Radiation Testing, Characterization and Qualification Challenges for Modern Microelectronics and Photonics Devices and Technologies

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Outline of Presentation

• Introduction
• Single Event Effect (SEE) Testing and Complex Device Packages
  - Packaging material
  - Thermal control
  - Particle interarrival angle
    • The direction the particle enters the device
• SEE Sensitive Devices
  - Optical devices and the increased sensitivity of CMOS
    • Changing the way we test and predict space performance
• The Impact of System-on-a-Chip (SOC) Device Complexity
  - Example: Field Programmable Gate Array (FPGA) complexity
  - Fault isolation
  - Data interpretation
  - Statistical Data Gathering
  - Total ionizing dose (TID) test logistics
• Considerations

Disclaimer:
This is not a comprehensive talk, but about considerations and thought processes.

To be presented by Kenneth A. LaBel at the Government Microcircuit Applications & Critical Technology Conference (GOMAC), March 17-20, 2008, Las Vegas, NV.
Introduction

- At GOMAC 2007, we discussed a selection of the challenges for radiation testing of modern semiconductor devices focusing on state-of-the-art CMOS technologies.
- In this presentation, we extend this discussion focusing on
  - Device packaging,
  - Evolving physical single event upset (SEU) mechanisms
  - Device complexity,
  - The underlying goal is intended to provoke thought for understanding the limitations and interpretation of radiation testing results.

Device Packaging: What's the Issue?

- Complex silicon devices have fed the revolution for complex device packages
  - >1000 pin area arrays
  - Multi-GHz operating frequencies
  - Complex thermal control
- So, how does this impact SEE testing?
  - Space-based particle environment is more energetic than the typical ground-based heavy ion SEE test facility
  - Need to remove sufficient package material to allow particle to impinge on the sensitive circuits
  - Test ions are unidirectional; space is omnidirectional
**Device Package and Particle Penetration**

Example: Flip-Chip Ball Grid Array (FBGA)

Must remove sufficient amount of material to penetrate to backside of die AND penetrate to sensitive volumes

Heavy Ion Beam Won't Penetrate Through Balls
= Can Not irradiate Frontside of Die

**But wait!**

High speed, high power, large ball count
= Big cooler required on the topside!

Need to consider alternate cooling methods:
- external fans, TECs, spray cooling
- Real limitation for test facilities in a vacuum!

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Simulating the Space Environment

- As pointed out, heavy ion test facilities use a unidirectional beam to simulate the space environment
  - Part is usually tilted to simulate angular space effects
- The underlying assumption is often false

![Graph showing device cross-section vs. proton angle of incidence](image)

Challenges
- Tilting part =
  - Increasing path through device (ion range limitation)
  - Asymmetry of transistors =
  - Test in both tilt axes PLUS rotation
- Backside/frontside =
  -Impossible to perform without major effort
- Modeling =
  - Hard to model w/o detailed technology/circuit knowledge

Are We Approaching a Meltdown?

- With scaling, increased speed, reduced Vdd, electrical margins have eroded decreasing the amount of charge required to cause an SEU
  - Optical devices are long known to be sensitive to direct ionization from protons
  - Rodbell, et al have presented proton direct ionization on CMOS devices

![Graph showing proton energy vs. cross-section in cm²](image)

Energy and angular Proton effects in an optocoupler - an indication of direct ionization

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**Challenges for proton SEE testing**
- Increased angular tests
- Lower and higher proton energies may be required
- Space prediction tools need updating to accommodate

SOC: Are We Doomed to the Unknown?

- Using an FPGA as an example, the block diagram looks deceptively simple
  - Silicon with logic modules, I/O, and routing
- So, what's the problem?
  - It's not just logic, it's
    - Logic (user configurable)
    - Processors
    - Gbps I/O
    - Other embedded IP, and
  - It can store the configuration for this SOC internally
    - This can be SRAM-like for reconfigurability
SOC: Radiation Implications

- How does this highly multifunctional device relate to SEE test and radiation performance?
  - Myriad of potential failure modes can occur
    - Change of configuration memory,
    - State machine errors,
    - Logic errors related to
      - Cell spacing (multi-bit upsets or MBUs) or
      - Operating speed (SEU event may last longer than one clock period),
    - Software interrupts, and more
  - In the following charts, we will consider four implications to testing a SRAM-like FPGA with embedded IP.

SOC: SEE Test Issue 1 – Fault Isolation

- Fault isolation (root cause)
  - Understanding what within the device is causing an event.
  - Hitting a specific transistor with an ion and observing effect.
  - The current SEE test facilities are ill-equipped for this purpose
    - Higher energy microbeam facilities where you can focus a particle to a small spot size to identify what is upsetting as well as penetrating through layers of silicon would be advantageous
    - Other tools, such as two photon absorption (TPA) lasers may also be useful
  - Beware: SOCs are usually in packages such as FBGAs and the challenges discussed earlier play into this discussion as well.
  - Device complexity does not lead to full silicon testability
    - Errors can be masked (i.e., hit to configuration may mask state machine errors)
    - Hidden registers
    - Complete testing, as discussed in 2007, is impossible.

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SOC: SEE Test Issue 2 – Data Interpretation

- At GOMAC 2007, we discussed the fallacy of complete device test coverage
  - With the vast array of user configurability, operating modes, speed of operation, and so forth, it is impossible to cover all the bases for each potential application of the device.
- What does this imply? Is all existing SOC test data useless?
  - A data point is just a data point
    - An existing data point is a STARTING point
    - Testing has to take place using all designs, functions, speeds, etc., of the actual application
  - Databases are useful, but complete understanding of how someone else's test was performed is difficult

SOC: SEE Test Issue 3 – Statistical Data Gathering

- In many FPGAs, the susceptibility of the configuration storage memory may be the "big particle target" overshadowing physically smaller and/or less susceptible portions of the device.
  - What may happen is that SEUs may occur during a test in these "smaller" circuit portions, but are lost when the "bigger" area is upset.
- In addition, if we observe an anomaly on a specific output, where could it come from?
  - I/O error
  - Logic error
  - Configuration error
  - Processor fault
  - Latent error, ...
  
A radiation test should be designed to bound the worst-case.

- However, determining what is worst-case is suspect

- Implication: application specific testing is the norm for SOC devices
  - Change in any application will affect the radiation results
SOC: TID Test – Parametric Data Gathering

- Given the speed, logic size, IP, etc. in these devices, trying to reproduce the manufacturers detailed test vectors and parametric measurements would require years and years of effort as well as millions of dollars.
- Simplified tests are often undertaken looking primarily at functional go/no-go and limited parameters.
- These data must be viewed in the limited regard in which they were taken.
- Working with the device manufacturer and using their test system should be considered for these complex devices.

Considerations

- We have discussed just a few of the emerging challenges related to modern radiation effects testing
  - Device packaging and complexity
  - Emerging SEU mechanism concerns
- These are just the tip of the iceberg and should not be viewed as a comprehensive discussion
- The final thought is that radiation data must be very carefully scrutinized to understand what the data does or does not contain
  - In addition, the application-specific orientation of radiation data continues to grow
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  - Data Interpretation
  - Statistical Data Gathering
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