Test Standards: JESD57A & JESD234

2019 LANL Radiation Summer School

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Outline

June 14, 2019

- Purpose of test standards
- Applicable Facilities
- Beam Properties
- Pretest Activities
- Test Setup
- Data Collection
- Interferences
- Test Plan and Final Reports

Test Standard Scope and Limitations

Introduction

- **Purpose of the test standards**
  - Identify test procedures for measurement of single-event effects (SEE) in semiconductor devices
    - JESD57A – heavy ions
    - JESD234 – protons
- **What is JEDEC / JESD?**
  - JEDEC: Joint Electron Device Engineering Council
  - JEDEC is a global industry group that develops open standards for microelectronics.
  - Now known as the JEDEC Solid State Technology Association
  - JESD: JEDEC Standards Document (or something like that…)
- **Where to get them**
  - www.jedec.org
  - Free download with registration
  - May not reproduce by yourself without permission
- **Practical reality**
  - These are not "cookbook" recipes – neither are fully comprehensive
  - use them together with ASTM1192 and others
  - You will have to use your brain

What is a JEDEC Standard for?

- JEDEC Standard Notice

JEDEC standards and publications are designed to serve the public interest through eliminating misunderstandings between manufacturers and purchasers, facilitating interchangeability and improvement of products, and assisting the purchaser in selecting and obtaining with minimum delay the proper product for use by those other than JEDEC members, whether the standard is to be used either domestically or internationally.

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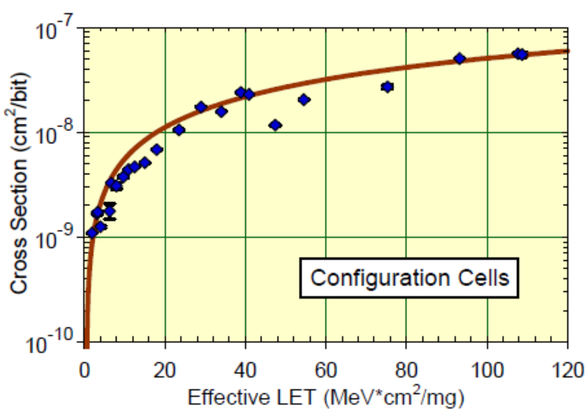
Goals and Limitations

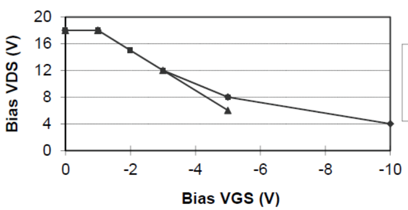
JESD57A – heavy ions

- **Van de Graaff or cyclotron**
  - Excludes sealed sources
  - Excludes pulsed beams
    - NASA Space Radiation Laboratory
- **Basic Effects**
  - All forms of heavy ion SEE
  - Heavy ion is Z>1
- **Goal: Plot cross section vs. LET**
  - SEB/SEGR: Safe Operating Area

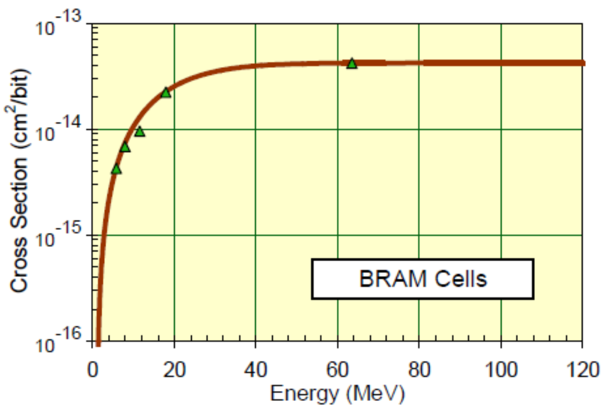
JESD234 – protons

- **Proton accelerator 40-500 MeV**
  - Excludes direct ionization
  - No comment on pulsed beams
- **Basic Effects**
  - All forms of proton SEE
  - Protons for TID or DDD are not covered
- **Goal: Plot cross section vs. energy**





