第29卷 第9期
2008年9月

半 导 体 学 报
JOURNAL OF SEMICONDUCTORS

Vol.29 No.9
Sep.,2008

Single Event Transients of Operational Amplifier and Optocoupler

Feng Guoqiang[1,†], Ma Yingqi[1,2], Han Jianwei[1], Zhang Zhenlong[1], and Huang Jianguo[1]

(1 *Center for Space Science and Applied Research, Chinese Academy of Sciences, Beijing* 100190, *China*)
(2 *Graduate University of the Chinese Academy of Sciences, Beijing* 100049, *China*)

Abstract: The single event transient effects of the operational amplifier LM124J and the optocoupler HCPL 5231 are investigated by a pulsed laser test facility. The relation of transient pulse shape to pulsed laser equivalent LET is tested, the sensitive areas of the SET effects are identified in voltage follower application mode of LM124J, and the mechanism is initially analyzed. The transient amplitude and duration of HCPL5231 at various equivalent LET are examined, and the SET cross-section is measured. The results of our test and heavy ion experimental data coincide closely, indicating that a pulsed laser test facility is a valid tool for single event effect evaluation.

Key words: pulsed laser; single event transient; operational amplifier; optocoupler
EEACC: 2550R; 2570B; 4270
CLC number: TN4 **Document code**: A **Article ID**: 0253-4177(2008)09-1729-05

1 Introduction

The single event effect (SEE) is the phenomenon when energetic electric particles bombard microelectronic devices or circuits loaded with data or commands leading to logic errors, functional abnormity, and even destruction of devices. For instance, SRAM, MCU, and power MOSFET devices struck by a single particle or ion can cause single event upset (SEU), single event latchup (SEL), and single event burnout (SEB)[1~4]. SEE is a critical space environmental effect that can seriously affect or threaten the security and reliability of the satellite electronics system. Fundamentally, the physical processes of production, propagation, and collection of ionization charge in a device by a single ion are also suitable for linear and photonics devices. The transient signal is produced in the output of circuits after a heavy ion hits the sensitivity node, which is a single event transient (SET)[5~7]. In recent years, transient induced in linear and photonics devices were identified as the cause of anomalies in TOPEX-POSEIDON, SOHO, Cassini, and MAP satellites. Thus, SET is gradually given weight and becoming the hotspot in SEE research[8,9].

Generally, SET induced in linear and photonics devices by heavy ion or proton includes operational amplifiers, comparators, ADCs, and optocouplers, which are extensively used in spacecraft electronic instruments. Although the duration of transient induced in linear and photonics devices is short, it influences the digital circuits connected with the output of linear and photonic circuits. This causes spacecraft operation abnormities and threatens the security and reliability of satellites. For the safe application of linear and photonics devices in space missions, the SET of operational amplifiers, comparators, and optocouplers that are widely used in space have been investigated with accelerator testing. The SET of linear circuits is also examined with a pulsed laser[9].

In this paper, we describe an SEE simulation by pulsed laser system to test the SET pulse shape characteristic of the operational amplifier LM124J and optocoupler HCPL5231, and the equivalent LET and cross section of HCPL5231 are achieved with theoretical methods and experimental techniques. The SET of the optocoupler is first investigated by pulsed laser.

2 Test facility and devices

2.1 Pulsed laser test facility

The single event effect simulation by pulsed laser test facility is independently established by the Center for Space Science and Applied Research of the Chinese Academy of Sciences. It includes six main parts: (1) pulsed laser, (2) energy adjustment of the pulsed laser, (3) energy measurement of the pulsed laser, (4) focusing the location of the pulsed laser, (5) controlling the test facility, and (6) monitoring the SEE. The main performance of the test facility is given in Table 1.

