"Total Ionizing Dose Performance of SRAM-based FPGAs and supporting PROMs"

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I. Introduction

Field reprogrammable (SRAM-based) FPGAs are increasingly being utilized for satellite and deep space applications. The advantages of these types of devices in these applications are numerous and well known, including the ability to create standard multi-platform application modules, the ability to re-configure the architecture on orbit or in space in response to changing mission requirements, the ability to make last minute design changes and, of course, the reduced time from design to flight (and the consequent savings in low volume ASIC tooling costs). This paper describes the testing methodology used to evaluate these devices for their response to total ionizing dose stress and summarizes the TID performance of the XQR4000XL, the XQVR Virtex and VirtexE families, as well as the families of supporting configuration SPROMs (both OTP and ISP versions).

Total Ionizing Performance was examined over various dose ranges, spanning orbital simulation at dose rates as low as 0.0158 rads(Si)/sec to Method 1019.5 [3] compliant dose rates of 50-300 rads(Si)/sec. Testing included in-situ monitoring of key parameters (such as Icc and/or timing), as well as full functional, parametric and timing evaluation of devices both pre- and post-dose. In addition, at various cumulative dose steps, devices were temporarily removed for full functional and parametric testing using the vendor's comprehensive final test program(s). Variation in the performance of some of the referenced devices with dose rate is presented.

II. Testing Methodology

Testing was performed utilizing the GammaCell Cobalt 60 source at Lockheed-Martin in Sunnyvale California (primarily for the moderate dose rate testing) and the Cobalt 60 source at McClellan Air Force Base (for testing at both the low and high dose rates). Annealing at both room temperature and at 100°C was used as a test for the rebound phenomenon. These anneals resulted in degraded devices returning to pre-rad performance, indicating that trapped surface state effects were not observed. The results typically show marginally higher dose degradation threshold at lower dose rates, as might be expected given the annealing responses observed.

III. Devices Tested

Five families of SRAM-based FPGAs and supporting PROMs were tested. All were manufactured in CMOS technologies. The device families included:

XQR4xxxXL, an SRAM-based 3.3v FPGA available in 13,000 to 62,000 gate versions

XQVRxxx, an SRAM-based 2.5v FPGA (Virtex ™)available in 300,000 to 1,000,000 gate versions

XCVxxxE, an SRAM-based 1.8v FPGA (VirtexE ™)available in 70,000 to 4,000,000 gate versions

XQR1701L, an OTP PROM with up to 1,000,000 bit density

XQR1804, ISP Flash-based PROM with up to 4,000,000 bit density

IV. Process Descriptions

XQR4xxxXL:

Material: <1-0-0> 20ohm-cm p-type epitaxial layer on highly doped substrate

Gate Oxide: SiO_2, nominal 65A

Gate Width: 0.35μM defined

Isolation: Isoplanar Field 7,500A nom

Operating Voltage: 3.3v

XQVRxxx:

Material: <1-0-0> 20ohm-cm p-type epitaxial layer on highly doped substrate

Gate Oxide: SiO_2, nominal 45/65A

Gate Width: 0.25/0.35μM defined

Isolation: Shallow Trench 7,500A nom

Foundry: UMC Group

Operating voltage: 2.5v

XQVRxxxE:

Material: <1-0-0> 20ohm-cm p-type

Gate Oxide: SiO_2, nominal 32/65A

Gate Width: 0.18/0.34μM defined

Isolation: Shallow Trench, 6,500A nom

Foundry: UMC Group

Operating voltage: 1.8v

XQ17xxL:

Material: <1-0-0> 18ohm-cm p-type

Gate Oxide: SiO_2, nominal 80A, UV

Gate Width: 0.60μM defined

Isolation: Isoplanar Field 9,000A nom

Foundry: Seiko

Operating Voltage: 3.3v

XQR18xx:

Material: <1-0-0> 20ohm-cm p-type epitaxial layer on highly doped substrate

Gate Oxide: SiO_2, nominal 65A, Flash

Gate Width: 0.35μM defined

Isolation: Trench 7,500A nom

Foundry: UMC Group

Operating Voltage: 2.5v

V. Radiation Test Results:

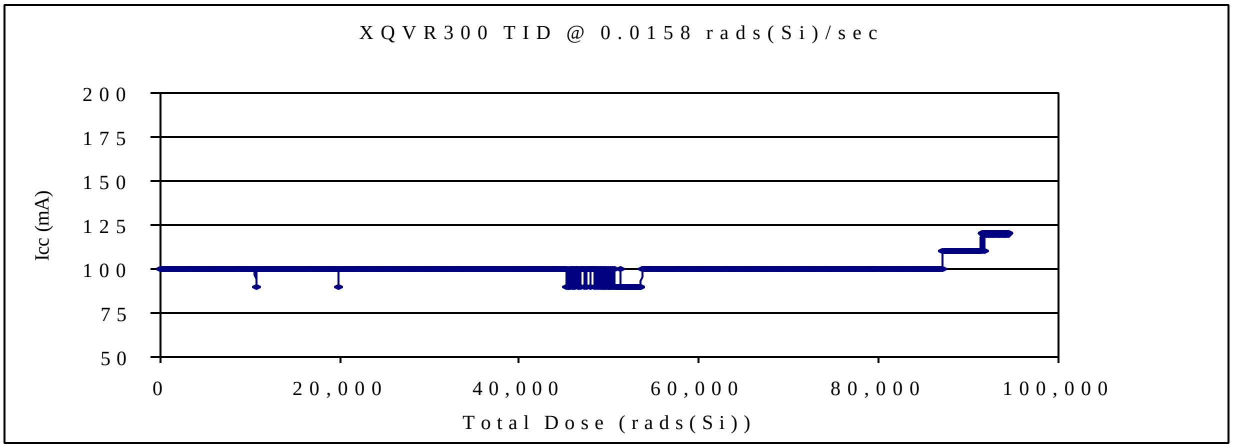
As would be expected from the thin gate oxides contained in these technologies, little or no parametric shift was noted during any of the radiation exposures. As seen in figure 2, the change in Tilo (a benchmark timing parameter monitored in-situ along with Icc) was negligible over the entire dose range. Similarly, testing for Vih, Voh, Vil, Vol, and the other numerous timing paths covered in the production test programs indicated that the devices stayed within specification for all dose ranges tested.

However, in the post radiation leakage behavior, a notable difference was seen between the Isoplanar and Trench isolated technologies tested. The commercial field oxide present in the Isoplanar isolated technologies was not hard, exhibiting increased leakage with dose at total dose as low as 30-40 krad(Si). Indeed, increased leakage to a value of 2x the pre-rad specification , not parametric shift nor functional failure, was what determined the total dose specification for both the XQR4xxxXL and the XQ17xxL technologies.

VI. Anneal Properties

Post radiation anneal was performed on all devices at both room temperature and at 100°C, looking for rebound behavior. None was seen. Elders effects were also not noted despite radiation dose rates varying approximately 4 orders of magnitude (see figure 1). Dose rate varied from extremely lose dose (simulating orbital rates with dose rates as low as 0.01 rads(Si)/sec to Method 1019 compliant dose rates of 50-300 rads(Si)/sec.

Similar results have been reported in the past for very low dose rate irradiation of FPGAs by D. Gingrich.[4]