Safe Operating Area IRHLF87Y20 Power MOSFET



Facilities and Beam Properties

Available Facilities

JESD57A – heavy ions

- **No specific facilities listed**
- **USA**
  - Texas A&M University
  - Lawrence Berkeley Nat'l Lab
  - NASA Space Radiation Lab
    - Brookhaven Nat'l Lab
    - Synchrotron – pulsed beam
- **Europe**
  - Univ. Catholique de Louvain (UCL), Belgium
  - (RADEF) at Univ. Jyväskylä, Finland
  - (GANIL) Caen, France
  - (GSI) Darmstadt, Germany
- **Asia**
  - (HIMAC) Chiba, Japan
  - (HIAF) China ?

JESD234 – protons

- **USA**
  - Medical proton therapy sites ~230 MeV
    - Massachusetts General Hospital cyclotron
    - [Loma Linda synchrotron]
    - [Other sites with uncertain availability]
  - Research cyclotrons ~10-60 MeV
    - [TAMU], LBNL, UC Davis
  - Indiana University Cyclotron Facility
    - Defunct since 2014
  - [NASA Space Radiation Lab - 2 GeV]
- **Canada**
  - TRIUMF 100, 500 MeV
- **Europe / Asia**
  - Paul Scherrer Institut (PSI), Switzerland
  - Svedberg Lab (TSL) Uppsala, Sweden
- **Asia**
  - [Univ. Tsukuba, Japan]

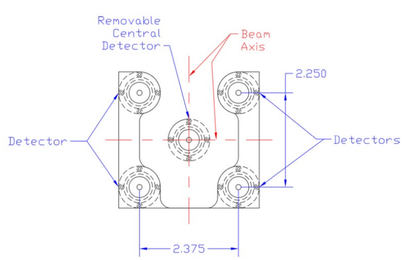
Beam Dosimetry – normally handled by facilities

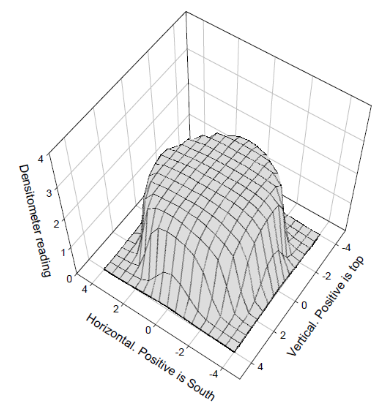
JESD57A – heavy ions

- **Energy and ion purity**
  - Surface barrier detector
    - [Not routine for standard beams]
    - Foil LET measurement – [never done]
- **Flux / Fluence**
  - Scintillator
  - Continuous flux monitoring to ±10%
- **Beam Uniformity**
  - ±10% uniformity [Gafchromic film]

JESD234 – protons

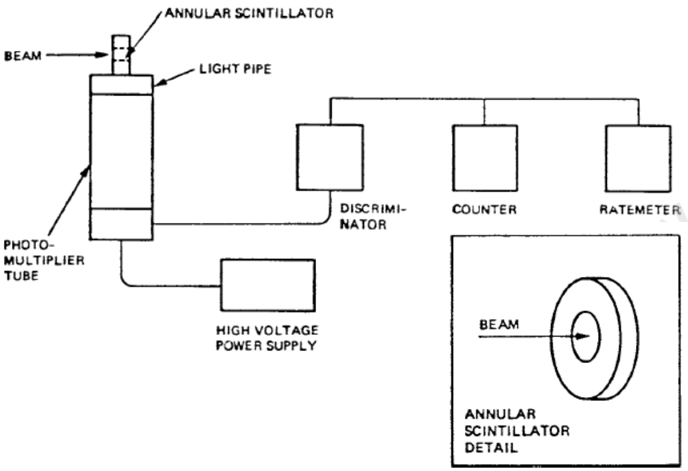
- **Energy**
  - Defined by machine tune
    - Stopping range measurement (medical)
    - Scintillators (lower energy)
  - Energy degraders spread beam energy
- **Flux / Fluence**
  - Continuous flux monitoring to ±10%
  - Scintillator / secondary electron monitor
- **Beam Uniformity**
  - ±10% uniformity (Gafchromic film)



