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Application of SEU imaging for analysis of device architecture using a 25 MeV/u ^{86}Kr ion microbeam at HIRFL

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ABSTRACT

The heavy-ion imaging of single event upset (SEU) in a flash-based field programmable gate array (FPGA) device was carried out for the first time at Heavy Ion Research Facility in Lanzhou (HIRFL). The three shift register chains with separated input and output configurations in device under test (DUT) were used to identify the corresponding logical area rapidly once an upset occurred. The logic units in DUT were partly configured in order to distinguish the registers in SEU images. Based on the above settings, the partial architecture of shift register chains in DUT was imaged by employing the microbeam of ^{86}Kr ion with energy of 25 MeV/u in air. The results showed that the physical distribution of registers in DUT had a high consistency with its logical arrangement by comparing SEU image with logic configuration in scanned area.

1. Introduction

The microbeam technology of heavy ions has been developed to investigate the basic mechanism of single event effects (SEE) occurred in electronic devices, due to its capability of irradiating the targets on the micro-scale and achieving the single-ion strike at the appointed place [1–6]. The patterns of sensitive regions in devices, for instance single event upset (SEU), single event latchup (SEL) and single event burnout (SEB), have been imaged by heavy-ion microbeam [7–12]. Simultaneously, the ion induced charge collection in p-n junctions or MOS transistors has been studied extensively by heavy-ion microbeam, which is crucial to understand the mechanism of charge collection and the evolution of single event transient (SET) [13–17]. However, up to now, the ion energies of microbeams used for SEE experiments are mainly from several MeV to hundreds of MeV [1–17]. From these microbeams, the linear energy transfer (LET) of light ion (He, C, O, F et al.) with enough ion projectile range in devices are usually lower to cause SEE in radiation-hardened devices. While, the ion ranges in devices of heavier ions (Cl, Kr, Xe, Au et al.) are mostly less than 30 μm which is requested ion range. Recently, the experiment results have demonstrated that the threshold ion ranges for accurate SEE measurement were larger than 60 μm, depending on the fabrication technology of device under test (DUT) [18]. In this experiment, we used the microbeam of ^{86}Kr ions with initial ion energy 25 MeV/u at Heavy Ion Research Facility in Lanzhou (HIRFL) [19,20]. The beam was extracted into air without significant beam spread and energy loss. With this feature, it is the first time of an experiment of SEE imaging by the high-energy heavy-ion microbeam at HIRFL.

The DUT is a commercial flash-based field programmable gate array (FPGA) device, the same type as that applied in a space project [21]. The constructed data acquisition and control systems were used to read the error data and the location coordinates of the beam spot [22,23]. As intended by design, the SEU sensitive areas of DUT's configured registers were imaged successfully in air. With analyzing the correlations between the SEU image and the logic configuration diagram, the physical distribution of registers in DUT was confirmed.

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2. Experimental method

2.1. DUT and test setup

The DUT in this study is a FPGA of Actel (ProASIC Plus APA600) manufactured by 220 nm flash-based CMOS process. The non-volatility and re-programmability of DUT are achieved by configuring the state of live-on-power-up in-system programming (ISP) flash switches [24]. The DUT has 21504 logic tiles (the logic unit), 126 k embedded RAM bits and 208 I/O blocks in total. Fig. 1 shows the brief logical architecture of DUT. It can be seen that the logic tiles are distributed in most areas of the chip. Each logic tile is able to be configured as a flip-flop, latch, or three-input/one-output logic function by programming the appropriate flash switches.

In this experiment, 90 percent logic tiles have been randomly configured as D-Flip-Flops (DFFs), which are equally divided into three shift register chains (Chain1, Chain2 and Chain3 shown in Fig. 1) according to the logical address from (1,5) to (224,100). Each shift register chain contains about 6500 DFFs with independent input and output circuits. The upset of DFFs induced by ion strike for each shift register chain is recorded by SEE test system independently with a special mark. For example, the recording data of an upset occurred in Chain 1 is marked with “A”. Similarly, “B” and “C” are corresponding to the upset data in Chain 2 and Chain 3, respectively. Through identifying the mark of upset data, we can quickly find which shift register chain the upset occurring in. After that the scanned area in logic address can be easily distinguished by judging its chain number. In addition, the embedded RAMs in DUT were not used for configuration in experiment. The DUT was de-capped before exposure to irradiation, as shown in Fig. 2, so that the ion is able to penetrate into the sensitive layer of transistors.

