Transient Ionizing Dose Effect on Neutron Irradiated SRAMs

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Abstract:

Two feature-sized static random access memories (SRAM) are irradiated by different level 1 MeV equivalent reactor neutrons, and are performed transient ionizing dose effect study subsequently. The latch up and data upset threshold dose rate of SRAMs are obtained by experimental research, respectively. The relationship between threshold dose rate and neutron irradiation fluence are gained; Transient ionizing currents in displacement damaged PN junction are studied using MEDICI toolkit. Results indicate the neutron irradiation could enhance the transient ionizing latch up and data upset threshold dose rate value, neutron induced gain reduction on parasitical transistors and carrier lifetime reduction are the main reason.

Keywords: Transient radiation effect; neutron; latch up; data upset; SRAM

1. Introduction

As semiconductor devices become more integrated, more and more CMOS integrated circuits are used in various electronic systems to achieve more advanced performance. Static random access memory (SRAM) has been the most commonly used storage device for microprocessors and many electronic systems due to its low power consumption. Transient ionizing dose effects on electronics is one of the most serious radiation effects on electronic devices, which can generate photocurrent inside the CMOS device in a very short time, leading to data upset, functional failure, or even burn out[1-4].

In this paper, different level neutron irradiation treatments were carried out for IDT6116 SRAM with a feature size of 0.8microns and HM628512C SRAM with a feature size of 0.18microns, and then a transient ionizing dose experiment was carried out on the "Qiangguang-I" accelerator platform. The latch up dose rate threshold and the data upset dose rate threshold of the SRAMs after different neutron fluences were obtained. The relationship between threshold value and neutron fluence is compared and analyzed, and the effect mechanism is analyzed.

2. Experimental details

The SRAM devices were irradiated with neutrons using Xi'an pulse reactor (XAPR), during irradiation the circuits were shorted and connected to the ground. The XAPR was operated with the power of 100kW, the 1MeV equivalent neutron flux is $5.84\times10^{9}\,\mathrm{cm^{-2}\cdot s^{-1}}$ and the neutron/gamma ray ratio (n/γ ratio) is $7.7\times10^{9}\,\mathrm{cm^{-2}\cdot rad(Si)^{-1}}$. The SRAM devices accumulated five fluences perpendicular to the direction of the neutron beam, with five devices per irradiance being irradiated, respectively. The

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1MeV equivalent neutron fluence of irradiation were: 5.0×10^{10} n·cm^{-2}, 1.0×10^{11} n·cm^{-2}, 5.0×10^{11} n·cm^{-2}, 8.0×10^{12} n·cm^{-2}, 6.0×10^{13} n·cm^{-2}. Neutron flounce is measured by activation foil.

In order to ensure the function and parameters of the devices after neutron irradiation, the parameters of the devices before and after neutron irradiation were tested by large-scale integrated circuit tester. Displacement damage induced by neutron irradiation is a permanent damage, the tests were performed after one week of neutron irradiation per batch.

Table 1 shows the test results of partial parameters before and after neutron irradiation in IDT6116 SRAMs. The parameter test results are in accordance with the specifications of the device datasheet except the 6.0×10^{13} n·cm^{-2} neutron irradiated samples. The failed sample may be due to the total ionizing dose effect caused by neutrons induced secondary particles and the accompanying gamma rays. However, due to the physical structure of the latch-up effect still exists, it will be used as a compared sample in this paper.

Table 1 Partial parameters of IDT6116 SRAM before and after neutron irradiation

1MeV equivalent neutron fluence / n·cm^{-2}	I_{cc} (nA)	I_{sb} (nA)	Function	t_{AA} (ns)	t_{AW} (ns)
Pre-rad(0)	57	71	Pass	18.0	4.4
5.0×10^{10}	17	55	Pass	17.6	4.4
5.0×10^{11}	63	67	Pass	17.6	4.2
8.0×10^{12}	52	69	Pass	16.6	4.4
6.0×10^{13}	51	64	Fail	20.0	799

Table 2 Partial parameters of HM628512C SRAM before and after neutron irradiation

1MeV equivalent neutron fluence / n·cm^{-2}	I_{cc} (nA)	I_{sb} (nA)	Function	t_{AA} (ns)	t_{AW} (ns)
Pre-rad(0)	0.5	0.5	Pass	42.0	9.0
5.0×10^{10}	31	3.3	Pass	37.6	9.6
1.0×10^{11}	27	1.9	Pass	39.0	10.0
5.0×10^{11}	0.5	0.4	Pass	45.0	9.4
8.0×10^{12}	31	10.0	Pass	36.0	9.2
6.0×10^{13}	51	6.2	Pass	37.0	9.3

The test results of partial parameters before and after neutron irradiation in HM628512C SRAMs are shown in Table 2. The parameter test results are in accordance with the specifications of the device datasheet, and the devices read and write normally.

