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An Embedded System Design for SRAM SEU Test

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***Abstract*—**An embedded system for SEU(single event upset) test needs to be designed to prevent system failure by high-energy particles during measuring SEU. SEU is a phenomenon in which the data is changed temporary in semiconductor device caused by high-energy particles. In this paper, we present an embedded system for SRAM(static random access memory) SEU test. SRAMs are on the DUT(device under test) and it is separated from control board which manages the DUT and measures the occurrence of SEU. It needs to have considerations for preventing system failure while managing the DUT and making an accurate measurement of SEUs. We measure the occurrence of SEUs from five different SRAMs at three different cyclotron beam energies 30, 35, and 40MeV. The number of SEUs of SRAMs ranges from 3.75 to 261.00 in average.

***Keywords*—**embedded system, single event upset, SRAM

I. Introduction

An embedded system is the computer systems which is tightly coupled with hardware and software. It is designed to perform a dedicated function for finite domain. It is important that embedded systems are designed to meet constraints for given objective functions. Especially the embedded system used for testing using radiation, reliability should be concerned in designing hardware and software. When we designed the embedded system for radiation test, it is important to guarantee that there are no faults in the system while performing the experiments. The temporary bit-flip data error in semiconductor device by high-energy particles is so-called SEU. Although SEU changes the stored bit, memory cells are not damaged permanently[1]. The effect of SEU to electronic devices is growing as the geometry of devices get smaller and the nano-scale semiconductor technology is used wider [2]. The analysis of SEU of semiconductor device is getting more important. In order to determine the SEU of semiconductor devices, the test system is designed to meet some constraints. It is considered that to minimize the occurrence of SEU at control circuits and to get status of DUT precisely during the experiment for designing reliable SEU test system [3],[4]. In this paper, we present an embedded system for SRAM SEU test. In hardware parts, it is required that circuits which control the system are separated from DUT circuits for protecting electronic errors by SEU. In software part, test system needs the software which manages memory devices in the board and the monitoring program in host PC. The software collects conditions of board include number of SEUs which is occurred during experiment. This information is sent to monitoring program in host PC through the Ethernet using socket communication.This paper is organized as follow. Section 2 introduces a hardware design of SEU test system. It also briefly discusses the reason of separation between control board and DUT. Section 3 explains organization of software on control board to manage DUT. Monitoring software which collects the results is illustrated in same section. The experimental environments and method are summarized in Section 4. The results are shown in Section 5. Finally Section 5 concludes the paper.

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II. Hardware of Test System

The hardware of SEU test system is separated into two parts: DUT and Control board. When high-energy particles, neutrons, from cyclotron collided directly with SRAM devices in DUT, control board is tracking change of data and collecting number of SEUs is occurred. DUT is stacked on control board. So, we can test many type of device to test by just making new DUT.

A. DUT board

On DUT, there are placed only SRAMs which we want to test the occurrence of SEU. SRAMs on DUT should be collided directly with neutrons which are injected from cyclotron. So, we placed only SRAM packages on front side of DUT. Except SRAMs, passive elements are placed on back side of DUT for minimizing the effects of high-energy neutron. There are fine SRAMs are on DUT. One BGA(ball grid array) type and four TSOP(thin small outline package) type SRAMs are used.

B. Control board

Control board is main part of SEU test system. During experiment, Initializing SRAM on DUT and collect the occurrence of SEU is the major role of control board. Figure 1 is shown the block diagram of control board. PXA255 microprocessor is used in control board. It is set to have 400Mhz CPU clock speed and 100Mhz memory clock speed. In control board, there is CPLD(complex programmable logic device) which is programmed to make chip select signals of the SRAMs on DUT. Control board can support Ethernet and serial communications. During experiment, control board manages DUT to get a status of SRAMs and to collect the number of SEUs are occurred. This information of DUT is sent to host pc through the Ethernet in real time. It is important that the control board is designed to shield from neutrons during experiment. Because control board manages, collects, and sends the information of DUT, the functions of control board must be guaranteed against DUT. For this reason, connector to DUT is placed spatially far from control chips include microprocessor. So, we placed almost control chips on one side to minimize system failure by neutrons. There are some transceivers between microprocessor and DUT connectors. Transceivers work a kind of buffer to prevent electrical errors which are caused by SET from DUT to control board.