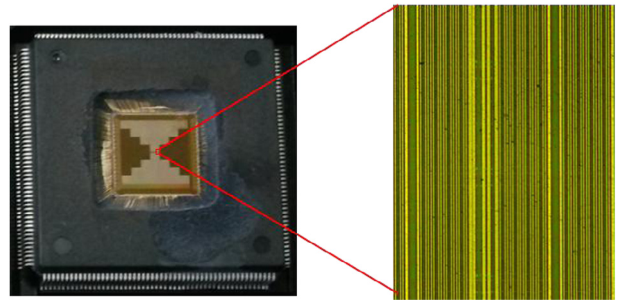

Fig. 2. The de-capped DUT and the target area scanned by heavy-ion microbeam.

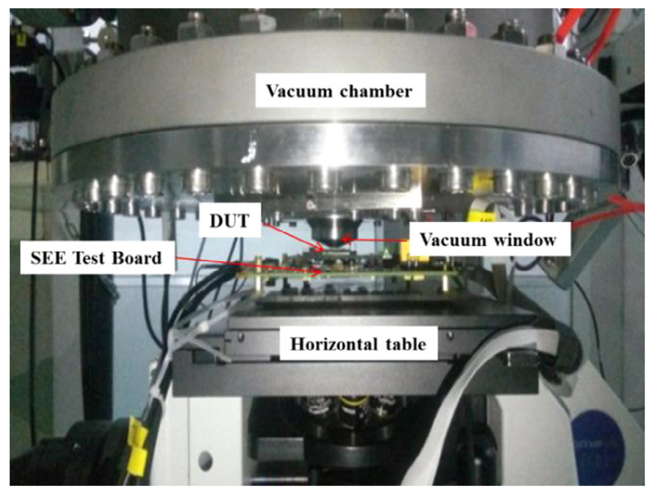

Fig. 3. The testing platform of heavy-ion microbeam at HIRFL.

2.2. The heavy-ion microbeam

The irradiation test was completed using the high-energy heavy-ion microbeam facility at HIRFL and the testing platform is shown in Fig. 3. The ^{86}Kr ions with energy of 25 MeV/u were delivered into air and focused to a 10 μm spot after passing through a 200 nm Si_3N_4 vacuum window and 1 mm air. The beam intensity used in irradiation test was about 10 ions/s. A channeltron installed in vacuum chamber was used to count the number of incident ions by collecting secondary electrons. The scanning magnets for X and Y directions were used to position an incident ion to the defined target area for irradiation. The detailed information about this microbeam line has been described in [19,20,22]. At the surface of DUT, the LET of ^{86}Kr ions is about 18.8 MeV·mg^{-1}·cm^{2} and its penetration depth is about 342.9 μm in silicon.

3. Results and discussion

3.1. SEU imaging of shift register chains

The heavy-ion microbeam was used to scan the surface of DUT in air. In the period of scanning, the DUT was fixed on a horizontal table and loaded with the blanket “1” data pattern. The step size of

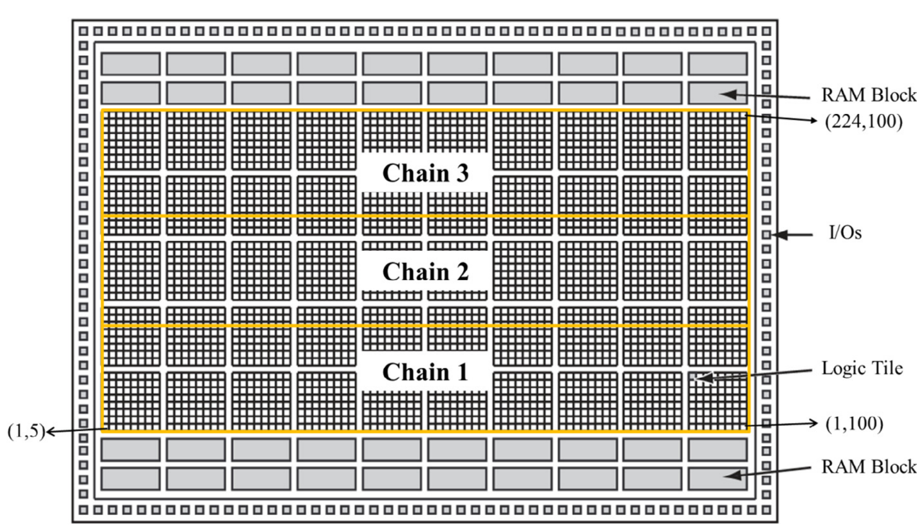

Fig. 1. The schematic diagram of the DUT’s logical architecture.

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