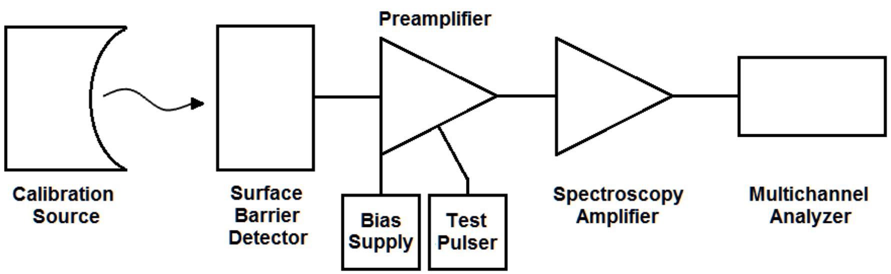


Typical beam measurement systems

- **Flux / Fluence**
  - Scintillator
    - Light flash from ionization
    - Light ~ energy (roughly)
    - Typically just count flashes



- **Energy measurement**
  - Surface barrier detector
    - Collects charge deposited by ionization
    - If particles stops, charge ~ energy

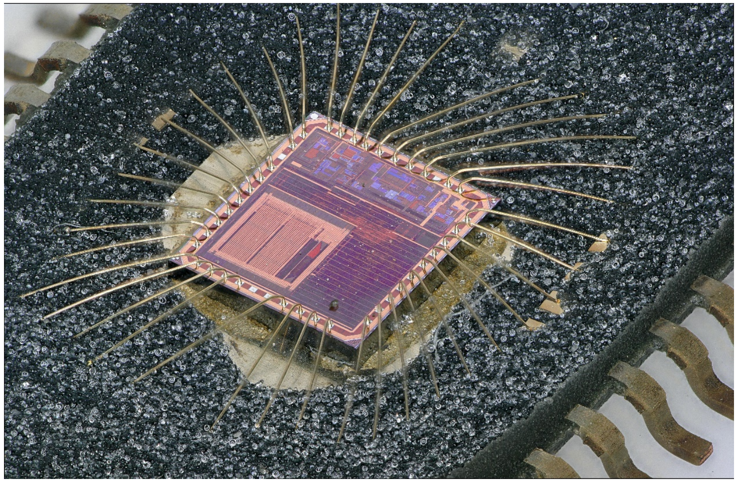


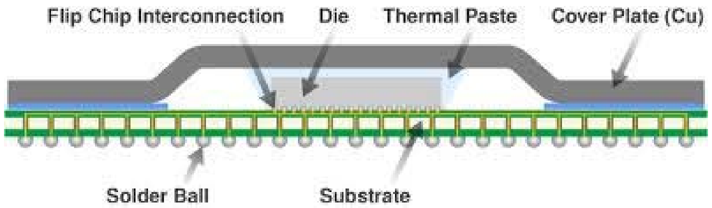
Pretest Activities

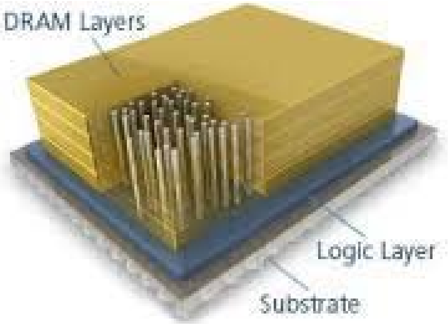
Part preparation

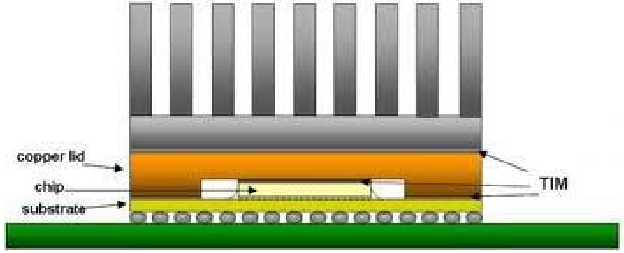
- **To successfully test a part, the beam must reach the sensitive region**
  - Heavy ion ranges typically 10s to 100s of microns
  - Protons > 10 MeV are very penetrating
- **Techniques**
  - Lid removal
  - Acid etch for plastic
  - Mill backside of substrate for flip chip

- Access to the sensitive volume is one of the biggest challenges for future testing



