SRAM IDT7026 SEU Prediction and On-Orbit Validation

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***Abstract*—Single Event Effect (SEE) prediction and validation is important for low cost electronic parts on-orbit application. As the SRAM IDT7026 has no space radiation-resistant measures, there are SEE risks when it is applied in aerospace activities. In order to assess the IDT7026 SEE performance, the SEE prediction and flight validation are performed. The on-orbit Single Event Upset rate for the SRAM IDT7026 is predicted using LET cross-section function fitted from ground SEU experiment data. To validate the prediction result, the flight experiment is carried out for IDT7026 and the on-orbit SEU data is obtained. The flight SEU rate is compared and analyzed with the prediction. The result indicates that the SEU prediction method can give appropriately support to electronic parts on-orbit application and the IDT 7026 can be used in spacecraft with some mitigation methods.**

***Index Terms*—single event upset prediction, LET cross-section, electronic part on-orbit validation**

I. Introduction

On-orbit spacecrafts are threatened by the space radiation environment. The radiation environment is mainly caused by Galactic Cosmic Ray, Solar Energetic Particles and Earth radiation belt particles [1]. The high energy proton, heavy ion and other particles can lead to Single Event Effect (SEE) easily when they inject into the electronic parts. SEE is a kind of electronic part or circuit failure caused by single high energy particle injecting into the semiconductor part or molectron. SEE can be classified as Single Event Upset (SEU), Single Event Latchup (SEL), Single Event Burnout (SEB) and Single Event Gate Rupture (SEGR) [2]. SEU is an electronic part logic turbulence fault caused by single particle ionization in the semiconductor. SEU will severely decrease the memory on-orbit performance.

Electronic parts on-orbit SEU prediction is meaningful for spacecraft system designers to choose the appropriate parts and make necessary anti-SEU hardening. SEU prediction methods have been studying by researchers and many remarkable achievements have been obtained [3, 4]. Ground particle accelerator experiment is necessary for electronic part on-orbit SEU prediction. The electronic part is tested using the particle beam which is produced by the accelerator to simulate the space radiation environment. The SEU cross section and Liner Energy Transfer (LET) relationship is then computed. The SEU rate can be finally predicted.

On-orbit experiment is an effective method to evaluate SEU prediction precision [5], [6]. SEU prediction error revise can be performed using the on-orbit experiment data thus to improve the SEU prediction precision.

In this paper, the SEU prediction and on-orbit experiment for the SRAM IDT7026 is presented. Firstly, the ground SEU experiment is performed and the SEU rate is predicted using space radiation model. Then the electronic circuit is designed and on-orbit experimented, and the flight SEU rate is obtained. Finally, the SEU prediction is compared with the on-orbit experiment, and the prediction error is analyzed.

II. SEU Rate Prediction

A. LET Cross-Section Determination

The heavy ion SEU experiment is carried out using tandem accelerator. The experiment system includes the SRAM experiment board, the remote computer and the control computer. The SRAM board implements the testing examples, power control, state monitor, safety management and data transformation with the remote computer. At the same time, the SRAM board receives and executes the instructions from the remote computer to change the testing examples. The control computer provides graphical user interface. The operators could manage the experiment course and process the experiment data through the interface, such as: 1) experiment data collecting, processing and displaying, 2) current overflow warning and safety guarding, 3) indirect instructions sending.

The experiment system provides a test cable vacuum commutator which is equipped with different kinds of cables to transfer the data and instructions between the remote computer and the vacuum chamber. The RS422 cable is used in this experiment to transfer the experiment data from the radiation target chamber to the remote computer. One end of RS422 is connected with the SRAM experiment board, the other end is connected with the radiation effect testing system. The control computer controls the remote computer through LAN using TCP/IP protocol to implement experiment items. During the SEU experiment, the experiment board is fixed on the trestle table of the vacuum chamber. The range and flux rate of the particle beam can be modulated to insure the SEU

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experiment effect. The electronic readout system for SRAM is 1s initially. The experiment system is shown in Fig. 1.