Pulsed X-ray irradiation was carried out on “Qiangguang-I” accelerator platform. The pulsed X rays are generated by high-speed electrons striking the tantalum target. The pulse duration is about 50 ns (equivalent pulse width is 25 ns), and the average photon energy is approximately 1 MeV. The PIN detector is used to measure the pulsed gamma-ray waveform, and LiF thermoluminescent dosimeters are used to measure the deposit total dose in pulsed irradiation. Dose rate is calculated from the ratio of the deposit total dose and equivalent pulse width in one pulse. It is simple to adjust the value of dose rate via changing the distance between the devices and the target. In addition, the measurement uncertainty of dose rate is kept at a level less than 20% (coverage factor k = 2).

The irradiated devices in neutron exposure and the pristine ones (as a contrast) were placed in the pulsed X-ray environment. All devices were write in 55H, and were biased to the nominal voltage. The status of latch-up can be judged by observing the current flowing through the Vdd pin. If the current increases suddenly from several milliampere to hundreds of milliampere or more, latch-up effect occurs; whereas there is no change of the current, indicating latch-up is not trigged. Then read back storage data and compare with the initial data to calculate the data upset. The dose rate can be flexibly adjusted by changing the distance of the devices and the beam source, and the thresholds of the devices can be find out via several times experiments.

3. Experimental results

Fig.1 shows the latch-up effect of IDT6116 SRAMs after different neutron irradiation. The normal operating current of this device is less than 0.06 amps, which will increase to more than 0.12 amps when the latch-up effect occurs. It can be judged whether the device is latched by the change of current.

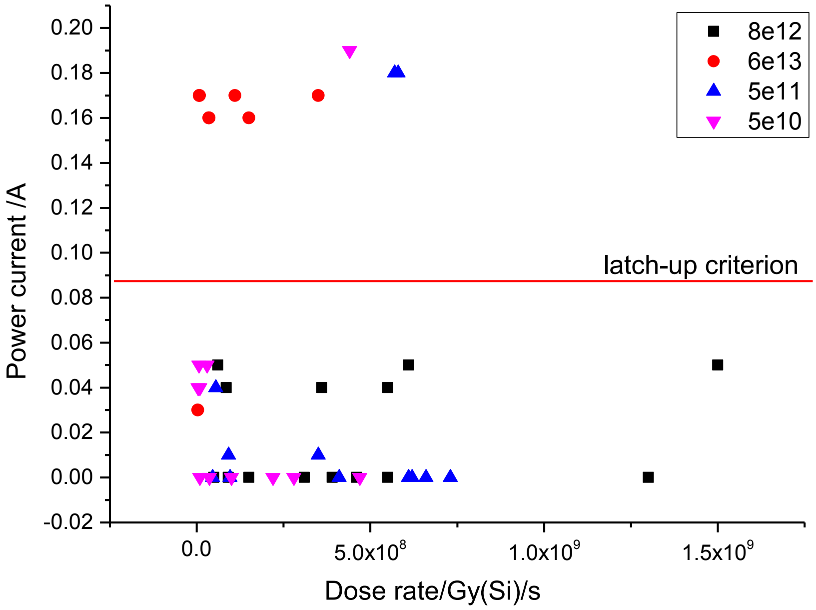

Fig.1 Transient ionizing latch-up effect of neutron irradiated IDT6116 SRAMs.

The results of latch-up threshold measurements in the devices irradiated by neutron are represented in Table 3. It can be seen that latch-up threshold increases evidently when neutron flux is up to 8.0×10^{12} n·cm^{-2}. However, as neutron flux is up to 6.0×10^{13} n·cm^{-2}, the threshold of latch-up drops sharply. That is mainly because the concomitant γ rays with neutron exposure enhance the trapped charges in the oxide layer, and increase the sensitivity of latch-up.

Data upsets in SRAMs are mainly due to the fact that when the photocurrent is large enough, due to the capacitive charging, when the transistor is turned on or off or the output voltage exceeds the device 0 and 1 noise margin, the data upset occurs.

Fig.2 shows the data upset effect of HM628512C SRAMs after different neutron irradiation, the transient ionizing dose rate ranges from 3.9×10^{6} Gy(Si)/s to 7.6×10^{7} Gy(Si)/s. It can be seen from the figure that the transient ionizing dose rate effect of the 0.18 micron feature size SRAMs is mainly reflected in data upset, and the effect has significant threshold characteristics. The results of data upset threshold measurements in the devices irradiated by neutron are represented in Table 4.