† Corresponding author. Email: gqfeng@cssar.ac.cn
Received 1 February 2008, revised manuscript received 23 April 2008

Table 1 Main performance of test facility

Wavelength/nm	1064
Pulse duration/ns	20
Frequency/kHz	1～50
Spot size/μm	3～4
Stepping gap/μm	0.5
Equivalent LET/(MeV · cm^2/mg)	0～200

First, the photon energy of the laser must be greater than the band-gap of the semiconductor in order to deposit energy in the device. For silicon (its band-gap is 1.1eV), the available wavelength is smaller than 1110nm, so a 1064nm laser is directly suitable for the SEE test. For the qualitative evaluation of the device under a test response to SEE, a key point in the SEE simulation experiment is to calculate the equivalent LET for the laser pulse. If one laser pulse is equivalent to an ion of LET, the amount of charge generated by an ion per unit length in the semiconductor is equivalent to that of a single laser pulse. If linear absorption in the semiconductor is considered alone, we get the equivalent LET equation for the laser pulse:

$$\mathrm{LET}(x) = 10^{-20} \times \frac{\alpha \lambda E_{\mathrm{ion}}}{\rho h c} E_{\Lambda} \exp(-\alpha x) \qquad (1)$$

where α[cm^{-1}] is the absorption coefficient in the semiconductor, λ[cm] is the pulsed laser wavelength, E_{ion}[eV] is the energy required for an ion to activate a pair of electron-holes, ρ[mg/cm^3] is the density of the semiconductor, h is the Planck constant, c is the velocity of light, and E_{Λ}[pJ] is the energy of laser pulse. When the testing laser energy is lower than nJ, the nonlinear effect is neglected. Considering the influence of reflection and refraction of device surface, the relative transmissivity is assumed to be 60%.

2.2 Devices under test

LM124J is a low power quad operational amplifier with a bipolar process by National Semiconductor, which is tested on a voltage follower configuration. HCPL5231 is a hermetically sealed logic gate optocoupler, which is widely used in digital signal isolated circuits by Avago Technologies. Figure 1 gives the test circuits of the two devices.

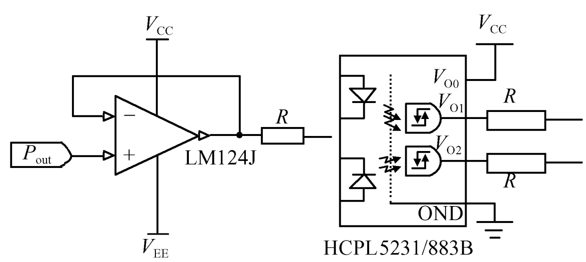

Fig.1 SET test circuits of LM124J and HCPL5231

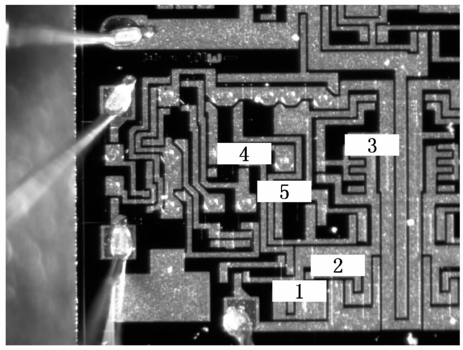

Fig.2 SET sensitivity area distribution of LM124

3 Experiment and results

3.1 Operational amplifier LM124J

3.1.1 SET sensitivity area

LM124J is configured as a voltage follower with a supply voltage of +15V/−15V and an input of 5V. The output has a 50Ω load and is connected with the oscilloscope TDS-2024B, which is used to capture the SET pulse. Before testing, the ceramic package lid has been removed. The scanning parameters are: a velocity of 0.22mm/s, a stepping length of 4μm, and a range of 1mm × 1mm, which covers the whole chip. Then, LM124J is automatically scanned from 150 to 1600pJ with an increase of 50pJ per cycle. Figure 2 gives the SET sensitivity area distribution of the device. When non-SET sensitive areas are irradiated with the pulse laser, no disturbing pulses are captured by the oscilloscope.

Considering the influence of the SET pulse on the following digital circuit, the SET disturbing threshold is decided as the amplitude >0.5V and duration >30ns. According to Eq. (1), we find the equivalent LET threshold of five sensitivity areas to be 10.5, 42, 39, 29, and 29MeV · cm^2/mg.

Test data indicate that the SET threshold and transient shape vary over the five different sensitivity areas, where areas 1 and 2 are negative SET pulses, areas 3, 4 and 5 are bipolar disturbing transients, and the threshold of area 1 is the lowest. Figures 3 (a) and (b) give the SET pulse shape characteristic of five different sensitivity areas at different equivalent LET.

3.1.2 SET characteristic versus equivalent LET

SET duration is the full wave at half maximum (FWHM) width. SET amplitude is the difference between the transient maximum amplitude and the minimum amplitude. The amplitude and duration of SET pulse eventually increase as the equivalent LET increases. The results are given in Figs. 4 (a) and (b).

