Experimental study on the single event latchup simulated by a pulse laser

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Abstract: This paper introduces major characteristics of the single event latchup (SEL) in CMOS devices. We accomplish SEL tests for CPU and SRAM devices through the simulation by a pulse laser. The laser simulation results give the energy threshold for samples to undergo SEL. SEL current pulses are measured for CMOS devices in the latchup state, the sensitive areas in the devices are acquired, the major traits, causing large scale circuits to undergo SEL, are summarized, and the test equivalence between a pulse laser and ions is also analyzed.

Key words: single event effect; pulse laser; single event latchup
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1. Introduction

Because CMOS devices have the virtues of low power, little noise disturbance, and so on, more than half of the integrated circuits on the market are made using CMOS technology. At the same time, CMOS devices are extensively used in the electronic systems of spacecrafts. However, it is easy to induce a single event latchup (SEL) of the ions undergoing irradiation in the CMOS devices. In fact, SEL events have occurred several times on board of satellites, and these events have caused functional abnormalities in satellites or electronic instrument failures in space[1]. Even now, SEL induced by ions in space is still one of the major problems in the use of CMOS devices in space electronic systems.

At present, the research on single event effects (SEE) simulated by pulse lasers has proven that the pulse laser has several advantages in the study of SEE. Large scale SRAM and CPU devices, which are sensitive to SEL, are used to study SEL events.

2. Elements and characteristics of SEL

SEL events can occur when using CMOS technology and originated from parasitical transistor structures. Intrinsic four PNPN structures make up a controllable silicon. Normally, the controlled silicon is in the turn-off state. The incidence of ions causes the controlled silicon to get into the turn-on state, and a current is produced in it. Due to the positive feedback characteristics of the controllable silicon, the current is increased continuously, and the PNPN structure comes into a rebirth current state, which causes an SEL event to occur[2, 3]. Figure 1 shows the current transformation curve for a BM3802 device to experience an SEL event in the kernel and the port. From Fig. 1, we can see that when an SEL has been induced and if there is no remedy step to adopt, the device will be destroyed by a large current over too long a time, and it can not be set back to the original state[4, 5]. The only possibility for recovery is to cut off the power source immediately and to resume supplying power after the SEL disappears[6, 7]. Usually, a power source controlled circuit is used to cut off the power supply in a few milliseconds, in order to protect the devices from burnout.

3. Brief introduction of the laser simulation system

We use a laser simulation system (LSS) for the first time to centralize four lasers of different wavelengths. The reasons for using this system to simulate SEE are: the simulation for soft errors does not damage the device under test (DUT); the system has preferably differentiated rates of interspace, which can determine the sensitive zero of the devices; the logic disturbance information of the SEE can be accurately obtained; the laser simulation is fast and safe.

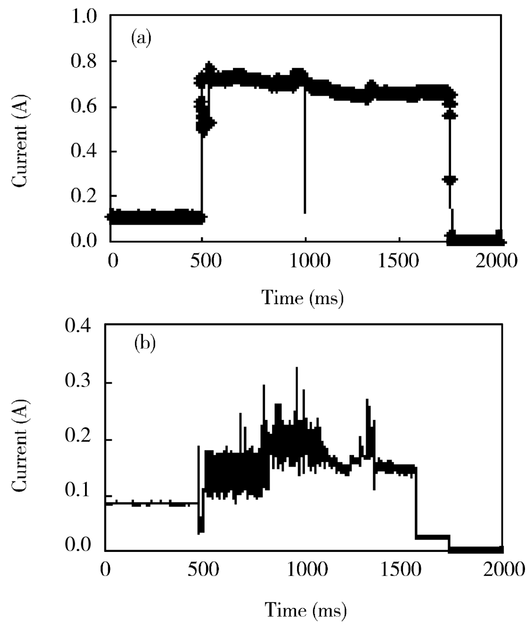

Fig. 1. Current transformation curve for a BM3802 device to experience an SEL event in (a) a kernel and (b) a port.

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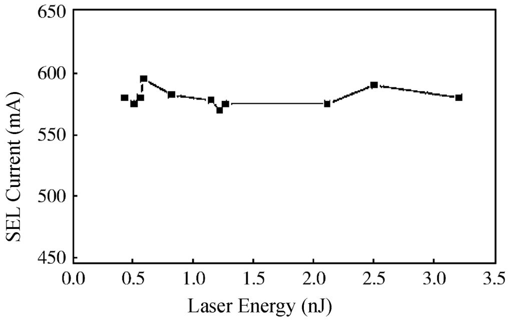

Fig. 2. Relationship between the current and the laser energy intensity.