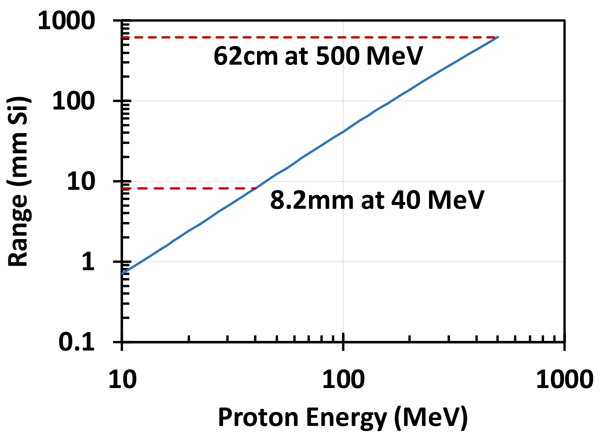


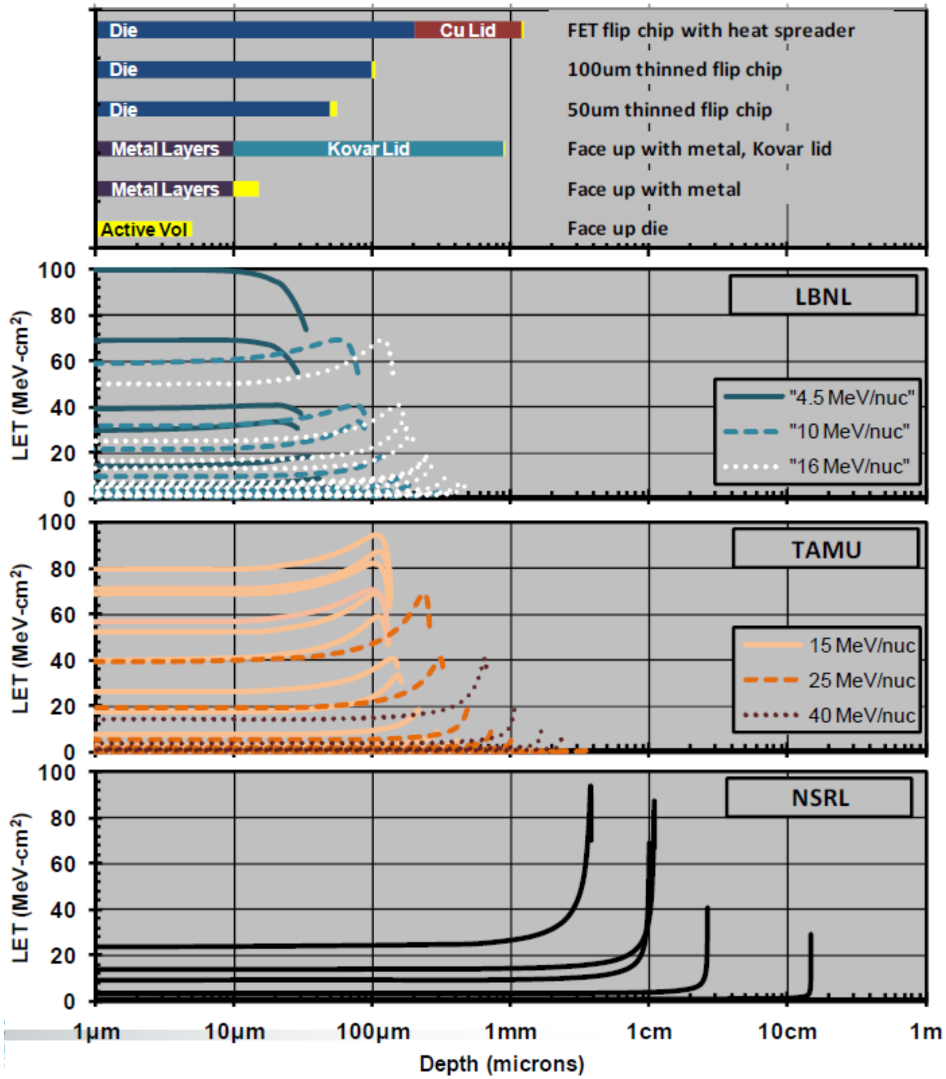




Beam Range

- **Penetration is a heavy ion problem**
  - Beam has to reach sensitive volumes
  - Package, metal layers
  - SEB/SEL may initiate at substrate
- **Part preparation is essential**
  - Delidding, decapsulation
    - Milling, acid for plastic, knife cut
  - Flip-chip die thinning
    - Affects power dissipation
    - Substrate charge diffusion





Select beams

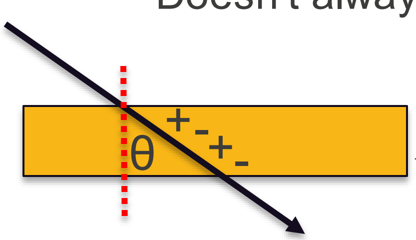
JESD57A – heavy ions

- **Ions determine LET coverage**