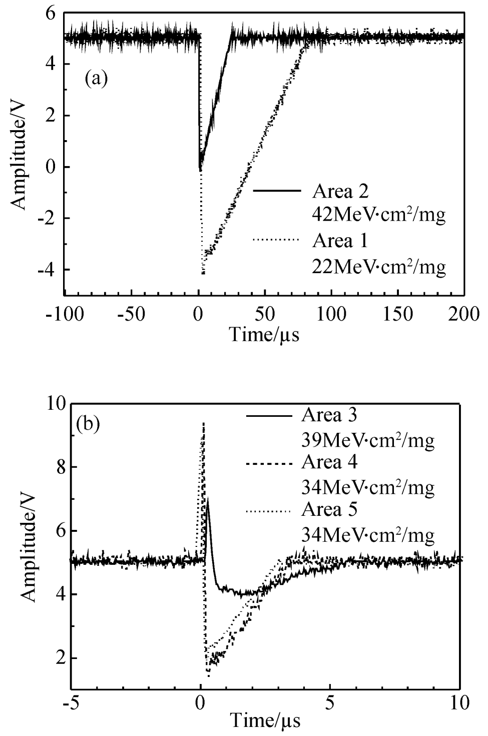

Fig.3 (a) SET pulse shape of areas 1 and 2;(b) SET pulse shape of areas 3,4,and 5

3.2 Optocoupler HCPL5231

When SET is tested by pulsed laser, the coupling medium and LED must be removed in order to allow the laser pulse to directly irradiate the device of

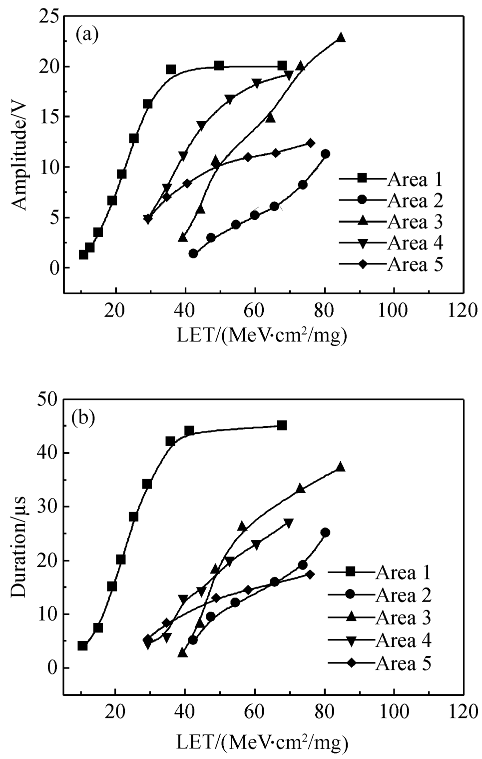

Fig.4 (a) SET duration distributions at various equivalent LET;(b) SET amplitude distributions at various equivalent LET

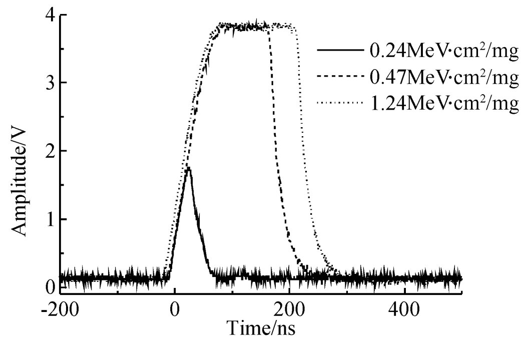

Fig.5 Pulse shapes at different equivalent LET

photo-detector. Five volts are applied to the device during testing, using a 50Ω resistor load.

3.2.1 SET pulse characteristic

Both amplitude and duration have to be considered when describing transients from linear and photonics devices. Optocouplers with internal logic gates are extremely sensitive to SET. The threshold LET, the LET at which transients first occur, is approximately $0.24\mathrm{MeV} \cdot \mathrm{cm}^2/\mathrm{mg}$, an extremely low value. The pulse amplitude and duration are 1.76V and 41ns. The characteristic is shown in Fig. 5.

