Correlation of Pulsed Laser and Heavy Ion Test Results for NAND Flash Memory

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1. Dell Services Federal Government;
2. MEI Technologies;
3. NRL;
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To be presented by Timothy Oldham at the NASA Electronic Parts and Packaging Program (NEPP) Electronics Technology Workshop (ETW), NASA Goddard Space Flight Center in Greenbelt, MD, June 11-13, 2012 and published on nepp.nasa.gov.

Outline

- Introduction/ Background
- Broad Beam Heavy Ion Results
- Initial Laser and Milli-Beam^{TM} Results
- Follow-up Laser Tests
- Discussion
- Conclusions

Broad Beam Heavy Ion Results

- **On 38 beam runs, observed 52 high current events**
- **None less than 1 sec in duration, most 10's of seconds, or minutes**
- **48 of 52 had stair-step structure characteristic of LSEL (Localized SEL)—changes in DC level**
- **Remaining four events appeared to have been due to bus contention**
- **Neither LSEL nor bus contention is unique to flash memory—numerous examples in other technologies**

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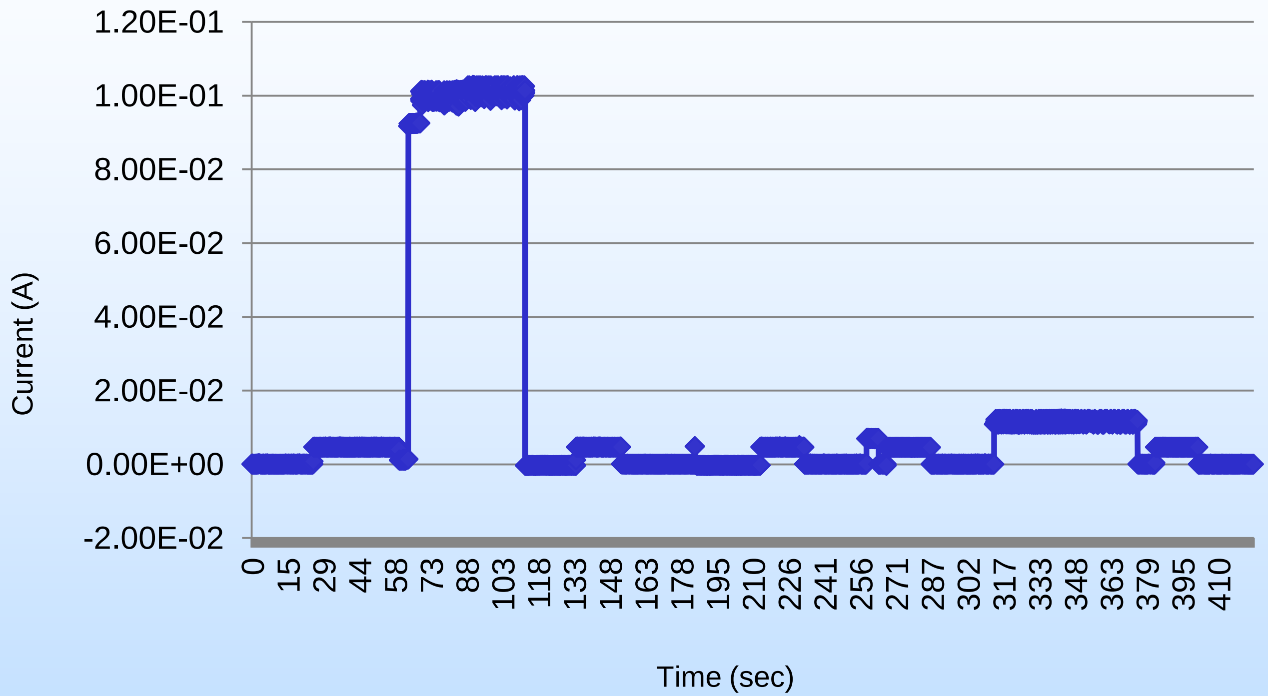
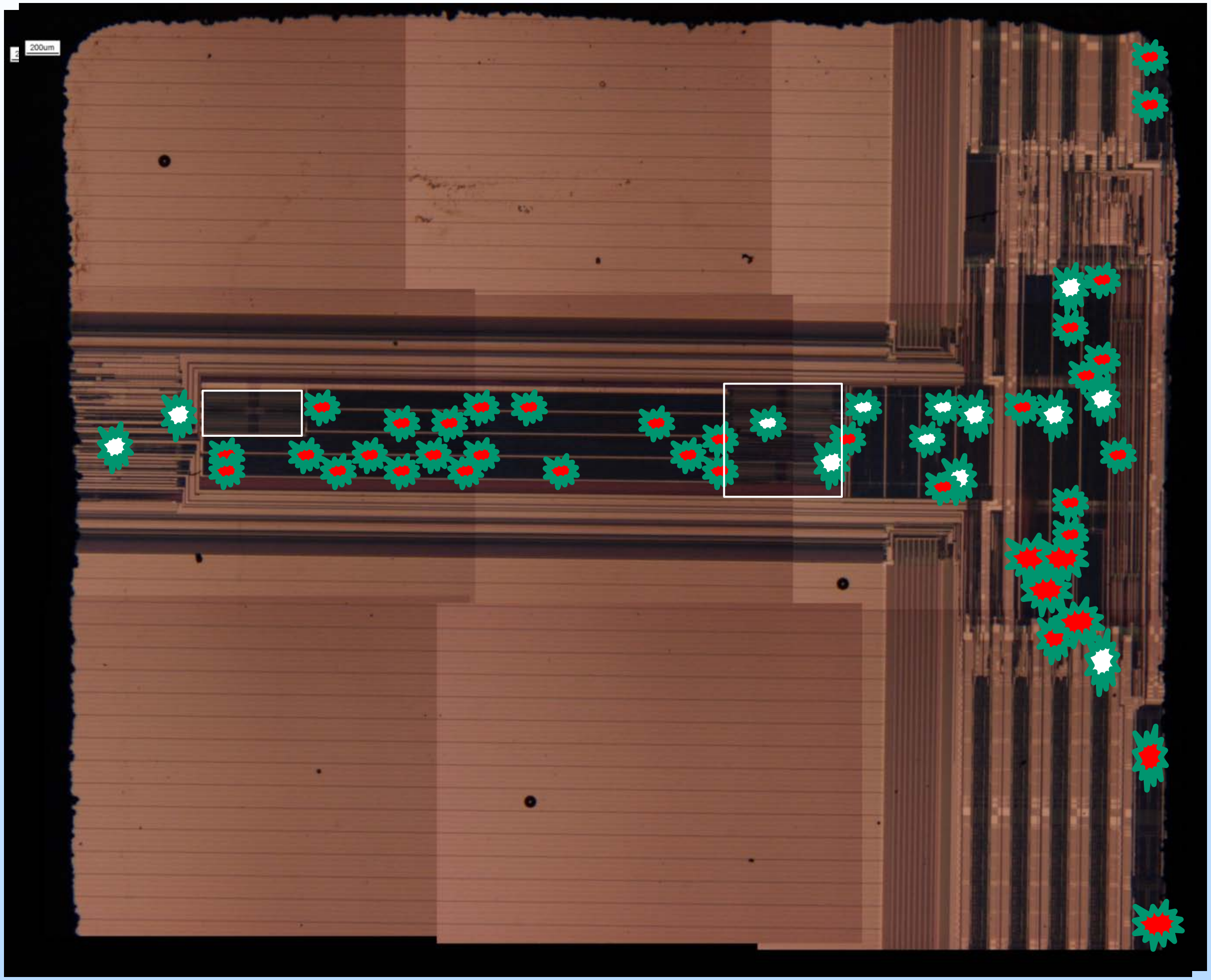
Current History for Heavy Ion Exposure