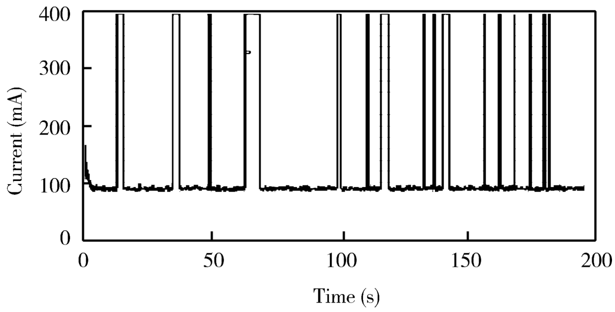

Fig. 3. Intel80C31 device SEL current curve.

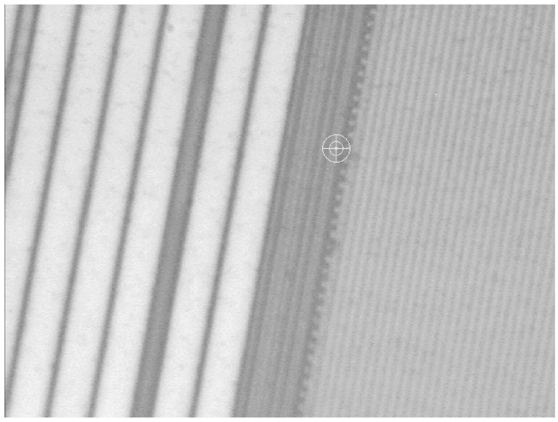

Fig. 4. Image of the BM3802 device decache zero to induce SEL.

4. Experiment and results of the SEL for laser simulation

In the SEL test simulated by a laser, SRAM devices, including IDT6116, IDT71256, HM65162, are used. The CPUs include 80C31 and BM3802 (corresponding to 486 devices).

4.1. Simulation results for an SRAM devices SEL test

In the SEL test for IDT6116 devices, a nano-second laser was used. A shift and scan apparatus is used to accurately scan each zero of the devices, and the devices' sensitive zero was measured. The threshold laser energy of 0.41 nJ is also reached by adjusting the laser intensity. The equivalent LET threshold is 14.90 MeV/mg/cm^2. The test results also indicate that the logic state appears to be unstable when an SEL is induced in the IDT6116 devices, and the temperature on the surface increases rapidly. So, we could conclude that the SEL current range is between 580–595 mA. The current distribution is not related to the pulse laser energy, which is mostly determined by the interior structure in the device. For example, under the incidence of a 0.57 nJ laser beam, the SEL current is about 590 mA, and under the incidence of a 1.21 nJ laser beam, the SEL current is 578 mA. The details are shown in Fig. 2.

In the HM65162 SEL test, a pico-second laser was used. When the HM65162 devices entered into the SEL state, their output states were disordered, and the temperature on the device surface increased rapidly. By adjusting the laser intensity, the threshold for the HM65162 devices to undergo an SEL was seen to be 0.74 nJ, and the equivalent LET is 26.46 MeV/mg/cm^2. The current range for the HM65162 devices to undergo SEL is between 310–345 mA. The rated current for the HM65162 devices is 70 mA. This indicates that the current needed for the HM65162 devices to undergo an SEL is four times larger than its rated current. At the same time, test results show that, as the energy of the incident laser increases, more upsets were induced. In the HM5611 device test, a pico-second laser was used (with a wavelength of 1.064 μm) for comparison. The laser energy threshold for the HM5611 device is 0.64 nJ, and in the SEL state, its SEL current range is between 310–330 mA, which is about four times larger than its rated range.

4.2. SEL test for CPU devices

4.2.1. SEL laser simulation test for the 80C31 device

In the Intel80C31 device test, the laser incidence was processed in different functional zeros, such as the ALU, RAM, and TIMER units. The research results indicate that, when SEL occurred and the current in the device became larger, the corresponding unit function was abnormal. A power reset is needed to reset the device to its normal state. The test results also indicate that the timer of an 80C31 device readily undergoes an SEL. Under the incidence of a nano-second laser, the SEL current range is about 385–400 mA, as shown in Fig. 3.

4.2.2. Laser simulation SEL test for BM3802 device

In the BM3802 device test, a nano-second laser was used. The test data indicates that the SEL current, which occurred in the decache unit, was between 780–790 mA. During the course of the test at the incidence position shown in Fig. 4, the kernel current reached 780 mA and the port current reached 200 mA at a laser energy of 172 nJ, as shown in Fig. 5. When the DUT recovers to the reset state, this device is still in a larger current state. This indicates that this DUT has been destroyed by the SEL current.