3.2.2 SET cross section

The photodetector is the most sensitive part to SET and is a testing objective, ranging $0.5\mathrm{mm} \times 0.5\mathrm{mm}$. The scanning parameters were set to a velocity of 0.22mm/s and a stepping length of 4μm. The SET disturbing threshold is amplitude >0.5V and duration >30ns. The amount of disturbing transients is measured by an SET monitoring instrument. The cross section equation is:

$$\sigma = \frac{\text{Number of SET}}{\text{Number of Pulsed Laser}} \times \text{Area} \qquad (2)$$

When the equivalent LET $> 4\mathrm{MeV} \cdot \mathrm{cm}^2/\mathrm{mg}$, the SET cross section is equivalent to the photodetector area, $0.25\mathrm{mm}^2$. The cross sections at various equivalent LETs are shown in Fig. 6. The results are in a good agreement with the heavy ion data[12,13].

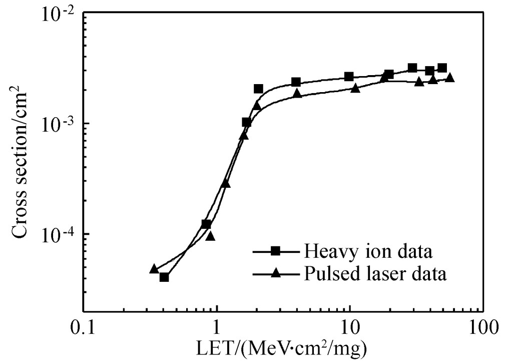

Fig.6 Cross section at various equivalent LET

4 Discussion

4.1 SET analysis of LM124J

From Fig. 2, areas 1 and 2 are located on the output stage. When they are irradiated by pulsed laser, the output transistor connected to the negative supply temporarily turns on, and then a negative transient is induced in the output of the device until the transistor shuts down, which is shown in Fig. 3 (a). Areas 3, 4, and 5 are the sources of constant current, providing the DC operating point. When irradiated, the constant current characteristic is changed for a while, creating drift for the DC operating point and inducing further bipolar SET pulse in the output.

The collection of ionization charge is gradually increased in the sensitive area as the equivalent LET rises, which may causes an increase of the disturbing transients' amplitude and duration. Test data is shown in Figs. 4 (a) and (b). The SET sensitive parts of LM124J configured as a voltage follower are output stage and constant current sources.

4.2 SET analysis of HCPL5231

When irradiated by energy particle or laser pulse, HCPL5231 has a longer ionization track for its depth of pn junction on the order of ten micrometers. So the charges collected by the junction are much more than normal junction, and the SET sensitive threshold is lower accordingly. The threshold LET tested by pulsed laser is approximately 0.24MeV · cm^2/mg, an extremely low value. The amplitude and duration of transients are gradually increased as the equivalent LET rises. Four volts of pulse amplitude are achieved before saturation. When LET is larger than 1.2MeV · cm^2/mg, the pulse width exceeds 200ns, and thereafter the enhancement begins to decrease. The ionization charges collected by the device may be progressively saturated.

Because the cross section of HCPL5231 is as large as 0.25mm^2, the threshold is 0.24MeV · cm^2/mg, an extremely low value, the device is not qualified for application in a space mission.

4.3 Analysis of testing errors

When the laser energy is less than 1nJ, the nonlinear effect is neglected. The equivalent LET threshold is 17.5 MeV · cm^2/mg for LM124J, and 0.4MeV · cm^2/mg for HCPL5231 according to Eq. (1), contrasting with the accelerator measured results of 9 and 0.29MeV · cm^2/mg.

Considering the influence of reflection and refraction, the relative transmissivity is assumed to be 60%. Due to a lack of the exact thickness of the passivation layer, accurate calculations are impossible. The equivalent LET threshold is then corrected as 10.5 MeV · cm^2/mg for LM124J and 0.24MeV · cm^2/mg for HCPL5231. We have 16.7% for LM124 and 20.8% for HCPL5231 as the relative errors by pulsed laser testing.

5 Conclusion

LM124J and HCPL5231 responses to SET have been qualitatively evaluated with SEE simulation by pulsed laser. Five SET sensitive areas were found on LM124J configured as a voltage follower, and the equivalent LET threshold is 10.5MeV · cm^2/mg. There is an extremely low LET value, 0.24MeV · cm^2/mg, for HCPL5231. The amplitude and duration of transients of both devices increase as the equivalent LET rises. The output stage and constant current source were identified as the sensitive areas of the LM124J, and the photodetector is the origin of SET sensitivity of the HCPL5231. The cross section results of the optocoupler are in good agreement with the heavy ion data, validating the pulsed laser test technique and the approach used to calculate the cross section and corresponding LET values.