  - Fewer ions available at higher energy
- **Destructive SEE**
  - Goal – find highest LET with no fails
  - Function of bias conditions
- **Non-destructive SEE**
  - Map out cross section curve vs. LET
  - Threshold and "knee" most important

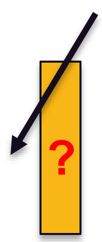
JESD234 – protons

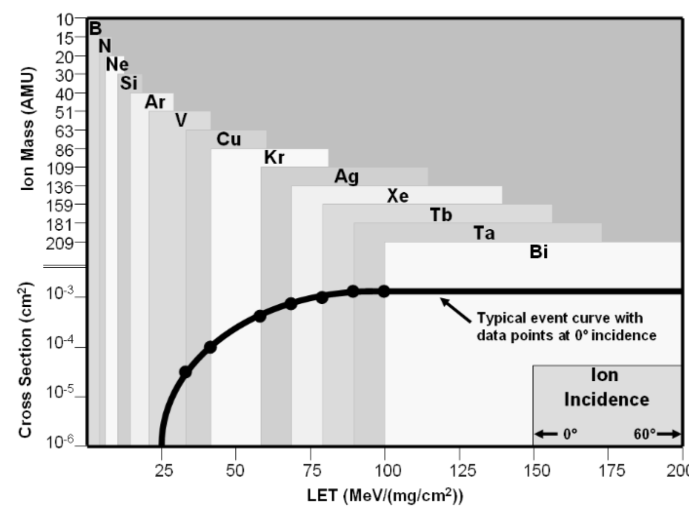
- **Protons – energy coverage**
- **Non-destructive SEE**
  - 200 MeV is high enough
  - Direct ionization below 5 MeV (out of scope)
- **Destructive SEE**
  - May need up to 500 MeV to be certain
  - Nuclear reactions, e.g., W plugs