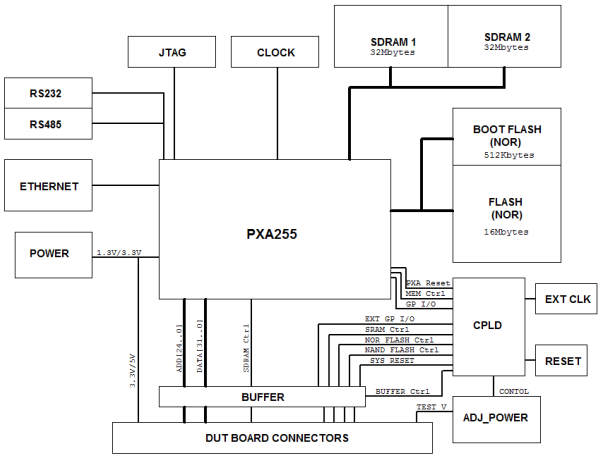

Fig. 1 Block diagram of control board

III. Software of Test System

The software to run proposed test system is separated with control board software and monitoring program. Control board software initializes data pattern in SRAMs before experiment. And during experiment, it keeps track of differences of data in real time and sends information to host PC. In the host PC, a monitoring program sends command which controls the control board and DUT and show the received information as a result in real time.

A. Software of control board

The major role of control board software is scanning data and checking the SEU is occurred or not in SRAMs. In addition, software sent the information which is included memory address where SEU is occurred and how the data is changed in SRAMs to host PC using the Ethernet. Processes of control board software are divided briefly into four parts.

1) Initialization

Before experiment, control board software can initialize the data of SRAMs. There are two initialization processes in software. First, SRAMs are initialized 0xff pattern for the first. And then, software checks whether the data is stored correctly or not. The objective of this initialization is to verify that the SRAMs are work normally. After socket communication is established between control board and host PC, SRAMs are initialized again by receiving pattern from monitoring program.

This is second initialization. First initialization is done in the early part of software, and second one is done when initialization command is received from monitoring program through the socket. In control board, initialization process is allocated memory space in SDRAM with the same amount of SRAMs.

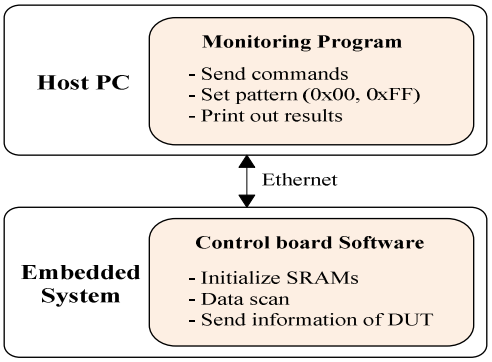

Fig. 2 Roles of software in the embedded system and host PC

Whole data in SRAMs are copied to memory in SDRAM at the end of scanning. Next scanning process compares the data in memory of SDRAM with the data in SRAMs to measure the occurrence of SEUs. In this paper, 0x00 and 0xff are used as the data patterns of second initialization. These patterns can be changed easily by modifying monitoring program.

2) Communicate through socket

There are a lot of information and command to send and receive between control board and host pc. We use socket communication which is easy to implement bi-directional communication. Socket is established at the first and keeps the connection during experiment. Experiment that using cyclotron is done in a shielded room for safety of experimenters. The only SEU test system is placed and run in the shielded room. Host PC and experimenters should be on the outside of shielded room. To connect between SEU test system and host pc, we use the Ethernet cable.