References

[1] Pickel J C, Blandford J T. Cosmic-ray induced errors in MOS memory cells. IEEE Trans Nucl Sci, 1978, NS-25: 1166

[2] Price W E, Nichols D K, Soliman K A, et al. A study of single event upsets in static RAMs. IEEE Trans Nucl Sci, 1980, NS-27 (6): 1506

[3] Stephen J H, Sanderson T K, Mapper D, et al. Cosmic ray simulation experiments for the study of single event upsets and latch-up in CMOS memories. IEEE Trans Nucl Sci, 1983, NS-30(6): 4464

[4] Titus J L, Wheatley C F. Experimental studies of single-event gate rapture and burn-out in vertical power MOSFETs. IEEE Trans Nucl Sci, 1996, NS-43(2): 533

[5] Koga R, Pinkerton S D, Moss S C, et al. Observation of single event upset in analog microcircuits. IEEE Trans Nucl Sci, 1993, NS-40(6): 1838

[6] Pease R L, Sternberg A L, Massengill L W, et al. Critical charge for single event transients (SETs) in bipolar linear circuits. IEEE Trans Nucl Sci, 2001, NS-48(6): 1966

[7] Johnston A H, Swift G M, Miyahira T, et al. Single event upset effects in optocouplers. IEEE Trans Nucl Sci, 1998, NS-45(6): 2867

[8] LaBel K, Marshall P W, Marshall C J, et al. Proton-Induced transients in optocouplers: in-flight anomalies, ground irradiation test, mitigation and implications. IEEE Trans Nucl Sci, 1997, NS-44 (6): 1895

[9] Savage M W, Turflinger T, Titus J L, et al. Characterization of SET response of the LM124A the LM111, and the LM6144. IEEE Radiation Effects Data Workshop, 2003: 121

[10] Huang Jianguo, Han Jianwei. The mechanism for SEU simulation

by pulsed laser. Science in China, Ser G, 2004, 47(5): 540(in Chinese)［黄建国，韩建伟．脉冲激光诱发单粒子效应的机理．中国科学 G 辑，2004，47(5)：540］

［11］ Huang Jianguo, Han Jianwei. Calculation of LET in SEE simulation by pulsed laser. Science in China, Ser G, 2005, 48(1): 113(in Chinese)［黄建国，韩建伟．脉冲激光模拟单粒子效应的等效 LET 计算．中国科学 G 辑，2005，48(1)：113］

［12］ Reed R A, Poivey C, Marshall P W, et al. Assessing the impact of the space radiation environment on parametric degradation and single-event transients in optocouplers. IEEE Trans Nucl Sci, 2001, NS-48(6): 2202

［13］ LaBel K A, Kniffin S D, Reed R A, et al. A compendium of recent optocoupler radiation test data. IEEE Radiation Effects Data Workshop, 2000: 123

运放和光耦的单粒子瞬态脉冲效应

封国强[1,†]　马英起[1,2]　韩建伟[1]　张振龙[1]　黄建国[1]

（1 中国科学院空间科学与应用研究中心，北京　100190）
（2 中国科学院研究生院，北京　100049）

摘要：利用脉冲激光模拟单粒子效应实验装置研究了通用运算放大器 LM124J 和光电耦合器 HCPL5231 的单粒子瞬态脉冲(SET)效应，获得了 LM124J 工作在电压跟随器模式下的瞬态脉冲波形参数与等效 LET 值的关系，甄别出该器件 SET 效应的敏感节点分布．初步分析了 SET 效应产生的机理．以 HCPL5231 为例，首次利用脉冲激光测试了光电耦合器的单粒子瞬态脉冲幅度、宽度与等效 LET 值的关系，并尝试测试了该光电耦合器的 SET 截面，实验结果与其他作者利用重离子加速器得到的数据符合较好，证实了脉冲激光测试器件单粒子效应的有效性．

关键词：脉冲激光；单粒子瞬态脉冲；运算放大器；光电耦合器
EEACC：2550R；2570B；4270
中图分类号：TN4　**文献标识码：**A　**文章编号：**0253-4177(2008)09-1729-05

† 通信作者．Email：gqfeng@cssar.ac.cn
2008-02-01 收到，2008-04-23 定稿