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EXPERIMENTAL STUDY ON SINGLE EVENT EFFECTS IN SEMICONDUCTOR DEVICES USING ACCELERATORS

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Abstract

Experimental methods are emphatically described for doing Single Event Effects (SEE) experiments on semiconductor devices using accelerators. The ions beam from accelerator can be scattered and reduced by several order of magnitude with an Au foil so it is suitable to do SEE experiments. A novel system is designed for measuring the very low intense proton beam and a method is founded for measuring the uniformity of the proton flux. The proton Single Event Upset (SEU) cross section is of the order of 10^{-14} cm^2/bit for Static Random Access Memories (SRAMs).The SEU heavy ion LET thresholds are in 4～8 MeV.cm^2.mg^{-1} and the saturation SEU cross sections are of the order of 10^{-7} cm^2.bit^{-1}. Hard error in single bit and functional error in SRAMs and Single Event Latch-up in 80C86 are observed in proton experiments.

1 INTRODUCTION

Many integrated circuits operating in space have been found to be susceptible to Single Event Effects (SEE) induced by energetic ions, such as protons and charged heavy nuclei. These failures (upsets, latch-up, burnout, etc.) results from the charge deposited by a single particle crossing a sensitive region in the device and are a function of the amount of charge collected at the sensitive node. The soft error or upset (SEU) is a change in the information stored on the circuit. This event induces no significant damage to the basic element that can be rewritten with the right value[1~3]. A hard error is characterized by permanent or semi- permanent damage such as latch-up (SEL), burnout (SEB), gate rupture (SEGR), or stuck-at-bit errors, etc.

A great deal of testing have been performed since SEEs were observed, however, a few were done in China. There are a few of accelerators that can provide available ions or protons and a few of apparatus suitable for testing, especially for protons. An Au foil were used for scattering the main beams to get appropriate incident protons at 35MeV Proton Linear Accelerator in Institute of High Energy Physics of China Academy of Science, and ions flux at HI-13 Tandem Accelerator in China Atomic Energy Academy. We developed a new measurement system and use reasonable methods to measure incident protons and ions flux precisely. SEE Tests were performed and satisfactory results were obtained.

2 TEST TECHNIQUES

A. *Experimental* Techniques of SEE induced by Proton

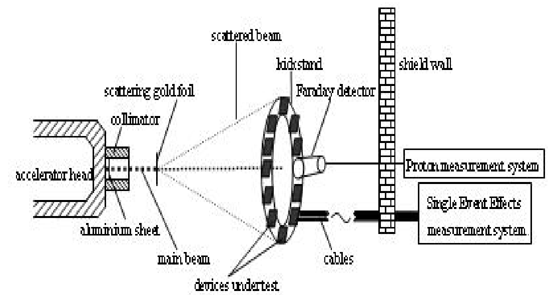

Figure 1 Experiment layout for proton Single Event Effects

The experiment of SEE induced by proton performed on 35MeV Proton Linear Accelerator in Institute of High Energy Physics of China Academy of Science.

Figure 1 shows the experiment layout for proton Single Event Effects. The thermoluminescence dosimeters (TLD) and Faraday detector are used for measuring the fluence of incident protons. The proton current measured by Faraday detector in Single Event Effects experiment is shown in Figure 2.

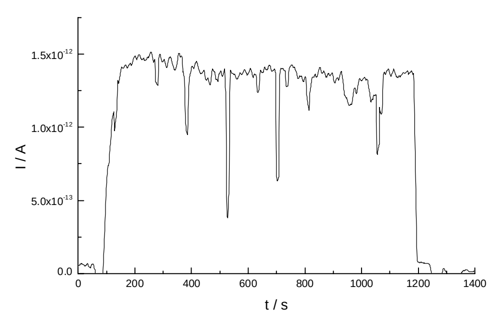

Figure 2 Proton current of the order of pA vs.time in Single Event Effects experiment

The fluence Φ of incident protons are calculated by integrating on proton current measured by Faraday detector.

$$\Phi = \frac{\int_0^t I_s(t)dt}{S \cdot e} \qquad (1)$$

where Φ is the proton fluence (cm^{-2}), $I_s(t)$ is the scattering proton current(A), t is the measurement time (s), S is the effective area (cm^2), e is the charge of electron, 1.602×10^{-19}(C).

The energy losses, absorbed doses and protons influence sensitivities of the TLDs were calculated on the theoretical grounds. Two types of TLDs are used for measuring the proton fluence on 35MeV-proton accelerator. The proton fluence uniformity of identical scattering distance and angle were measured using TLDs. The proton fluence nonuniformity of identical scattering distance and different scattering angle were also measured by TLDs. The proton fluence nonuniformity ratios of different scattering angle meausred by TLD agree with the theoretical value. The measuring data of proton fluence are compared with Faraday detector's data and the results agree within estimated uncertainties ($\pm$10%).

The energy of incident protons was attenuated with aluminium slice. The scatter gold foil was utilized to weaken the intensity of the beam of protons. A new long line test control system of memory single event effects has been developed. The upset cross sections on 64Kbit up to 4Mbit SRAM devices were measured.

B. *Experimental Techniques of SEE induced by Heavy Ion*

The experiment of SEE induced by heavy ions performed on HI-13 Tandem Accelerator in China Atomic Energy Academy. The experiment layout for heavy ion Single Event Effects is shown in Figure 3.