3) Data scan

Counting occurrence of SEUs on SRAMs is the most important part of the control board software. Data scan process allocates some memory space which is the same amount of each SRAM on DUT. Initialized data of SRAMs are duplicated to this memory at the start of experiment. After every 30 seconds, this process compares the data in SRAMs with the data in memory to check any differences of them [5]. If there are some difference between SRAMs and memory, process send address, original data, and changed data to host PC. The original data means the data which is in memory at previous scan. The changed data means the data which is in SRAMs at that time. After data scanning from beginning address to end, process duplicates the data in SRAMs to memory for renewing. Therefore data scan process scans all data of SRAMs compared with the data in memory and renews it every 30 seconds.

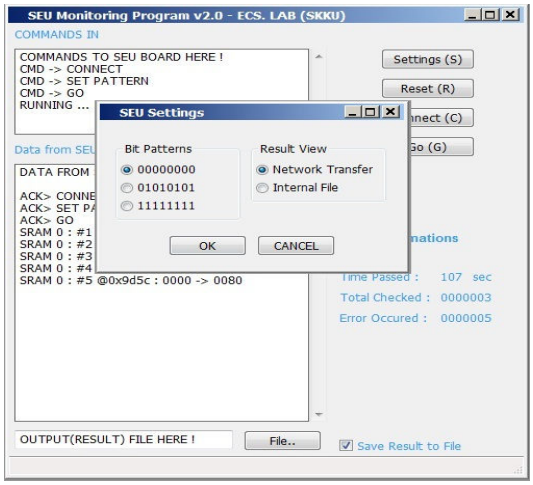

Fig. 3 Monitoring Program in host PC

4) Report

Every 30 seconds, the information of SEUs on SRAMs is sent to host PC through socket communication. In this information there are five elements about SRAMs and its SEUs. Identification number of SRAM is the first element of it. This number identifies the SRAMs as a number. Number of SEUs which are occurred at that SRAM is second element. Third one is address of SRAMs where SEU occurs. This address is sent as hexadecimal. The rest elements are the original data in memory which is stored 30 seconds before and the changed data in SRAM. Both are using hexadecimal.

B. Design monitoring software

The monitoring program runs on host PC. Data pattern for initializing SRAMs and Start/Stop commands are sent to control board from the monitoring program. We use wxWidgets in graphical design component. wxWidgets is a cross-platform graphical user interface and tools library. Figure 3 is shown graphical user interface of the monitoring program. There are two text windows. Upper window shows commands which are sent to control board and its acknowledgement signals. The information of SEUs from control board is shown at lower window. Elapsed time of experiment, the number of counting SEUs, and total number of SEUs are shown at monitoring program. There are four buttons to command. Data patterns for initializing SRAMs can be set in *Settings*. *Reset* button clears the text in two windows. *Connect* button establishes socket connection between control board and host PC. Go button commands to control board to start experiment. After experiment is done, the information of SEUs at lower window can be stored to host PC as a text file.

IV. Experimental Result

For occurring SEUs in SRAMs, we use MC-50 cyclotron in KIRAMS. MC-50 cyclotron can produce maximum 51MeV proton beam. In this paper, we use 30, 35, and 40MeV proton beam to Be target for producing high-energy neutron particles. Only SEU test board is placed at shielding room for safety. To prevent system failure by neutron particles, especially control board are shielded except DUT. When the neutron particles are produced from the cyclotron, data which is initialized 0x00 or 0xff in SRAMs are stored to memory at the same time. After every 30 seconds, control board software scans the data of SRAMs compared with the data of memory which is stored previous step. If there are any differences of the data, software sends it to monitoring program through Ethernet. Scanning the data is done total ten times within 5 minutes. Experiments are run four times under the same condition for each SRAM. Table I shows that SEUs count of SRAM #0 when initialization pattern is 0x00 using 40MeV beam. It is run four times under the same condition and each row from 30 to 300 represents the number of SEUs during 30 seconds. 0 to 3 SEUs are occurred in SRAM #0 each during 30 seconds. The average number of SEUs which are occurred in SRAM #0 within 5 minutes is 12.00. When initialization pattern is 0xff, the average number of SEUs which are occurred is 12.25 within 5 minutes. It is presented in Table II. Table III shows that the average number of SEUs of five SRAMs. Each SRAM is initialized to 0x00 and 0xff. To produce neutron particles, cyclotron beams are set as 30, 35, and 40MeV. Depending on different SRAMs, it has a different tendency between 0x00 and 0xff pattern. But by increasing cyclotron beam power, they tend to be increased the occurrence of SEUs.