- **"Effective LET" concept**
  - Off-normal beam angle increases LET
  - Fills in LET values between ions
  - Doesn't always apply – shape of SV



$$LET_{eff} = \frac{LET}{\cos(\theta)}$$





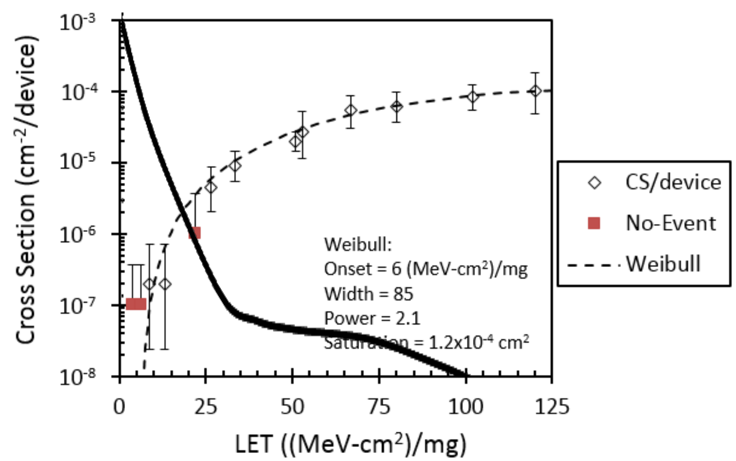
Select Flux and Fluence

JESD57A – heavy ions

- **Fluence**
  - “get a statistically meaningful number of events without overloading the device tester or dosimetry”
  - Cross section determines how much fluence is needed to get enough events
  - Flux determines how long it takes to get that fluence
    - Can’t overload tester or dosimetry
- **Flux**
  - For heavy ions, dosimetry limits flux to about 1e8 ions/cm2/sec
  - Specific ions may be as low as 1e3 due to ion source capability
- **LET values**
  - Recommend 6 values minimum
  - Threshold, saturation, knee all matter

JESD234 – protons

- **Fluence**
  - Sufficient to ensure all SVs exposed
  - Rule of thumb: 1e10 p/cm2 for soft parts, 1e12 p/cm2 for hard parts
  - DOSE important! Use multiple parts
    - 6.3e10 p/cm2 = 10 krad(Si) at 50 MeV
- **Flux**
  - Typical range is 1e5 to 1e9 p/cm2/sec

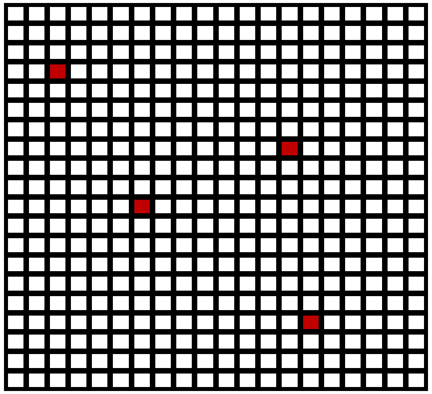


95% Confidence Level error bars

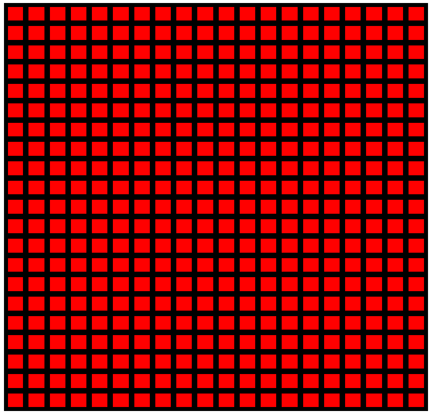
Beam Coverage

- **How do we know the die is adequately sampled?**
  - Fluence is particles/cm2
  - 1 cm2 of a silicon die contains 1e8 squares, each 1 square micron
  - Sensitive volumes in modern parts can be MUCH smaller than that

- **JESD57A has no coverage requirement**
  - 1e6 ions/cm2 will yield 100 errors at a 1e-4 cm2 saturated cross section
  - This is only 1% coverage (or less)!!