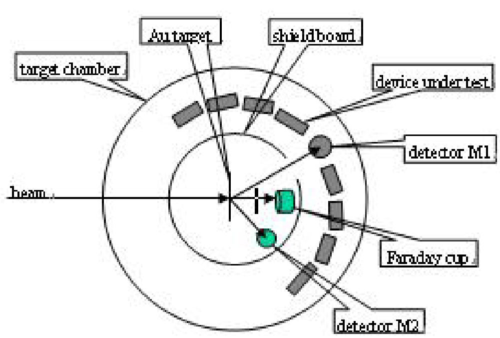

Figure 3 Experiment layout for heavy ion Single Event Effects

The species, energy, LET and ranges of heavy ions in Si devices used in experiment are listed in Table 1.

The scatter gold foil was utilized to weaken the intensity of the beam of heavy ions. The recoil Au nuclei energy and range are smaller than scattering heavy ion. The influence of recoil Au nuclei on scattering heavy ions is very little (Table 2).

Table 1 Species, energy, LET and ranges in Si of heavy ions used in experiment

ions	energy of primary ions /MeV	energy of scattered ions /MeV	LET in Si / $MeV.cm^2mg^{-1}$	ranges in Si /μm
^{12}C	50	49.19	2.3	63
^{16}O	50	48.93	4.6	36
^{19}F	60	58.46	5.5	57
^{28}Si	112	107.81	10.0	35
^{35}Cl	100	95.35	15.4	28
^{63}Cu	120	109.94	33.8	18
^{79}Br	170	152.51	40.1	19

Table 2 Influence of recoil Au on scattering heavy ions

ions	energy of primary ions /MeV	Energy of Recoil Au /MeV	proportion of recoil Au in scattered ions	ranges in Si /μm
C	50	8.1	3.1‰	1.8
O	50	10.4	3.2‰	2.2
F	60	14.4	3.3‰	3.0
Si	112	36.6	3.6‰	6.5
Cl	100	38.4	3.8‰	6.8
Cu	120	67.1	4.8%	10.9
Br	170	104.4	5.4%	13.1

3 TESTING RESULT AND ANALYSIS

The device SEU cross section

$$\sigma = N/\Phi \qquad (2)$$

where σ is SEU cross section(cm^2), N is the device memory unit upset number, Φ is the particle fluence.

The proton induced SRAM devices SEU cross section is about the order of 10^{-14}cm2/bit in this experiment. They are the same order compared with the other country. Hard error in single bit and functional error in SRAMs and Single Event Latch-up in 80C86 are also observed in this experiments.

The heavy ion (C, O, F, Si, Cl, Cu, Br) induced IDT7164 devices SEU LET threshold value is 4.2MeV.cm^2/mg and the saturation cross section is $2.5\times10^{-7}cm^2.bit^{-1}$in this experiment. The IDT71256 devices SEU LET threshold value is 4.0MeV.cm^2/mg and the saturation cross section is 1.5×10^{-7} $cm^2.bit^{-1}$. The HM628128 devices SEU LET threshold value is 6.0MeV.cm^2/mg and the saturation cross section is 1.25×10^{-7} $cm^2.bit^{-1}$. Fig. 4 shows Single Event Upset Cross Section vs. heavy ion LET for IDT series SRAM devices. The comparison of Single Event Upset Cross Section for HM series SRAM in different integration level is shown in Fig.5.

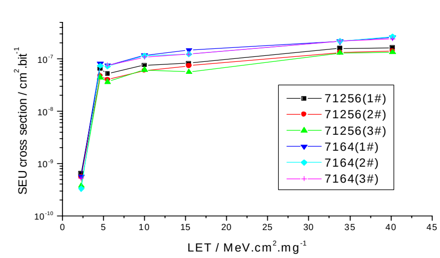

Figure 4 Single Event Upset Cross Section vs. heavy ion LET for IDT series SRAM

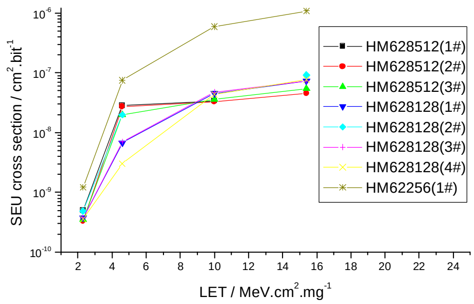

Figure 5 Comparison of Single Event Upset Cross Section for HM series SRAM in different integration level

4 SUMMARY

The thermoluminescence dosimeters(TLD) are used for measuring the fluence of incident protons. The energy of incident protons was attenuated with aluminium slice. The scatter gold foil was utilized to weaken the intensity of the beam of protons and heavy ions. A new long line test control system of memory single event effects has been developed. The proton and heavy ion induced SEU cross sections on 64Kbit up to 4Mbit Static Random Access Memories (SRAMs) devices were measured. The proton Single Event Upset (SEU) cross section is of the order of 10^{-14} cm^2/bit for SRAM. The SEU heavy ion LET thresholds are in 4～8 MeV.cm^2.mg^{-1} and the saturation SEU cross sections are of the order of 10^{-7} cm^2.bit^{-1}.These experiment data are indispensable to estimate the single event upset rate in the space orbit.

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