Micron DUT 20, Run 13, Au, Dyn R/E/W, Watchdog, OK after reset

Laser Test Results—2011

20X lens, 0.0 Attenuation

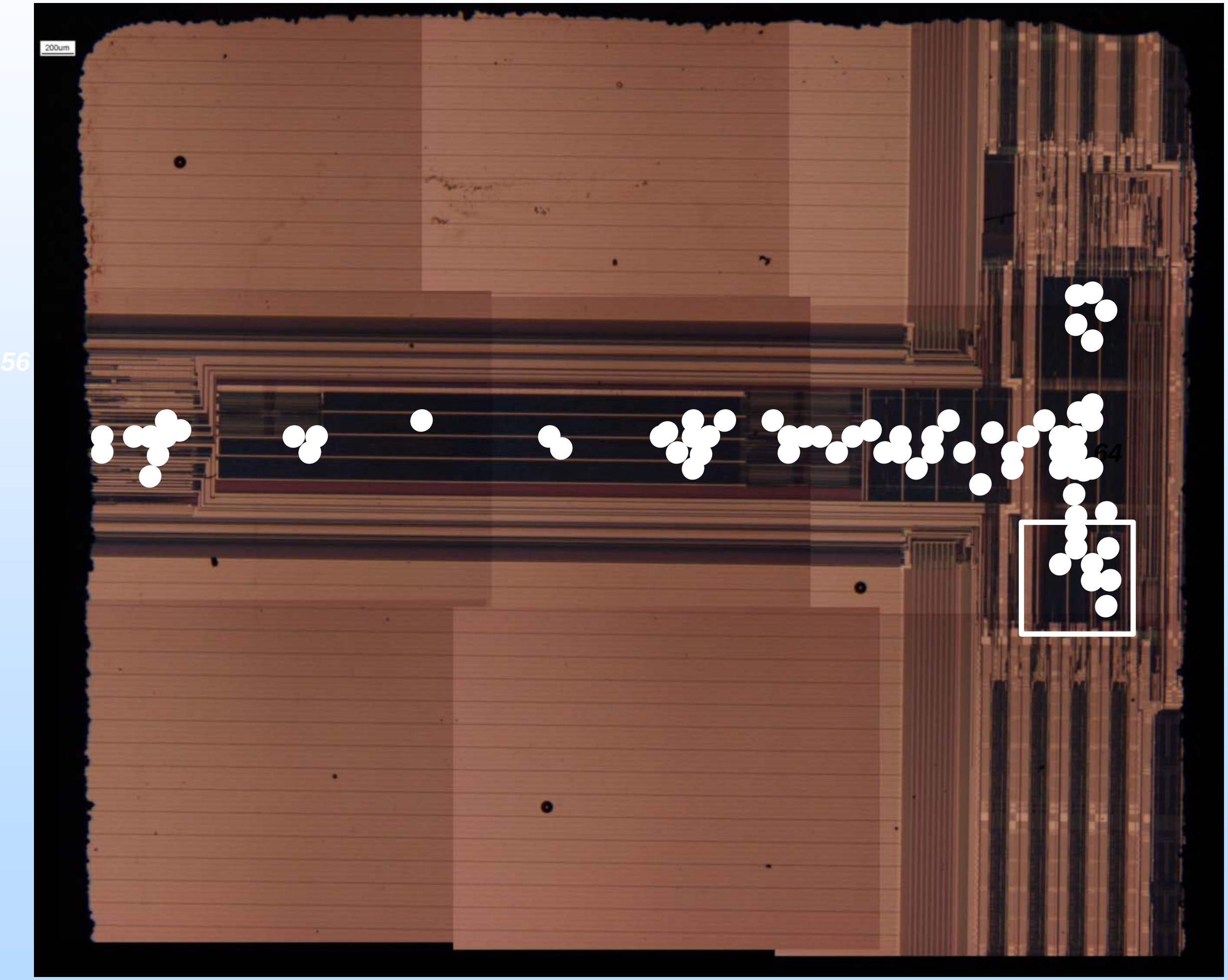


Micron 4G NAND—Dynamic Read

Initial Laser Experiment (2011)

