Radiation Hardness Evaluation Comparison Between Heavy-Ion and TPA Pulsed-Laser on 65nm SRAM

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I. INTRODUCTION

Pulsed-laser single-event effects (PL SEE) [1] have established themselves as a valuable tool for understanding the mechanisms of SEE phenomena in semiconductors. They are also recognized as an efficient alternative method for radiation hardness testing, for heavy-ion evaluations [2]. However, to accurately predict the radiation testing results, key parameters such as the thickness of the semiconductor substrate, material of the chip, the size of the beam and many other important factors must be carefully considered [3].

In this study, we conduct an in-depth analysis of results from heavy-ion and pulsed-laser can be matched. By performing precise SEE tests utilizing two photon absorption (TPA) mechanism [4], the research demonstrates how pulsed-laser can mimic the heavy-ion result and give us more insight of the error generation mechanisms.

II. EXPERIMENT

A. CMOS device selection reason

We conducted experiments using 65 nm CMOS technology SRAM, employing TPA mechanisms. While several studies focusing on heavy-ion and laser correlation primarily investigate BJT or bulky diodes, emphasizing the collection of charges, these devices are not particularly suitable for tests utilizing long-wavelength single photon absorption (SPA) [5] or highly localized charge with TPA. This is because the resulting ionization tracks from these laser-induced methods differ significantly from those generated by heavy-ion radiation. Several studies have been conducted to overcome this limitation, including research utilizing axicon lenses to elongate the beam shape for this purpose. Meanwhile, we focused on the possibility that this limitation may not significantly affect CMOS devices.

In the industry, CMOS devices are far more prevalent. The doping region thickness in typical CMOS structures is only about 10 to 100 nm, while the depletion region thickness ranges from 10 to 100 nm. Even when accounting for phenomena such as charge funneling, only a small portion of the entire ionized track will make effects on the CMOS device.

This highlights the importance of focusing more on CMOS devices in pulsed-laser SEE testing. CMOS better represent practical applications, and their dimensions make them very useful candidates for evaluating the effects of laser-induced ionization events to explain particle-induced events. By targeting such devices, a more accurate understanding of SEE phenomena in CMOS VLSI environments can be achieved.

B. Evaluation Method

Three DUTs for the CMOS SRAM were prepared, and each DUT contained a set of the front and back of the SRAM (Fig. 1). No significant differences in the results were observed between these chips in both laser and heavy-ion evaluation.

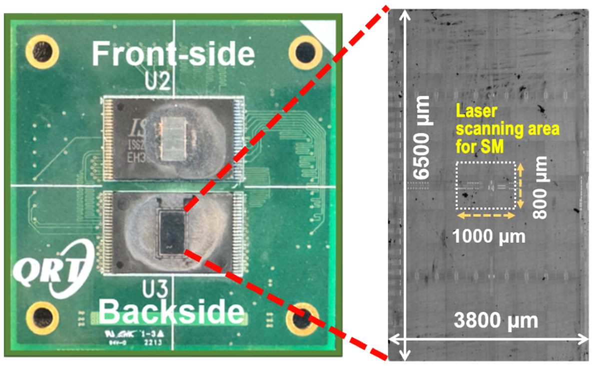

Fig. 1. DUT for laser and heavy-ion evaluation, Entire SRAM IR image for PL and heavy-ion evaluation with laser scanning area for SM

The entire chip size of the SRAM evaluated using an IR camera mounted on a laser is shown in Fig. 1, and the laser scanning area is also included to obtain a sensitive map (SM).

Three DUTs for the CMOS SRAM were prepared, and each DUT contained a set of the front and back of the SRAM (Fig. 2). No significant differences in the results were observed between these chips in both laser and heavy-ion evaluation. The entire chip size of the SRAM evaluated using an IR camera mounted on a laser is shown in Fig. 1, and the laser scanning area is also included to obtain a sensitive map (SM).

First, for the heavy-ion evaluation, we utilized the RADEF in Finland. The tests were performed using five types of ions: Ne, Ar, Fe, Kr, and Xe.

Second, to derive cross-sections comparable to the heavy-ion results, we performed uniform laser irradiation scans across the entire chip at varying depths. The same read-and-write operations employed during the heavy-ion tests were repeated to detect errors. To test out this memory device, the read operation was performed approximately once every 20 laser pulses to effectively capture error occurrences. Finally, by varying the laser injection depth, we scanned specific regions, including both the SRAM cells and peripheral circuit areas.

These comprehensive tests provided robust data for understanding the correlation between heavy-ion and laser-induced SEEs, as well as identifying depth-dependent sensitivity regions across the device.

III. RESULTS and DISCUSSION

A. Error rates' difference with different depth

Using the SEE analysis, we demonstrate how much shift in depths affects the result. From these results we can understand that the TPA test is believable since it is nearly identical to the heavy-ion result due to its long beam profile (compare to the sensitive area).

