2006 – 2010: Four Years at the Low Noise Underground Laboratory of Rustrel

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ABSTRACT

Alpha contamination is become a major concern in ICs. To qualify packaging solutions for commercial, industrial, and aerospace/defense components, a program in place since 2006 is updated. The chosen methodology associates the use of real time testing in altitude and underground environments. Experiments are performed on Xilinx FPGAs. Goals, experiment design, statistical confidence, results are analyzed and discussed.

I. INTRODUCTION

From the late 1970s, the Soft Error Rate (SER) due to alpha particles had serious consequences for several companies. With decreasing critical charge, problems created by radioactive impurities and cosmic radiation increase [1] and the SER due to alpha particles yet presents a major reliability concern to logic processes. Solutions exist to limit alpha contamination but are often costly. In [2] the cost is detailed on what constitutes a recall of contaminated components. Prevention becomes critical to the success of a semiconductor company. Creating and maintaining the proper procedures for assembling products with the proper materials and performing the testing required is mandatory to a successful soft error effects mitigation strategy.

Several works have shown the use of an underground site to separate the component of the SER caused by cosmic rays from that caused by on-chip radioactive sources of alpha particles [3-5]. This is the chosen methodology presented here for the Rosetta experiment of Xilinx to detect contamination. Indeed, for more than four years, Rosetta has been operating at the Low Noise Underground Laboratory of Rustrel (LSBB) in order to extract any potential alpha contamination contribution to SER from 200 devices under test, in a place devoid of any radiation sources. By observing other arrays at altitude, and comparing their upsets rates, one can extract the steady state (non-altitude dependent upsets) from the altitude dependent upsets, and compare the steady state rate from atmospheric testing, to the results from LSBB.

In this paper, the updated data from LSBB is presented and compared with the same information as extracted from the atmospheric arrays at differing altitudes [6]. The two methods are compared.

II. UPDATED DATA FOR 130 NM TECHNOLOGY

Underground data from LSBB

The first device installed at LSBB was the 130nm xc2vp50 FGPA. The number of components under test was decided to be 200 units (two separate arrays of 100 components each). Because there are so different, configuration memory and Block RAM (BRAM) memory are studied separately. The two arrays comprise 13.4512 Megabits per device configuration and 4.276 Megabits per device BRAM so 2,692 Megabits of configuration and 855 Megabits of BRAM under test. Xilinx devices used in that work have been fabricated not to be sensitive to thermal neutrons and have been proven to be immune to neutrons with energies in the thermal range and below. Thus, as devices are in a place devoid of cosmic rays, alpha contamination would be the most probable cause of upsets (only cause), if upsets do occur.

The 200 components have been running at LSBB [8-9] for 5.86 million hours as of March 23, 2010. There have been *8 configuration* bit upsets, and *1 BRAM* upset. This translates to 101 FIT/Mb from 44 to 200 FIT/Mb for a 95% confidence interval (CI) for the configuration, and 40 FIT/Mb from 1 to 222 FIT/Mb for a similar 95% CI for the BRAM.

The CI is large, as the number of upsets is small. Few upsets from alphas is a good result for the product, but it is somewhat frustrating for the experimenter, as the results could be very different if we could spend more time waiting. The goal is to be sure the assembly methods did not use the wrong materials, so the benefit of the test may not seem apparent; however, if contamination was present, the expected upset rate would be from 10 to 100 times as great. Such an upset rate is easily recognized in a very short time under test at LSBB.

Atmospheric Results to Date

Atmospheric testing [10-11] was performed on 200 devices each at White Mountain, San Jose (California), Albuquerque (New Mexico), Pic de Bure and University Aix-Marseille (France). 350 configuration upsets have occurred since 2003. To find how many of these upsets are due to alpha particle in the packaging and assembly, and how many of these are from neutrons (or protons), the sites are separately modeled for both an atmospheric rate which depends on altitude, latitude and longitude, and a constant background rate from packaging.

Unfortunately, there is no single solution to the problem, as we have more known than unknown variables. One can do a “best fit” by assuming pairs of values, atmospheric and alpha packaging FIT/Mb rates and minimizing the error using a least squares method. By minimizing the error, a value of 369 FIT/Mb is arrived at for the atmospheric contribution and a value of 70 FIT/Mb for the alpha particles from packaging. This one best fit is for 337 atmospheric upsets and 13 alpha upsets. Thus the 70 FIT/Mb prediction is from 37 to 119 FIT/Mb for a 95% CI. Comparing this result to the LSBB result of 101 FIT/Mb from 44 to 200 FIT/Mb, we see a plausible agreement between these two methods. To get a better answer, more upsets are required.