- **Front surface, single photon experiment, 590 nm (green) light, multiple metal layers**
- **Total of 50 Single Event Functional Interrupts (SEFIs)**
- **37 events (red spots)—high current, 80 mA or more, DUT reset cleared high current in every case**
- **13 events (white spots)—functional interrupt, without high current, many required power cycle to restore normal operation**

Milli-Beam^{TM} SEFI Locations



Milli-Beam™ Test Results

- Over 800 beam runs with Xe ions (LET~60)
- Fluence was always 10^7 ions/cm^2, but exposed area was only 100 µm by 100 µm (10^{-4} cm^2)
- About 125 SEFIs overall, but none with current > 20 mA
- Current signatures qualitatively different than in broad beam heavy ion tests
- SEFI locations similar to laser tests, but current signatures different

Planned Laser Experiment

- $E (pJ) = A (10/10^{OD}) * (1.424)$
- **Optical density = 0, 0.3, 0.5, 0.6, or 1.0**
- LET = 3.05 * E(pJ) (NRL Opinion)
- LET = 14.7 * E(pJ) (Sandia Opinion)

  J.R. Schwank et al., IEEE TNS, 58, 2968 (2011).
- Empirical correction—fraction of light reaching Si surface

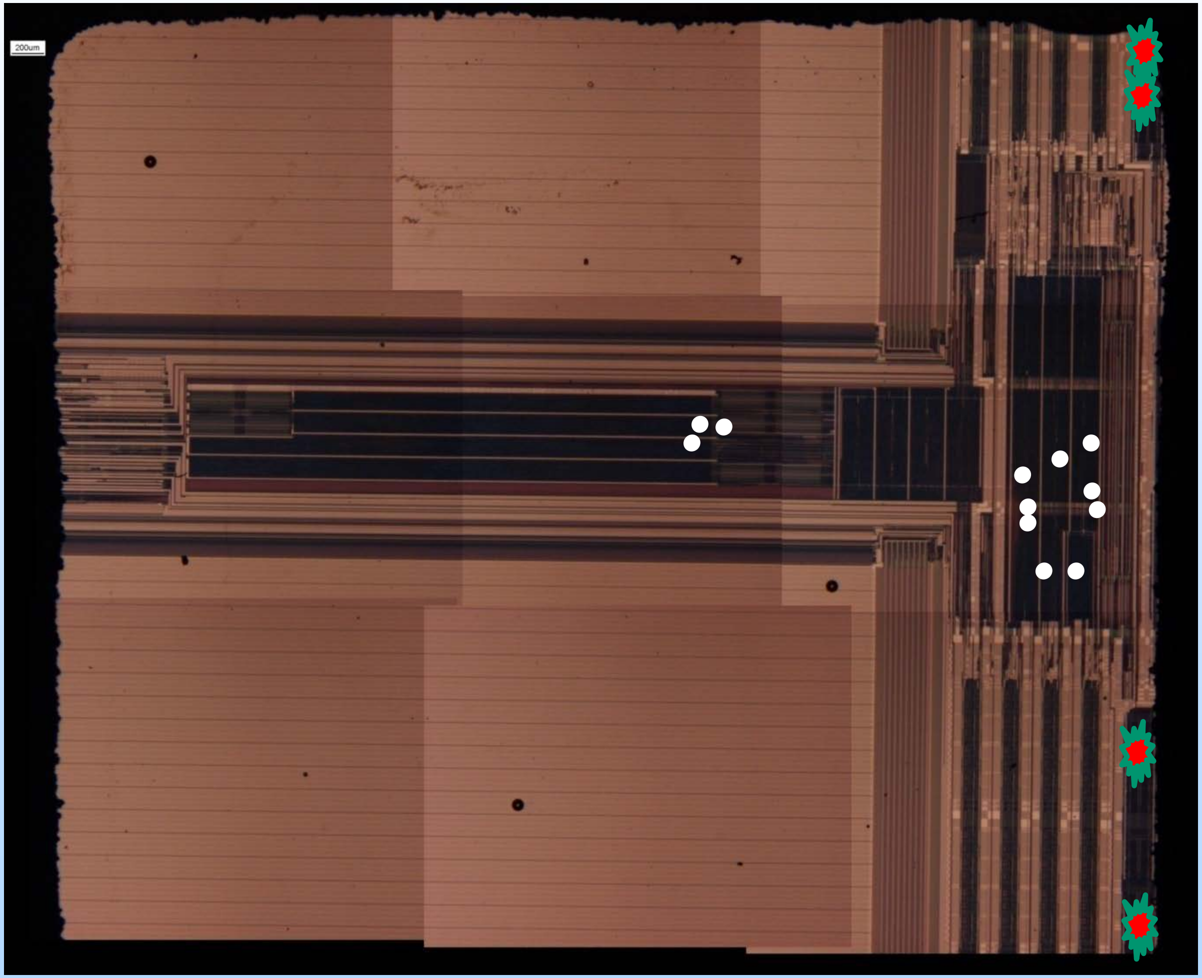
Laser Effective LET

Attenuator OD	E(pJ)	Effective LET
0.0	228	695
0.3	114	347
0.5	72	220
0.6	57	175
1.0	22.8	69.5

- **Shape and volume of energy deposition volume different for ions and laser**
- **For front surface laser illumination, much of light does not penetrate metal**