Fig. 2 illustrates the variations in test results for different depths. We can observe that the number of errors does not significantly change at a certain range of depths, which roughly matches the size of the laser spot length in depth (10−15μm). Depth of 10−15μm in air can be estimated to correspond to approximately 40−60μm in silicon substrate. This indicates that the effective size in depth of the laser beam is much longer compared to the effective charge sensitive volume depth on this device. It suggests that for CMOS devices like this SRAM, short ionized trace produced by laser irradiation compared to long ionized trace heavy ions will not make a significant difference on the test outcomes. This implies that differences in trace length may not substantially affect error behavior in such devices.

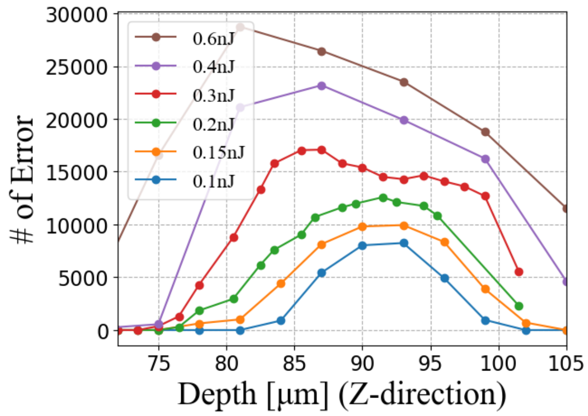

Fig. 2. Number of error under test performed in different depth and energy

$$\frac{dI}{dz} = -\alpha I - \beta I^2 \tag{1}$$

Fig. 3 compares the cross-section measured using pulsed-laser and heavy-ion testing. In the case of TPA lasers, the x-axis corresponding to LET is proportional to E_{LASER}^2 (laser-energy²) This is because, as referenced in a modified version of Beer-Lambert law (1), where it describes transferred energy by travel distance of light, I is light intensity, α and β are one-photon and two-photon absorption, the dominant energy transfer for TPA is proportional to the intensity square. A key observation is the similarity in their saturation value, indicating a strong correlation between the two testing methodologies despite the differences in energy deposition mechanisms.

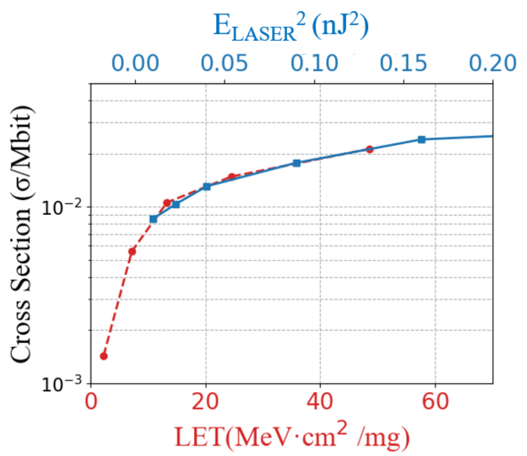

Fig. 3. Cross Section (σ/Mbit) of TPA laser (Blue-Slid) and heavy ion (Red-Dashed)

B. Sensitive map of 65 nm SRAM

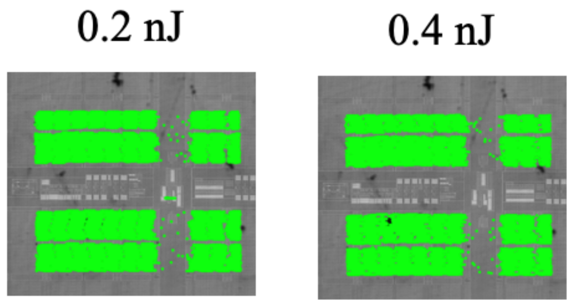

Fig. 4. Sensitive map of 65nm SRAM drawn for different Energy

Fig. 4 describes a sensitive map obtained by scanning a specific area of 65 nm SRAM with two different energies (0.2 nJ vs. 0.4 nJ). Through this figure, it was confirmed that most errors occurred in the cell area, not in the peripheral circuit. As can be seen in Fig. 2, the number of errors occurring differs depending on the energy, but it was observed that there was no significant difference in the sensitive map even though it was investigated with different energies.

When drawing a sensitive map, the scanning space was set to 3μm (~7μm²), but the cell size (~0.5μm²) was much smaller than the scanning space, so we understood that the location of error occurrence within the cell was not clearly displayed. Therefore, if the scanning space is further decreased, the resolution will be increased, allowing a clearer sensitive map to be drawn.

IV. CONCLUSION

This paper demonstrates how radiation hardness of CMOS devices can be alternatively tested using a pulsed-laser. Three different precise irradiation tests with pulsed-laser allowed us to deeply understand the error mechanism of the SRAM device.

By comparing pulsed-laser test result to heavy-ion test result, one promising finding of this study is that even without employing optical systems for longer beam profile, evaluations for heavy-ion SEE can still be effectively performed on many industrial semiconductor devices (CMOS) using a standard focused laser.

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