TABLE I
NUMBER OF SEU IN SRAM #0WITH 00 PATTERN AT 40MEV BEAM ENERGY

0x00	40MeV				
Time	Exp.1	Exp.2	Exp.3	Exp.4	Avg.
30	1	2	1	3	1.75
60	2	0	0	2	1.00
90	1	1	2	1	1.25
120	1	0	1	2	1.00
150	2	2	0	3	1.75
180	0	2	0	0	0.50
210	0	0	0	2	0.50
240	1	0	1	2	1.00
270	2	3	0	2	1.75
300	0	3	0	3	1.50
Sum.	10	13	5	20	12.00

TABLE II
NUMBER OF SEU IN SRAM#0 WITH FF PATTERN AT 40MEV BEAM ENERGY

0xff	40MeV				
Time	Exp.1	Exp.2	Exp.3	Exp.4	Avg.
30	0	0	3	2	1.25
60	0	2	3	1	1.50
90	0	1	0	1	0.50
120	0	0	3	0	0.75
150	1	1	1	3	1.50
180	2	0	0	0	0.50
210	0	1	2	1	1.00
240	1	0	1	1	0.75
270	1	3	2	2	2.00
300	3	5	2	0	2.50
Sum.	8	13	17	11	12.25

V. Conclusion

In this paper, we proposed the guideline of designing an embedded system for measuring SEUs of SRAM effectively. To design the embedded system for SRAM SEU test, it is important that the control board is separated from DUT for

TABLE III
AVERAGE NUMBER OF SEUS OF SRAMS

	Pattern	30MeV	35MeV	40MeV
SRAM #0	0x00	4.75	6.25	12.00
	0xff	3.75	6.00	12.25
SRAM #1	0x00	25.25	35.25	66.25
	0xff	18.00	40.50	57.75
SRAM #2	0x00	25.75	48.00	88.25
	0xff	24.25	50.75	86.75
SRAM #3	0x00	104.50	175.00	257.00
	0xff	110.00	171.75	261.00
SRAM #4	0x00	46.75	70.50	114.50
	0xff	38.75	61.50	95.00

preventing the effect of high-energy particles. We placed the control chips to one side except DUT connectors. The buffers are inserted between control chips and DUT connectors to prevent electrical errors by SEU from DUT. The software of embedded system should be designed to make an accurate measurement of SEUs and to manage the DUT effectively. It communicates with monitoring program on host PC in order to transfer the information of DUT which is included the number of SEUs are occurred in SRAMs. We measure the occurrence of SEUs of five different SRAMs on our embedded system. We use three different beam energies at 30, 35, and 40MeV to produce neutrons. The safety of experimenters is also needed to be assured. So we placed only the test system in the shielded room. In addition, the control chips needs to be shielded again to prevent system failure during experiment. The measured results are sent through Ethernet directly to host PC which is placed on the outside of the shielded room. The monitoring program in host PC can be to arrange the results and stored it. The results show that the occurrences of SEUs of SRAM tend to be increased as the cyclotron beam energy is increased 30 to 40MeV. But there is no quite difference between two patterns which initialize the SRAMs.

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