- **JESD234 requires full DUT coverage with "high confidence"**
  - 1e10 protons/cm2 puts 100 protons into each 1x1um box
  - For rare events (destructive), may need 1e12 protons/cm2 or higher



Test Setup at the Beam

Test Setup

JESD57A – heavy ions

- **Vacuum vs. air testing**
  - Feed-throughs, cycle time
- **Nearby equipment less concern**
  - Primary beam doesn't go far in air
  - Fewer secondaries at typical energies
- **Cable lengths – 20m-100m**
  - "setup as close as possible to DUT"
- **Sample size**
  - Qualification (MIL-PRF-38535) = 4
  - Non-qual: get statistical confidence

JESD234 – protons

- **Vacuum only for energy <10 MeV**
  - out of scope for JESD234
- **Nearby equipment needs shielding**
  - Secondary neutrons often intense
  - Paraffin, polyethylene, boron, "BORAX"
- **Cable lengths**
  - Same issues as for heavy ions
- **Sample size**
  - Recommend 5 for homogenous lots
  - More for random lots, pad for TID loss

Data Collection

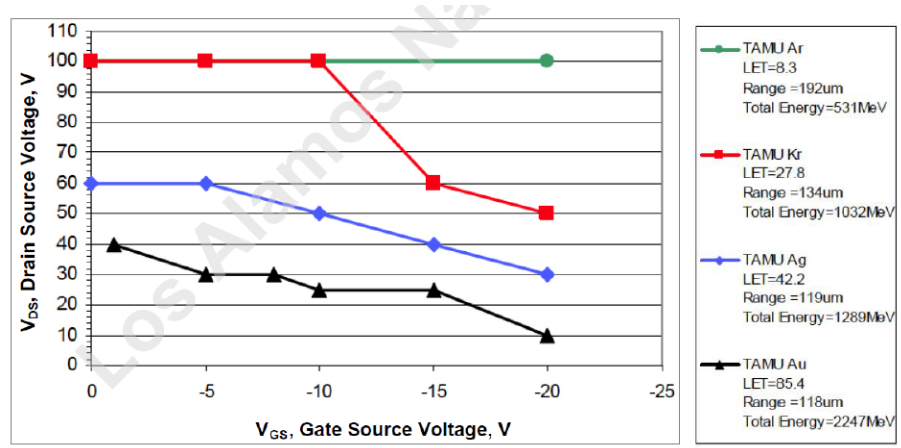
Data Collection

JESD57A – heavy ions

- **Non-destructive SEE**
  - – Map out cross section vs. LET
  - – Tilt and rotate as applicable
    - Watch penetration depth with angle
    - Effective LET may apply
  - – Minimum fluence
    - 1e7 ions/cm2 or 100 errors suggested
    - If no errors, limit is Poisson 95% (3.7)
- **Destructive SEE (SEL/SEB/SEGR)**
  - – Map safe operating area (SOA)
    - Set LET, increase bias until failure
  - – Normal incidence typically worst-case
  - – Effective LET should not be used
  - – Ensure penetration to substrate
  - – Minimum fluence
    - 5e5 ions/cm2 for large discretes
    - 1e7 ions/cm2 for small ICs

JESD234 – protons

- **Non-destructive SEE**
  - – Cross section vs. energy
    - May just qualify at 200 MeV
  - – Check grazing angles
    - Not eff LET, it's about spray of recoils
  - – Typical fluence
    - 1e10 or 100 upsets, whichever first
  - – Vary energy, temperature, bias, etc.
- **Destructive SEE**
  - – Similar to above, include roll angle