Given that the intent was to prove there were no additional alphas introduced from using the wrong materials, the experiments are both successful. The manufacturing flow utilizes assembly houses with dedicated ultra-low alpha materials and machinery, with all lots of materials requiring both a manufacturing certificate of compliance from the supplier of the raw materials (solder bumps and under-fill for flip chip devices, or molding compounds for wire bond devices), and a re-test of the materials before their issuance to the assembly house stockroom.

III. 65NM TECHNOLOGY NODE

Virtex 5 devices (one array of 100) have been at LSBB since June, 2007. This array has more configuration and BRAM bits than the two previous Virtex II Pro arrays. Again, the results are such that with only *4 configuration* upsets, and *1 BRAM* upset, we again show we have no contamination, but actual determination with any high degree of confidence of the actual alpha SER is again difficult due to the small number of upsets recorded. The uncertainty for a 95% CI is from +250% to -73%.

Data from Virtex 5 devices in San Jose as compared to the higher elevations is also insufficient to provide any extrapolation of the alpha upset rate with any certainty: here too the uncertainty is +200/-60%.

IV. 40/45NM TECHNOLOGY NODE

Virtex 5 (40nm) and Spartan 6 (45nm) are both in production, and being supplied to customers at this time. Spartan 6 is fabricated for Xilinx by Samsung, and two arrays of 100 devices have accumulated more than ½ million device hours in San Jose. These parts were also tested per the JEDEC89A [12] Thorium Foil method, and based on certificates of compliance counts of alpha rates, and testing of the raw materials, the expected typical alpha upset rate is estimated to be 135 FIT/Mb (95% CI, +100/-50%). Considering that the Los Alamos LANSCE neutron test results predict 129 FIT Mb (95% CI, +20/-20%) at sea level for New York City (again per JEDED89A), Xilinx has decided to publish the alpha upset rates starting with the 40/45nm technology nodes.

Virtex 6 is a flip chip device. It cannot be tested by the Thorium foil method, so one array of 10 devices is scheduled to go to LSBB. Based on previous 65nm data and extrapolating, we believe this device will have an alpha upset rate roughly ½ that of the sea level upset rate. Presently LANSCE data for Virtex 6 indicates a sea level SER of 163 FIT/Mb (95% CI, +20/-20%), and predictions are that the alpha upset rate will be typically 80 FIT/Mb (95% CI is greater than that of the Virtex 5 estimates, plus errors as a result of the predictions). The results of all testing/predictions are published quarterly [13].

V. DISCUSSION

The authors have presented their results from 7 years of atmospheric testing at different altitudes, alongside the 4 years of results from the underground testing. The two datasets agree, within the confidence intervals defined by the number of events. For the 130nm, in both cases, the actual number of upsets from alpha particles is low (~4% of total upsets are potentially alpha upsets), which is a validation of the materials, and processes and procedures used to produce the devices. Unfortunately, knowing the values to a higher confidence level either means more megabits must be tested (more devices) or, more time must pass in order to accumulate more upsets. In no case it is possible to examine individual lots of devices, so the assembly flow must be strictly controlled, and inspected for compliance frequently. The problem of controlling alpha generating materials is still under study, and developments in metrology are needed to measure the extremely low level of contamination present [14-16] for better control of the process, and confidence in the assembled product quality.

VI. CONCLUSION

The authors have collaborated to develop a process to qualify how the substrate packages are verified so as not to have any sources of alpha particle contamination. It appears that the association of the Rosetta experiment and the LSBB provides an ideal testing plan to get a complete evaluation of the devices sensitivity in natural environment in a reasonably short period of time. In less than 6 months, evidence of any contamination is apparent. By testing the components in LSBB in its unique environment, it is possible to check if the components are contaminated or not. By also utilizing the testing of arrays at different altitudes, the alpha upset rate prediction may be verified, at least to within the CI defined by the number of events recorded. Atmospheric testing does not provide sufficient confidence in a short period of time, as time has to be spent at sea level and also at altitudes, requiring more arrays and more time as compared to having one array at LSBB, and as few as two arrays at altitude.

In conclusion, discovery of a problem with the materials is assured by such testing, but determining the actual rate with any precision is not possible, neither with the atmospheric arrays, nor with the underground arrays, without testing many times as many devices.

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