EXPERIMENTAL STUDY ON SINGLE EVENT EFFECTS IN SEMICONDUCTOR DEVICES USING ACCELERATORS

HE Chao-hui, YANG Hai-liang, GENG Bin, CHEN Xiao-hua, ZHANG Zheng-xuan, LI Guo-zheng
Northwest Institute of Nuclear Technology, P.O.Box 69-13, Xi’an, 710024, China

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 the range of $4 \sim 8$ 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.) result 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 SEE's 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.

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 is shown in Figure 2.

2 TEST TECHNIQUES

A. Experimental Techniques of SEE induced by Proton

![Figure 1 Experiment layout for proton Single Event Effects](image)

Figure 1 Experiment layout for proton Single Event Effects

The fluence $\Phi$ of incident protons are calculated by

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

$$\Phi = \frac{\int I_p(t)dt}{S \cdot e}$$  \hspace{1cm} (1)
where $\Phi$ is the proton fluence ($\text{cm}^{-2}$), $I_s(t)$ is the scattering proton current (A), $t$ is the measurement time (s), $S$ is the effective area ($\text{cm}^2$), $e$ is the charge of electron, $1.602 \times 10^{-19}$ (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 measured 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](image)

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

![Table 1 Species, energy, LET and ranges in Si of heavy ions used in experiment](table)

<table>
<thead>
<tr>
<th>Species</th>
<th>Energy of primary ions (MeV)</th>
<th>Energy of recoil ions (MeV)</th>
<th>LET in Si/MeV.cm²/kg</th>
<th>Range in Si (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>50</td>
<td>31.1</td>
<td>3.12</td>
<td>1.3</td>
</tr>
<tr>
<td>O</td>
<td>50</td>
<td>36.4</td>
<td>3.2%</td>
<td>2.2</td>
</tr>
<tr>
<td>F</td>
<td>60</td>
<td>24.4</td>
<td>3.3%</td>
<td>3.9</td>
</tr>
<tr>
<td>Si</td>
<td>112</td>
<td>56.6</td>
<td>3.5%</td>
<td>6.5</td>
</tr>
<tr>
<td>Cl</td>
<td>186</td>
<td>36.4</td>
<td>3.9%</td>
<td>6.8</td>
</tr>
<tr>
<td>Ca</td>
<td>226</td>
<td>67.1</td>
<td>4.9%</td>
<td>10.9</td>
</tr>
<tr>
<td>Br</td>
<td>170</td>
<td>104.4</td>
<td>5.4%</td>
<td>13.1</td>
</tr>
</tbody>
</table>

### Table 2 Influence of recoil Au on scattering heavy ions

![Table 2 Influence of recoil Au on scattering heavy ions](table)

<table>
<thead>
<tr>
<th>Ions</th>
<th>Energy of primary ions (MeV)</th>
<th>Energy of recoil ions (MeV)</th>
<th>LET in Si/MeV.cm²/kg</th>
<th>Range in Si (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>50</td>
<td>31.1</td>
<td>3.12</td>
<td>1.3</td>
</tr>
<tr>
<td>O</td>
<td>50</td>
<td>36.4</td>
<td>3.2%</td>
<td>2.2</td>
</tr>
<tr>
<td>F</td>
<td>60</td>
<td>24.4</td>
<td>3.3%</td>
<td>3.9</td>
</tr>
<tr>
<td>Si</td>
<td>112</td>
<td>56.6</td>
<td>3.5%</td>
<td>6.5</td>
</tr>
<tr>
<td>Cl</td>
<td>186</td>
<td>36.4</td>
<td>3.9%</td>
<td>6.8</td>
</tr>
<tr>
<td>Ca</td>
<td>226</td>
<td>67.1</td>
<td>4.9%</td>
<td>10.9</td>
</tr>
<tr>
<td>Br</td>
<td>170</td>
<td>104.4</td>
<td>5.4%</td>
<td>13.1</td>
</tr>
</tbody>
</table>

### 3 TESTING RESULT AND ANALYSIS

The device SEE cross section

$$\sigma = N / \Phi$$

(2)

where $\sigma$ is SEE cross section ($\text{cm}^2$), $N$ is the device memory unit upset number, $\Phi$ is the particle fluence.

The proton induced SRAM devices SEE cross section is about the order of $10^{-14}\text{cm}^2$/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 SEE LET threshold value is 4.2MeV.cm²/mg and the saturation cross section is $2.5 \times 10^{-7}\text{cm}^2$.bit⁻¹ in this experiment. The IDT71256 devices SEE LET threshold value is 4.0MeV.cm²/mg and the saturation cross section is 1.5×10⁻⁷ cm².bit⁻¹. The HM628128 devices SEE LET threshold value is 6.0MeV.cm²/mg and the saturation cross section is 1.25×10⁻⁷ cm².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](image)
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 $4 \sim 8$ 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.

ACKNOWLEDGMENT

The authors are grateful for the continuing support of the scientists and researchers of the 35MeV Proton Linear Accelerator in IHEP and the HI-13 Tandem Accelerator in CAEA.

REFERENCES