Micron 4G NAND—Dynamic Read/R/E/W

2012 Experiment 20X lens – OD = 0.0



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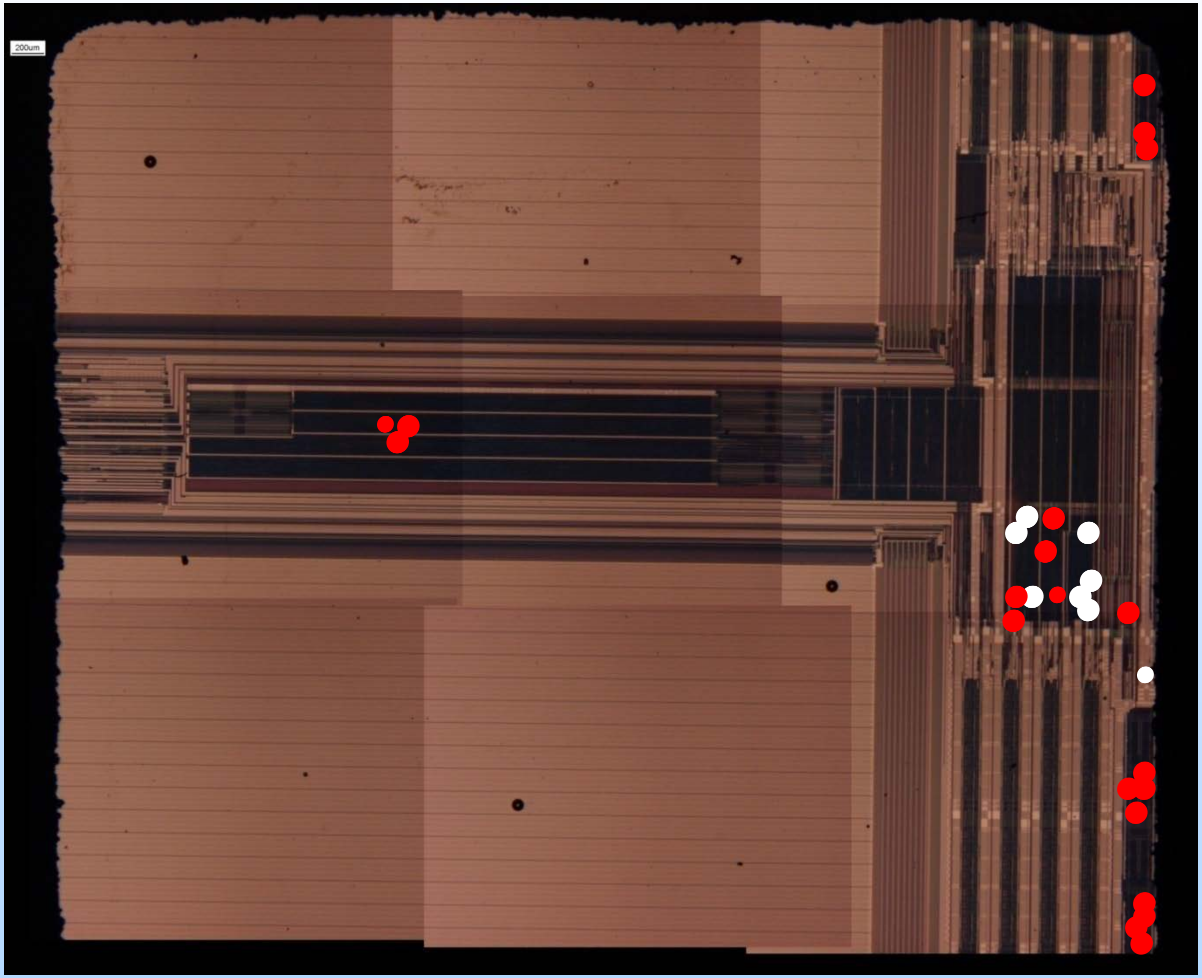
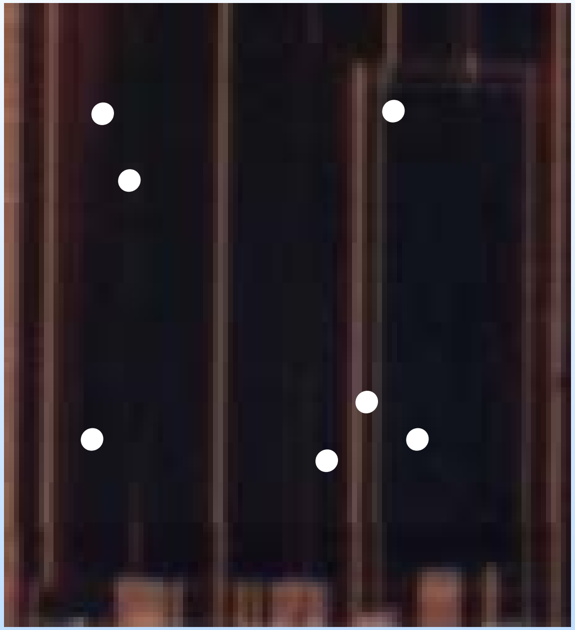
Micron 4G NAND—Dynamic Read/R/E/W

100x Lens, Att.=0

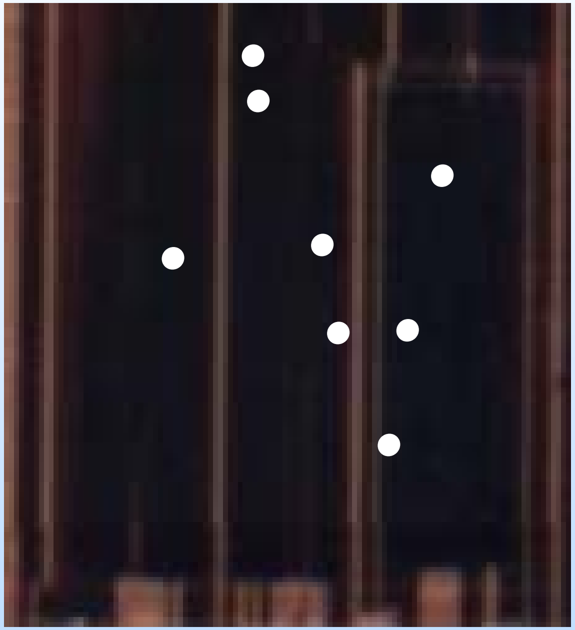


Laser/Milli-Beam™ Correlation



Laser-Induced SEFIs,

Attenuation =0.3 OD



Milli-Beam™ SEFIs

Laser/Milli-Beam^{TM} Comparison

- Energy deposition region volume and shape is different
- Ions penetrate metal over-layers, laser light does not
- Apparent correlation occurs because physical differences produce offsetting effects, not because underlying physical mechanisms are the same
- Both techniques can be very useful for identifying critical regions in sensitive technologies