It is obvious that the SEL current range for each functional unit is different. For instance, the SEL current that occurs in the Icache unit is between 655–658 mA. Figure 6 shows the current curve for the BM3802 unit to undergo an SEL in the Icache unit. From Fig. 6, we see that the current in

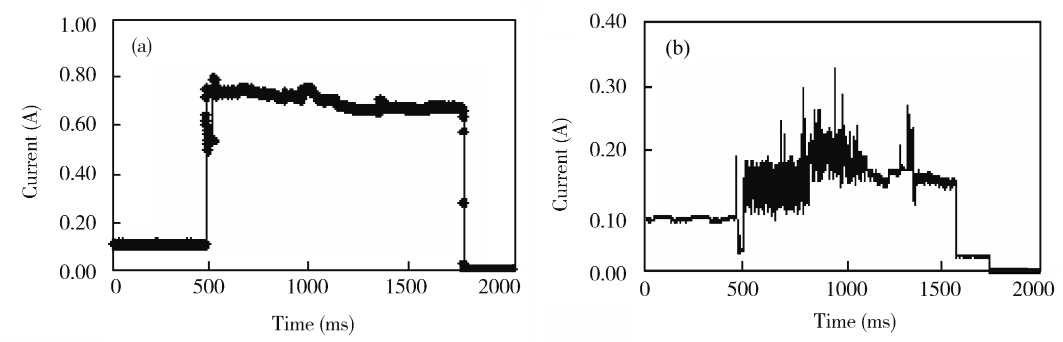

Fig. 5. (a) The kernel and (b) the port current inducing SEL in the decache zero of the BM3802 device.

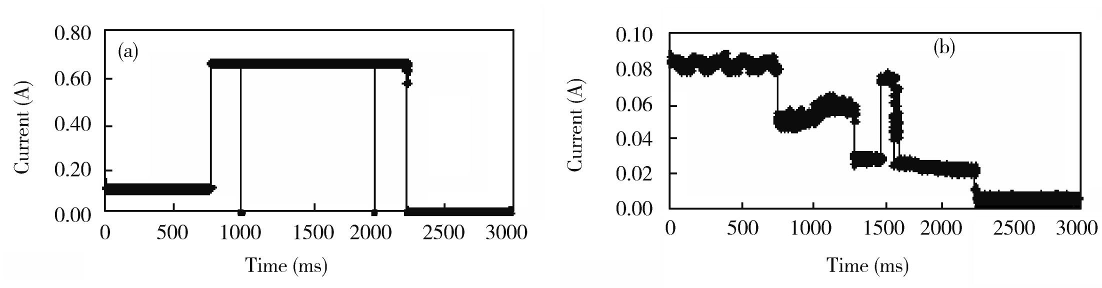

Fig. 6. (a) The kernel and (b) the port currents inducing SEL in the decache zero of the BM3802 device.

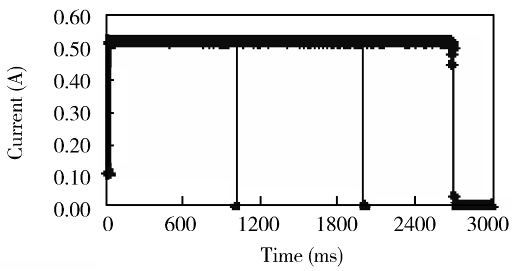

Fig. 7. The kernel current inducing SEL in the Itag zero of the BM3802 device.

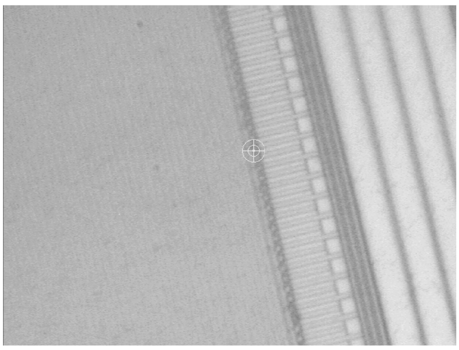

Fig. 8. Image of the BM3802 device Itag zero to induce SEL.

the port of the BM3802 device does not increase by a large amount, and the SEL event is caused by the current in the kernel. So, the detection and protection of the current in the kernel is the emphasis for the SEL protection of CPU devices.

Figure 7 shows the transformation curve for the BM3802 device to undergo an SEL event. From this figure, we can observe that the SEL current in the Itag unit is about 520 mA. An image of the Itag surface is shown in Fig. 8.