Table 3 Change of latch-up threshold after neutron exposure

neutron flux (1MeV equivalence)/n·cm^{-2}	Latch-up threshold
Pre-rad(0)	5.9×10^{7}Gy(Si)/s
5.0×10^{10}	4.4×10^{8}Gy(Si)/s
5.0×10^{11}	5.7×10^{8}Gy(Si)/s
8.0×10^{12}	$>1.5\times10^{9}$Gy(Si)/s
6.0×10^{13}	3.3×10^{6}Gy(Si)/s

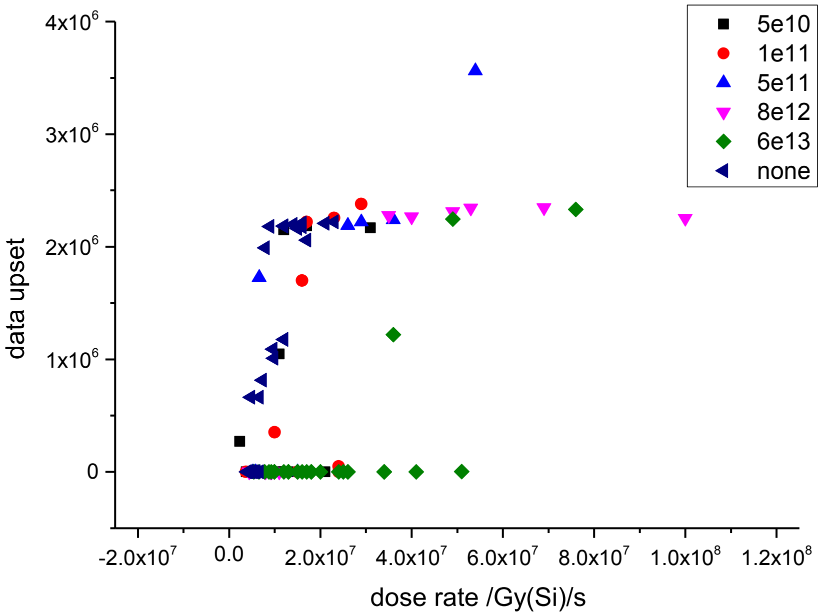

Fig.2 Transient ionizing upset effect on neutron irradiated HM628512C SRAMs.

Table 4 Change of data upset threshold after neutron exposure

neutron flux (1MeV equivalence)/n·cm^{-2}	Data upset threshold
Pre-rad(0)	4.7×10^{6}Gy(Si)/s
5.0×10^{10}	1.0×10^{7}Gy(Si)/s
1.0×10^{11}	1.5×10^{7}Gy(Si)/s
5.0×10^{11}	2.0×10^{7}Gy(Si)/s
8.0×10^{12}	3.0×10^{7}Gy(Si)/s
6.0×10^{13}	4.0×10^{7}Gy(Si)/s

It can be seen that the neutron pre-irradiation significantly improves the device's ability to resist transient ionizing dose rate induced data upset.

4. Discussion

Parasitic P-N-P-N structure in CMOS circuits and the equivalent circuitry are exhibited in figure 3. Under pulsed X-ray irradiation, the largest photocurrent in the P-N-P-N structure is from the junction of N-well and P-epi, namely the dominant portion to trigger latch-up, flowing through R_{sub} and the base of Q_n. Because of current amplification of Q_n, the current from the collector of Q_n is β_n times the current injected into the base of Q_n, then leading to the base current of Q_p augment. In other words, the necessary and sufficient condition for latch-up occurrence is that the primary photocurrent, flowing through the circuitry in one circulation, results in more current.

