粒子闭锁 静态存储器

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