BM3802 devices are still made using a 0.18-μm CMOS technology, which determines that the devices are sensitive to SEL events. In the course of the SEL tests, each unit of the device has a special current range: the SEL current in the decache is between 781–790 mA, the current in the Icache unit is between 655–658 mA, and the current in the Itag unit is between 520–600 mA. As a whole, the SEL current for the BM3802 is between 510–790 mA, which is about three to five times larger than in its normal state.

5. Result analysis and discussion

5.1. Major characteristics allowing the pulse laser to simulate SEL

When using a pulse laser to simulate SEE, the laser pulse width is very important for the charge collection and the laser threshold to induce the SEE. If the laser pulse width is smaller than the circuit response time (about 80 ps), it can be considered that charge is produced and spread out instantly. In this way, the charge quantity inducing a disturbance or a latchup is invariable, and equals the critical charge, which causes the invariability of the energy threshold. Additionally, the relationship between the laser energy and the pulse width is:

$$P = E/\sqrt{\pi}\tau . \qquad (1)$$

Obviously, in the same laser beam spot, if an equal charge track is produced, the greater the laser pulse width, the more laser energy is needed. But too much laser energy will induce the burnout effect in the devices. Therefore, intensive lasers should be avoided in simulations of single event effects. The time for ions to be produced and spread out is about 1 ps. From the point of view of the laser simulation, the width of the laser should be potentially narrow. Compared with the collection

Table 1. Data simulated by laser test.

Device under test	Laser energy threshold（nJ）	SEL current range（mA）	Rated current（mA）
IDT6116	0.41	570–590	80
HM65162	0.75	310–350	70
IDT71256	0.50	380–430	60
Intel80C31	13.30	360–400	38
BM3802	90.00	750–780	150

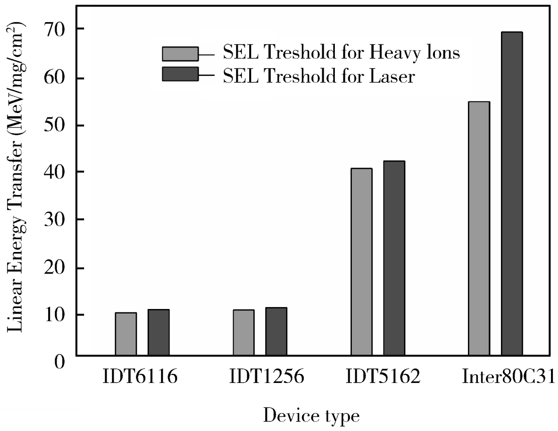

Fig. 9. Comparison between laser simulation test results and heavy ion simulation test.

time of the exhaust zero and the funnel zero, a typical pulse width is about 15–25 ps. The laser in our laboratory has a pulse width of about 20–30 ps, which can meet the demands of the SEE evaluation for sub-micron devices.

Also, research into laser simulation for SEE has confirmed that pulse lasers have an obvious advantage in multi-layer structure circuits. They are covered with a thick medium on the surface of the device, which prevents the ions from reaching deeper circuits in these devices. The nano-second laser with a wavelength of $\lambda = 1.079$ μm penetrates to a depth of about 1400 μm, which could reach deeper circuits to realize the test for sensitive units[8]. This has been proven in the simulation for the SEL test.

When a latchup occurs, there are large scale currents induced in the DUT, which are also larger than the rated currents in the device. Each CMOS has a special latchup current range. The laser energy threshold and the latchup current range are shown in Table 1.

From the data in Table 1, we can find that the CMOS device latchup current is about 0.3–1.0 A.

5.2. Comparison of test results

On the basis of the equivalent analysis for LET, we research the similarity between the laser threshold and the heavy ions obtained in the test. Detailed results are shown in Fig. 9. From this figure, we can see that the SEL threshold obtained in the laser and in the ion simulations are consistent. There are differences for some devices. For example, the HM65162 device SEL threshold obtained by the laser is 42.2 MeV/mg/cm^2, but the heavy ion test result is 40.6 MeV/mg/cm^2. Therefore, the calculated formula still needs to be amended, and further research needs to be performed on the SEE laser simulation.

In addition, the SEL current range for these DUTs, measured by laser and heavy ions, is consistent and it is mostly determined by the microcircuit structure, which is not closely related to the laser energy intensity.

6. Conclusions

A typical SRAM and CPU device SEL test is developed by the pulse laser. The sensitive zeros for an SEL have been measured, and the threshold for an SEL has been obtained. The test results show that the SEL current range is mostly determined by the microcircuit structure. There is a special SEL current range for each CMOS device, and the SEL current for typical CMOS devices is between 0.3–1.0 A. The laser equivalent LET threshold for the laser and for the ions is consistent.

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