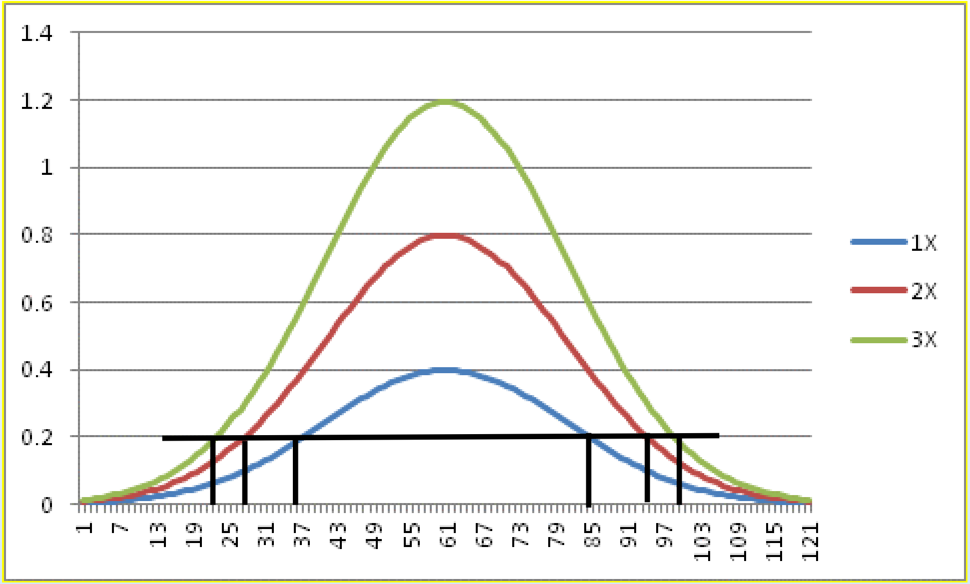
Milli-Beam™/Broad Beam Differences

- Broad beam heavy ion irradiations produced many high current events, when DUT was hit by thousands of ions/sec in thousands of locations
- Milli-Beam™ produced no high currents when ions were confined to a small region
- Shindou et al. (IEEE TNS, vol. 52, pp. 2638-2641, 2005) identified bus contention as source of high currents (called pseudo-SELs), which could be cleared with DUT reset, no power cycle required

Discussion

- **Bus contention is thought to occur when multiple ions generate SET pulses, which turn on different portions of the control circuitry. If logic components, that are not supposed to be on at the same time, actually are on at the same time, contention results.**
- **In laser tests and broad beam HI tests, nearly all high current conditions could be cleared with DUT reset, consistent with bus contention**

Laser Spot Size/Power Level



- If threshold illumination for turning on a transistor is taken to be FWHM for the lowest power level, area above threshold is more than 2x greater for second power level and 2.6x greater for highest power level
- Bus contention is expected to be sensitive to the number of transistors illuminated above threshold

Conclusions

- **Correlating laser power with effective LET is still subject to significant uncertainty**
- **At moderate laser power levels, apparent differences between laser results and Milli-Beam™ ion results seem to be resolved**
- **Difference between Milli-Beam™ and broad beam HI high current results appear to be explained as bus contention in the broad beam tests**
- **Bus contention is thought to be due to multiple ion interactions, and not to SEE, which needs to be recognized and accounted for in interpreting other broad beam test results.**

Acknowledgement

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