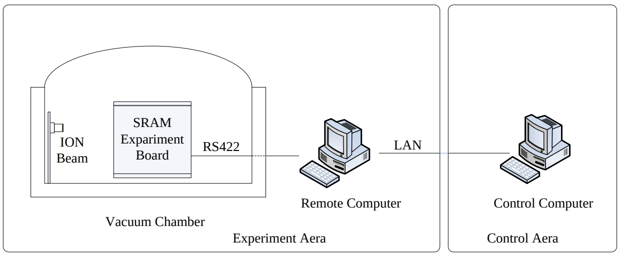

Figure 1. Ground experiment system.

The particles selected are shown in Table I. Two different energy particles ($^{1}H^{+}$) are used to perform proton SEU experiment in order to verify whether the proton SEU happens. The $^{7}Li^{3+}$, $^{12}C^{6+}$and $^{16}O^{8+}$ are used to test SRAM SEU LET threshold, the $^{35}Cl^{11+}$ and $^{48}Ti^{12+}$ are used to perfect the SRAM SEU cross section and determine the saturation cross section, the $^{74}Ge^{20+}$ is used to confirm the saturation cross section.

TABLE I. SRAM SEU EXPERIMENT RADIATION SOURCE

ION species	End voltage (MV)	Strip probability (%)	Energy (MeV)	Surface LET (MeV/mg/cm^2)	Range in Si(μm)
$^{1}H^{+}$	12.5	100	6	-	-
$^{1}H^{+}$	12.5	100	25	0.02	3.6
$^{7}Li^{3+}$	11.4	88.8	46	0.44	269
$^{12}C^{6+}$	11.4	12.5	80	1.73	127
$^{16}O^{8+}$	11.4	1.0	103	3.05	99.4
$^{19}F^{9+}$	11.4	0.2	115	4.06	87.9
$^{28}Si^{10,12+}$	11.4	0.7	143	9.01	54.5
$^{35}Cl^{11,14+}$	11.5	0.2	164	12.9	47.4
$^{48}Ti^{10,15+}$	11.4	3.0	169	21.8	34.7
$^{74}Ge^{11,20+}$	11.4	0.1	212	37.2	30.8

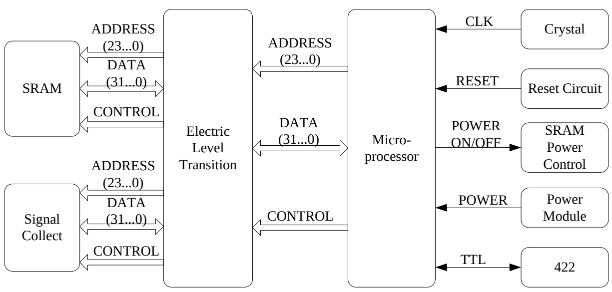

Figure 2. SRAM experiment board design.

SEU experiment board is made up of SRAM to be tested, CPU module, power supply module, signal collecting module, power supply control module, serial 422 module, electric level transition module and the electronic interface. The SRAM to be tested is 1cm from the electronic parts around it. The electric power of SRAM is provided by power supply control module and is independent from the other electronic parts power supply on the experiment board. The electric power of other electronic parts is supplied by the power supply module and the outside power supply. The SRAM electric current is collected by signal collecting module. The input signal of SRAM is provided by CPU and the output signal of SRAM is collected by CPU at the same time. The SEU events are recorded and the statistical results are sent to the remote computer through RS422. The design of SEU experiment board is shown in Fig. 2.

CPU module is mainly responsible for test and communication managing. The SRAM SEU events and operating voltage/current are recorded by test management function. The data collected during SEU testing include: 1) storage data and program operating results, 2) exception types and their occurrence time, 3) SRAM operating voltage and current. The collected data are combined and used by SEU prediction.

Power supply control module uses MOSFET to control SRAM power on/off. During the experiment, when the current or voltage exception occurs due to SEL, the CPU controls the MOSFET to power off the SRAM and reset the system.

In addition, the experiment software is designed. The pertinently measure methods are applied to deal with different SEE types and insure the recognizing of fault types and their occurrence time.