Interferences

Interferences

JESD57A – heavy ions

- **Total Ionizing Dose from beam**
  - Dose[rad(Si)] = 1.6e-5*LET*Fluence
  - 1e7 Xe(10 MeV/nuc)/cm2 = 9 krad
- **Flux**
  - Beam cal, tester duty cycle
  - Multiple ion strikes
- **Fluence**
  - Increase if no events
  - Test dead time, logical masking
  - Assume next ion causes error
    - Error bar uses 3.7 (95% confidence)
- **Package shadowing**
- **LET**
  - Avoid Bragg peak, account for layers
  - No interpolation for threshold LET
  - Be wary of effective LET
- **Latchup**
  - Maximum temperature and voltage

JESD234 – protons

- **Total Ionizing Dose from beam**
  - 6.3e10 p/cm2 at 50 MeV = 10krad
  - Finding low SEE cross sections may mean using many parts
- **Displacement damage**
  - No guidance but noted as effect
  - Especially bipolar, power, CCDs, BiCMOS
  - Electrical degradation
- **Other dose effects**
  - SEE cross section may change with dose
  - Memory patterns burn in
  - Protons for TID/DD ok but out of scope
- **Flux**
  - Duty cycle, deadtime
- **Maximum energy**
  - 200 MeV generally enough
- **Direct ionization**
  - Beware even up to 25 MeV at grazing angle
  - Out of scope

Test Plan and Final Reports

Test Planning / Test Plan Document

JESD57A – heavy ions

- **Device information**
- **Sample size**
  - Qual: 4 parts per MIL-PRF-38535
  - Non-qual: statistical sample per MIL-HDBK-814
- **Test Facility Information**
- **Test setup description**
  - Boards, cables, software, test equipment, thermal management
  - No floating DUT pins
  - SEL/SEB/SET test capability
    - Circuit limitations
    - Max/min SET pulse width/amplitude
  - Digital SET not in scope
    - Require on-chip counting

JESD234 – protons

7.1.2 Test plan contents

The test plan shall include at a minimum the following:

a) Test matrix (see 7.1.3)
b) Facility information
c) Purpose or objective of test
d) Description of test setup and schematic
e) List of required equipment
f) Detailed test procedures
g) List of proton energies to be utilized
h) Data collection

7.1.3 Minimum test matrix

a) Bias condition
b) Static or dynamic [frequency]
c) Input Patterns, Operational Modes
d) Temperature (note if ambient or junction temperature)
e) Fluence
f) Flux
g) Angle of beam incidence

Final Report

JESD57A – heavy ions

- **JESD234 has similar report**

- **Explain test goals**
- **Explain test conditions**
- **Report results**
- **Analysis**
  - Projected rates
  - Describing new phenomena
  - Identifying error types

- **More complete = more useful**

8 Final report

8.1 Test data sheet

The test data sheet shall contain the following information:

1) Dates, times, names of test personnel.
2) Type of accelerator, name and location; ion species and energy tune.
3) DUT types, part number, serial numbers, functional description, technology, manufacturer, date code and mask number if known.
4) Device duty factor and fractional portion of the chip tested, if applicable.
5) Purpose for each test run and any changes from previous test run.
6) DUT operating parameters (bias, clock frequency, temperature, load, etc.)
7) DUT test patterns or operational modes, including duty factor.
8) Beam conditions including ion species, energy, and LET at the surface of the DUT or other appropriate reference location, air gap (if applicable), and angle of incidence.
9) Fluence, average flux, run time.
10) Number of errors, locations, and special comments (anomalous incidents).
11) Transient events and recovery time when instrumental.
12) Special test results, e.g., SEL, SEB, SEGR, SEFI, etc.

8.2 Test report

The test report shall contain the following information:

1) Test objective.
2) Complete description of the product(s) tested.
3) Description of test setup, test circuit diagram, and methods including device characterization and aliveness tests performed.
4) Complete description of beam conditions including methods used to determine the LET at the given reference location(s), DUT operating conditions during irradiation, and ambient conditions.
5) Summary of results including failure criteria as applicable.
6) Conclusions.