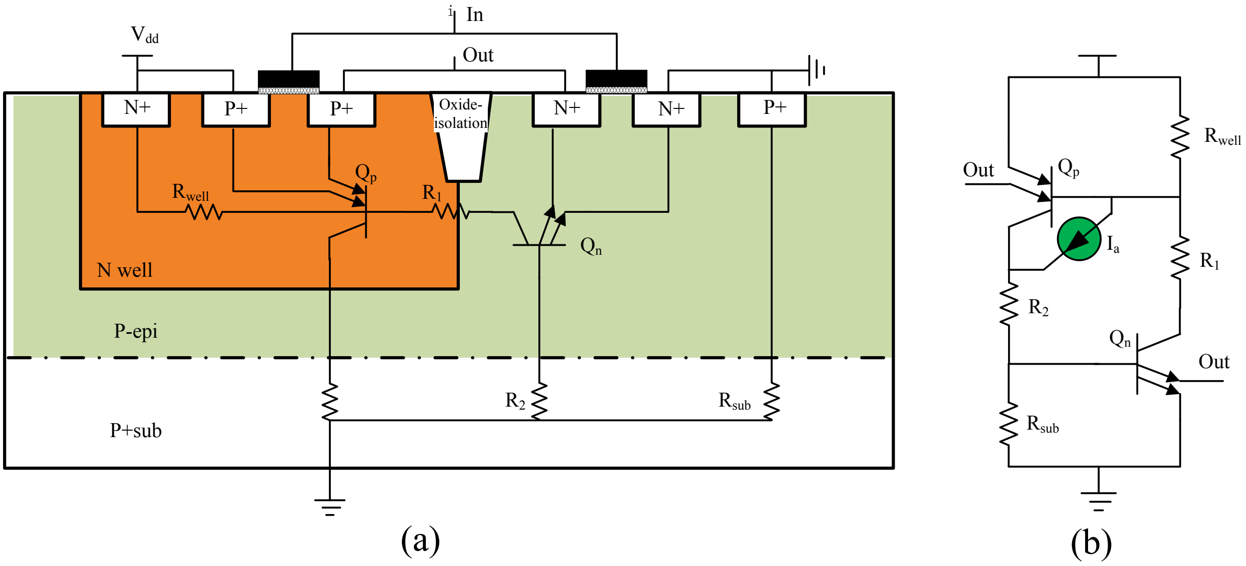

Fig.3 The parasitic P-N-P-N structure in CMOS devices and the equivalent circuitry:
(a) the parasitic P-N-P-N structure, (b) the equivalent circuitry.

The latch-up holding current is an important parameter of the latch-up effect and can be defined as the minimum on-current required to maintain the latch-up state. As shown in equation (1):

$$I_H = \frac{\beta_{npn}(\beta_{pnp}+1)I_{RW} + \beta_{pnp}(\beta_{npn}+1)I_{RS}}{\beta_{npn}\cdot\beta_{pnp}-1} \tag{1}$$

Here the β_{pnp} and β_{npn} are the gain of parasite transistors in the P-N-P-N structure, I_{RW} represents the current flowing through R_W, while I_{RS} represents the current flowing through R_S. Obviously, the smaller the product of the current gain, the larger the required latch-up holding current. An infinitely great current is needed to hold the latch-up while $\beta_{pnp}{\cdot}\beta_{pnp}$ degrade to 1. This means neutron induced gain degradation [5] of parasite transistor could enhance the anti-latch-up ability of SRAMs.

In order to further analyze the effect of neutron irradiation on the transient photocurrent caused by carrier lifetime degradation, the physical process of the effect was calculated based on the two-dimensional PN junction structure using the MEDICI software. Simulation results indicates the carrier lifetime does not affect the time response of the photocurrent induced by transient ionizing radiation. But the magnitude of the photo current is significantly reduced while the carrier lifetime reduces, as shown in Fig.4. The reduction of the photocurrent would improve the device's ability to resist transient ionizing dose rate induced data upset.

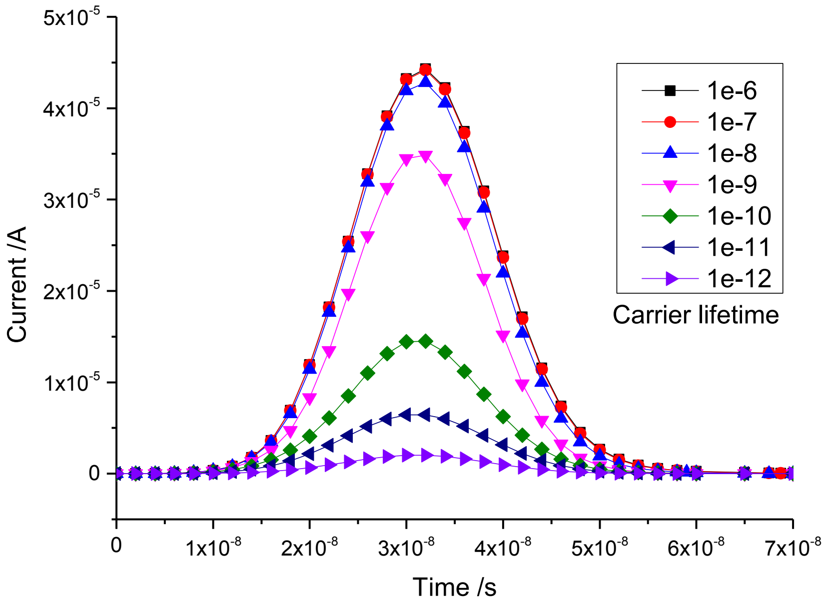

Fig.4 Simulation result of Photo current versus carrier lifetime.

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5. Conclusion

Neutron pre-irradiation could significantly improve the transient ionizing latch-up and data upset threshold dose rate value of SRAMs. Also, the reactor neutron and parasite gamma ray induced total ionizing dose effect should not be neglected. Displacement damage induced gain reduction and carrier lifetime degradation are the main reason for this effect.

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