The particle beam is used to perform radiation experiment for SRAM. The SRAM upset cross sections under different heavy ion LET radiation are measured and the SEU saturation cross section is obtained. The SEU saturation cross section is around 0.025cm^2. The SRAM heavy ion SEU LET threshold is around 4MeV/mg/cm^2 (1‰ saturation cross section [7]). The cross section is drawn up using Weibull function fitting algorithm in Fig. 3.

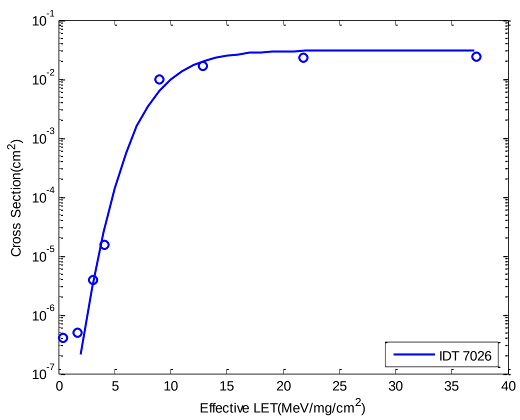

Figure 3. LET cross-section.

B. *Electronic Part On-Orbit SEU Prediction*

To predict the electronic parts on-orbit SEU rate, the space particle radiation environment during spacecraft mission should be considered. The space particle radiation environment includes the radiation particle intensity, energy range and space distribution, and especially the deposited energy in electronic part unit length namely LET. These space particle parameters are the basic external inputs for SEU prediction. To compute the radiation condition at the location of electronic part, the shielding from outside space to the electronic part should be studied such as spacecraft cover, equipment shell and other equipments shielding. It is necessary to modeling the part SEU sensitive structure, simulating and validating the sensitive structure and the radiation source sensitive parameters, and studying the simulation and analytical methods of electronic part parameters. SEU prediction methods include two aspects: the SEU caused by heavy ion and the SEU caused by proton. The Heavy ion SEU prediction is calculated as (1) and the Proton SEU prediction is calculated as (2) [3].

$$R = \int_0^\infty \Phi(L)\sigma(L)d_L \tag{1}$$

$$R = \int_0^\infty \Phi(E)\sigma(E)d_E \tag{2}$$

R stands for SEU times, $\Phi(\cdot)$ stands for radiation particle energy function of the electronic part, $\sigma(\cdot)$ stands for part SEU cross section function, L stands for heavy ion LET, E stands for proton energy.

The space environment parameters are simulated using space environment models. The SRAM SEU rate is predicted with both the space environment parameters and the SRAM SEU LET cross-section function. The flight experiment time is three months from 20th Feb to 20th May 2014. The prediction time should be in accordance with the flight time. The spacecraft cover and the other equipment can shield some radiation particles, the shielding materials can be calculated to equivalent AL shielding thickness.

At the pre-research, the SEU rate is predicted according to different equivalent AL shielding, the result is shown in Fig. 4. As the outside radiation environment decreased with the increase of shielding thickness, the SEU rate gradually falls down. However, the shielding has less effect on the radiation environment when the equivalent AL is thicker than 12mm and the SEU rate is stable. During the spacecraft design, the shielding thickness, the spacecraft weight, the radiation protection ability should be synthetically considered by the designers so as to make the appropriate shielding thickness design.

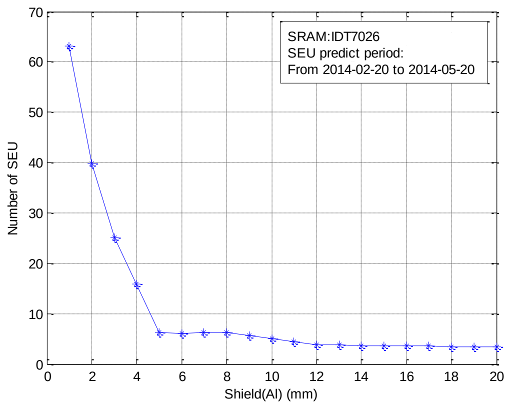

Figure 4. SEU prediction result.

III. FLIGHT SEU EXPERIMENT

The spacecraft operates on the sun synchronous orbit. The SRAM SEU experiment was performed for three months. To supervise the SRAM on-orbit SEU, the electronic parts experiment payload was designed. The electronic system consists of the SRAM to be tested, the anti-fuse FPGA and the control microprocessor. The payload is shown in Fig. 5.