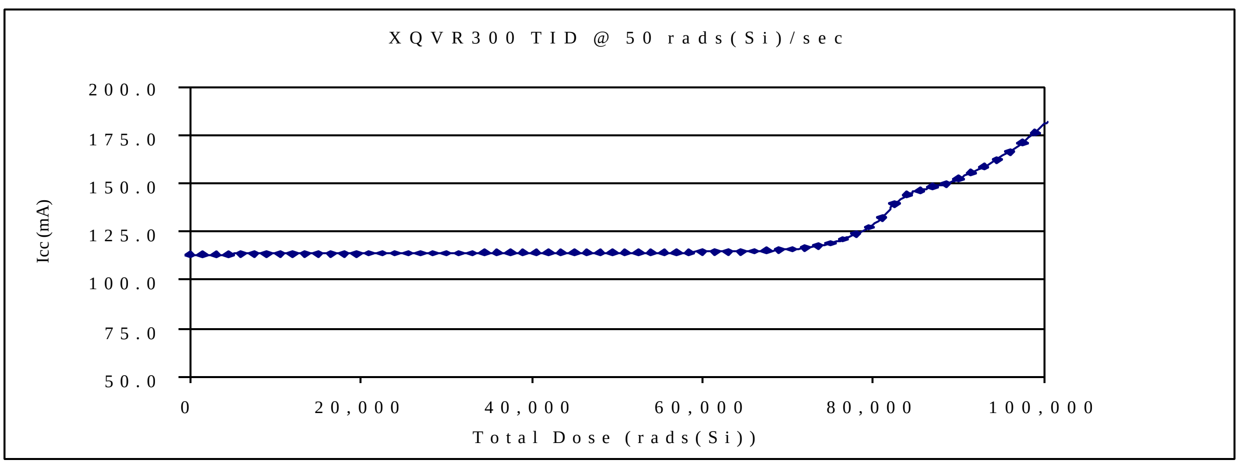


Figure 1. A comparison of the effect of dose rate on the leakage performance of a 0.25µM FPGA technology utilizing Trench Isolation

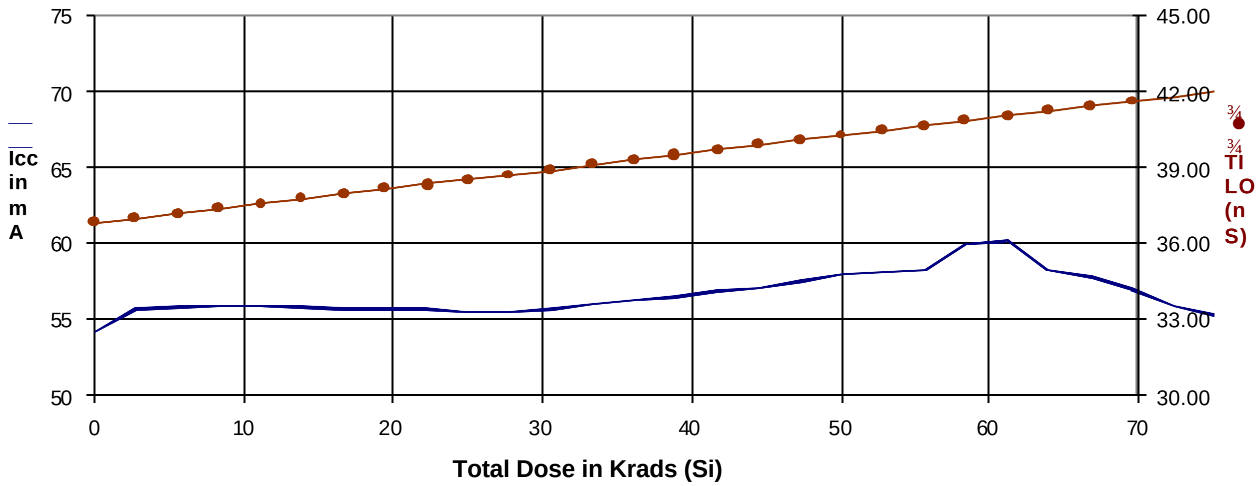


Figure 2. The radiation performance of a 0.18μM FPGA technology utilizing Trench Isolation