Testing module: the anti-fuse FPGA writes the testing data to the SRAM through data bus transceiver. After several clocks, the SRAM memory data is readout through the data bus transceiver. The data or results are then stored into the FIFO. The control system fetches the data from the FIFO and send it to the spacecraft manage computer finally.

Control module: this module is an important part of the flight experiment payload. The experiment function includes: 1) system initial, 2) SRAM operate state monitor and control, 3) communication with spacecraft through CAN, 4) communication with other function module through RS422, 5) remote parameter collection control, 6) module operate mode control, 7) secondary power supply management, 8) program on-orbit injection process.

SRAM module: according to the parameters to be validated for the SRAM, the operating current, temperature and the voltage should be on-orbit tested. The data write/read function is tested by software. The on-orbit adaptability and life can also be checked.

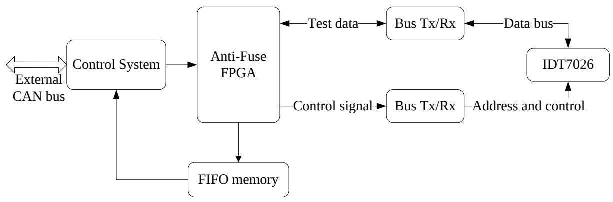

Figure 5. Experiment payload design.

The spacecraft was launched in 2013 and carried out different kinds of scientific experiments according to flight plan. The equivalent AL shielding is 8mm according to the spacecraft design. The electronic part payload was on-orbit experimented. The SRAM SEU performance is shown in Table II.

TABLE II. SRAM FLIGHT VALIDATION RESULT

Device name	Upset times	Shielding(mm)	Test period(day)
IDT7026	4	8(AL)	90

IV. EXPERIMENT RESULTS ANALYSIS

The shielding to the SRAM IDT 7026 is 8mm calculated from the spacecraft cover, the equipment shell and the PCB boards. From the prediction, the SEU will take place 6 times from 20th Feb to 20th May at 8mm equivalent AL. The on-orbit experiment SEU result is 4 times. The experiment result is in accordance with the prediction.

However, there is an error between the flight result and the prediction result, the error mainly comes from:

1) The space environment models were used in the prediction to simulate GCR LET-flux data of different time on the orbit. There are errors between the simulated LET and the on-orbit LET.

2) The experiment time is not enough due to the flight mission schedule and the SEU events obtained are insufficient. The flight data only reflects the SEU performance in a short time. The prediction will be more accurate if the experiment time was long enough.

3) Eight different LET particles were chosen in the ground SEU experiment. The particles mainly distributed at the low LET and saturation LET segment, however, the LET points at the curve inflexion were few which are important for curve shape determination. Increase LET experiment points can improve LET-cross section fitting precision.

4) Though the SRAM type in the ground experiment was the same as the one used in flight experiment, the manufacture batch numbers are not the same. This may lead to different anti-radiation performances. The different anti-radiation performances will lead to different results in the SEU experiments.

5) In order to decrease the heavy ion energy loss and make sure the conditions for SEU experiment in ground test, only the naked part was tested using the particle beam. However, the on-orbit SRAM was not only encapsulated but also shielded by 8mm equivalent AL. This will have a significant impact on the prediction result.

V. Summary

With the development of aerospace technology, the low cost electronic parts have been widely used in spacecrafts. SEU prediction is an important method to evaluate the low cost electronic part on-orbit performance. In order to assess the SRAM IDT7026 on-orbit performance, the on-ground prediction and the flight validation methods are proposed. The IDT7026 was used in ground SEU experiment and the LET cross-section function was fitted using the experiment data. The on-orbit SEU rate was calculated using SEU prediction method. During 20th Feb to 20th May 2014, the SRAM was on-orbit experimented on the sun synchronous orbit spacecraft and the flight data was obtained. The prediction result and the flight experiment result are compared and the error is analyzed in general purpose. From the result, the prediction is in accordance with the flight SEU rate in acceptable error range. The result also indicates that the IDT7026 should take properly SEE mitigation measures in flight application. This research is important for low cost electronic part on-orbit application.

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