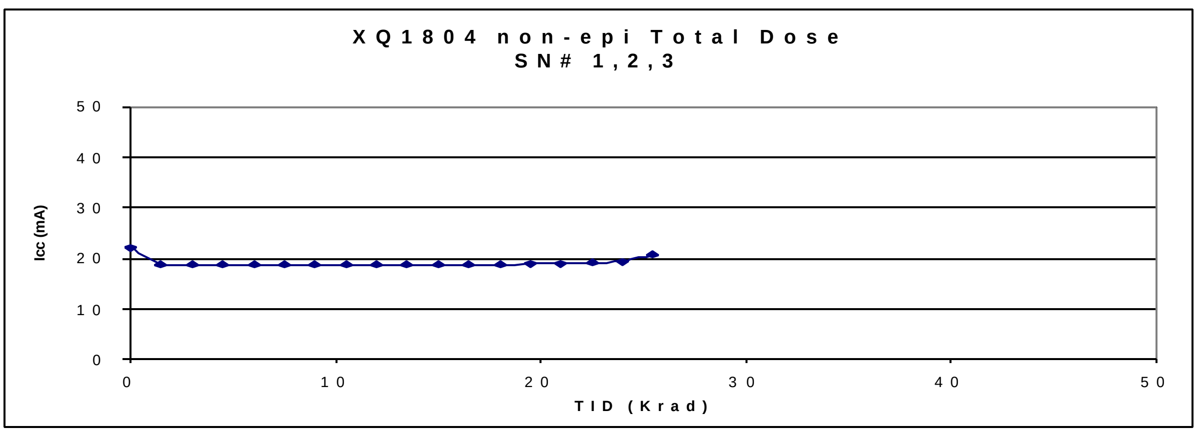


Figure 3. The radiation performance of a 0.35μMFlash ISP PROM utilizing Trench Isolation

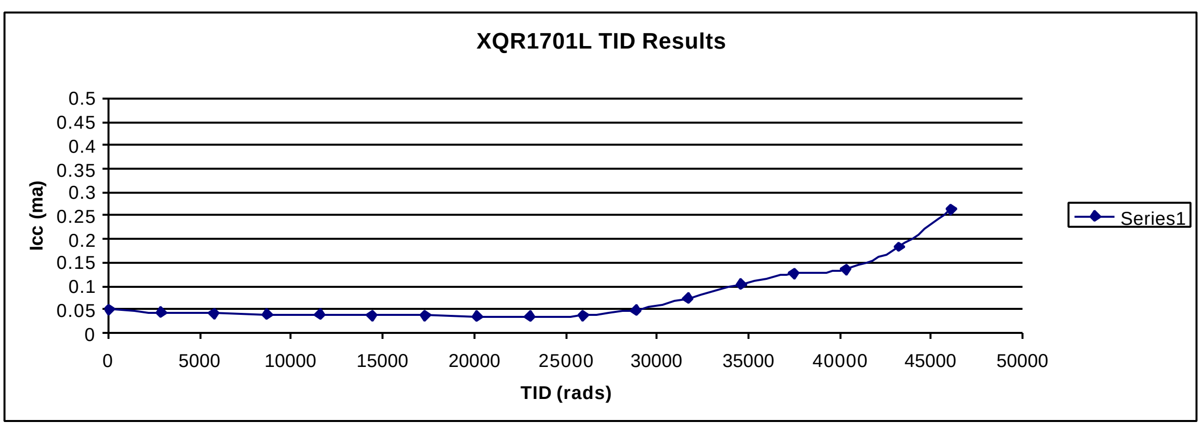


Figure 4. The radiation performance of a 0.65μM OSP PROM utilizing Isoplanar Isolation

VII. Conclusions/Recommendations

The results of this total dose radiation characterization of SRAM-based FPGAs and supporting PROMs has shown the suitability of these COTs devices for many orbital applications. Somewhat higher dose degradation thresholds at lower dose rates were seen, as might be expected given the annealing response observed during the room temperature and elevated temperature anneal tests. Total dose specifications were established for the following products based on this study:

XQR4xxxXL, SRAM-based 3.3v FPGA available in 13,000 to 62,000 gate versions usable in applications up to 60krads(Si).

XQVRxxx, SRAM-based 2.5v FPGA (Virtex ™)available in 300,000 to 1,000,000 gate versions usable in applications up to 100krads(Si).

XCVxxxE, SRAM-based 1.8v FPGA (VirtexE ™)available in 70,000 to 4,000,000 gate versions usable in applications up to 100krads(Si).

XQR1701L, OTP PROM with up to 1,000,000 bit density usable in applications up to 60 krads(Si).

XQR1804, ISP PROM with up to 4,000,000 bit density usable in applications up to 60 krads(Si).

In addition, several of these devices are available fabricated on epitaxial substrates, and are immune to Single Event Latch.

VIII. Acknowledgements

The authors wish to thank Teratum Lowchareonkul, Rommel Deguzman and An Tran for meticulously taking the TID data, and to Earl Fuller and Dr. Gary Lum for their advice and support.

IX. References

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3. MIL-STD-883, Method 1019.5, December 1997
4. D. Gingrich, private communication.