Variable Depth Bragg Peak Test Method

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Introduction

• The Variable Depth Bragg Peak, VDBP, test method is another tool in the RAD effects tool kit.
• It has advantages, disadvantages and limitations as all test methods do.
• Testers have the responsibility of selecting the most effective tools to use for each test project.
• The VDBP test capability at the NASA Space Radiation Lab has been facilitated and demonstrated in the last 3 years.
• The purpose of this presentation is to describe this recently developed capability so that this test tool may be considered among others when test plans are made.

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Outline

1. Why the VDBP test method?
2. What is the VDBP test method?
3. How is it done?
4. What do model checks show?
5. Examples
6. Discussion

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Why the VDBP Method?

• Protons have long ranges but proton tests expose parts to LET(Si) values less than 15 MeV/mg/cm². While VDBP allows tests to LET(Si) greater than 85 MeV/mg/cm².

• VDBP method may be used to test parts, such as flip chips and stacked (3d) devices, that can not be tested to high LET(Si) values with low energy heavy ions because they can not be delidded.

• VDBP method may also be used, for a variety of reasons, to test parts to high LET(Si) values without the package modifications that are required to test them with low energy heavy ions.

• With the VDBP method, it is possible to monitor circuit response in board level tests as various devices, in unmodified commercial packages, are exposed to high-LET(Si) ions.

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What is the VDBP Method

The Variable Depth Bragg Peak test method is a way to manipulate the depth in a micro-electronic device-under-test of the Bragg peak, which occurs near the end of the long range of a high energy heavy ion species, so that the response of the device, when the sensitive volume is exposed to ions at a number of empirically determined LET(Si) values, may be measured.

It includes and extends the traditional low energy heavy ion test method.
How is it done? Setup

Side view of typical set up. Beam from right to left.

Front view of typical set up.

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Exposure Set Up

Known: Ion Species (Gold, Iron, Carbon, etc.)
Energy of Ions from Booster Synchrotron, $E_B \pm \Delta E_B$

Need to know: Energy of Ions at DUT, $E_D \pm \Delta E_D$

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Calibration Set Up

Replace DUT with IC2 and measure IC2/IC1 ratio to find thickness needed to stop ions.

$E_D$ is determined but not spread in energy, $\Delta E_D$.

**Must model.**

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Calculation Model

Model spreader, vacuum window, air and IC1 with equivalent thickness of poly. Model DUT as thick Silicon slab. Transport beam with TRIM to get $\Delta E_D$ and Bragg curve.

$$\text{LET}(\text{Si})(D_{\text{Si}}, T_{\text{DEG}}) = \text{LET}(\text{Si})((V\text{F} \times T_{\text{DEG}}) + D_{\text{Si}}),$$

where $V\text{F} = (D_{\text{Si}}(0) - D_{\text{Si}}(T))/T$

Way to manipulate depth of Bragg peak in DUT. Examples follow.

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VDBP Model Checks

Gold - 217 MeV/u from Booster - 170.3 MeV/u at DUT
Delta E = 1% for 2.4323 Sigma
NASA Space Radiation Laboratory

TRIM Monte Carlo calculation compared to TRIM table values.

Peak lowered from table values by energy spread.

TRIM Monte Carlo calculation compared to FLUKA calculation including all secondary ions.

Agreement is excellent.

TRIM Monte Carlo calculation compared to SOBPk for calculation. (Propagates Gaussian spread in energy-no straggling).

Agreement is excellent.

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# Data Collection and Analysis I

## Record Run #, # of Upsets, Fluence and Poly Thickness for each Exposure.

LET(Si), cross-section and cumulative dose(Si) are calculated and plotted as data is taken.

Find poly thickness at maximum cross-section (6.447 mm) in this case.

Depth in Silicon of sensitive volume (SV) is still not known so set to zero.

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<table>
<thead>
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<th>Run #</th>
<th># of Upsets</th>
<th>Fluence (ion/cm²)</th>
<th>Actual LET(Si) (MeV/μm²)</th>
<th>Poly Thickness (mm)</th>
<th>Cross Section (cm²)</th>
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**Beam Energy Booster: Gold**

**Beam Energy BDT:**

**Constant:**

**T-poly at max section:
Depth in Silicon of SV:**

<table>
<thead>
<tr>
<th><strong>T-poly at max section</strong></th>
<th><strong>Depth in Silicon of SV</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>6.447 mm</td>
<td>0 mm</td>
</tr>
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</table>
Find depth in Si of SV (0.552 mm) using the marker in the LET(Si) vs depth in Silicon graph. Spread sheet uses VDBP method to assign LET(Si) values to all points and plots response. Note change in Device Response curve.

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Finally the spreadsheet is used to find the Weibull parameters by fitting the response curve as shown.

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Example 1: SEU Response

4 MBIT SOI/CMOS SRAM from Freescale

Buchner et al., NSREC-2011

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Certification with VDBP Method

- Example of manipulating the Bragg peak to ensure that all depths in a part are exposed to specified high LET(Si) and fluence to certify the part.
- Example of how to manipulate the Bragg peak to determine the LET(Si) threshold when a part fails destructively.

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Example 2: Certification Test

Expose every depth in a COTS part to LET(Si) > 60 MeV/mg/cm² with 1E6 ions/cm².

Poly degrader thickness is changed in small (~0.3 mm) steps after each exposure to the specified fluence so that Bragg peak positions in the part are close together. If does not fail, it is “certified.” If it fails destructively, go to next test procedure.

Exposure sequence:

1\textsuperscript{st} exposure - no degrader, red curve, all depths at minimum LET for set up.

2\textsuperscript{nd} exposure - degrader to stop beam before part, blue curve. Then remove in steps.

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Certification Test Results

As an example, a certification test was performed on a Power Monitor/Reset Chip while its transient response was monitored.

Part certified as no failures occurred when exposed to LET(Si) greater than 60 MeV/mg/cm² for a fluence of 1E6 ions/cm².

As a byproduct of the certification test the transient response was determined.

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Example 3: Certification Failure

Part failed destructively. 
Know that it failed at some LET(Si) between the minimum of 24 MeV.mg/cm² and max of 85 MeV/mg/cm² and that the SV depth is about 0.7 mm.

Do not know failure threshold.

Need second part and test to find threshold LET(Si).

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Example 3: Certification Failure

Change to new part.

Sequence of the 2nd test is:
1st no degrader.

Then add degrader until part fails.

Use depth of SV from 1st test, dashed line at 0.7 mm, and Bragg curve (solid black curve) for degrader thickness at failure in 2nd test to assign LET(Si) threshold value, \(~30\) MeV/mg/cm\(^2\), and fluence at failure to estimate failure cross-section.

International Rectifier JANSR2N7392 MOSFET was used for this demonstration. Failure threshold was in the 27 to 31 MeV/mg/cm\(^2\) range and the failure cross-section was \(~2E-6\) cm\(^2\).
In previous tests with low-energy heavy ions on de-lidded devices, the AD9240 ADC exhibited non-destructive latch ups in both the analog and digital portions of the circuit.

To demonstrate latchup measurement capability, this device was tested at NSRL in its commercial package.

5 volts on the analog and digital parts of circuit.

Power shut off and reset in 1.5 seconds when current exceeded trigger value.

Time structure of NSRL beam is 0.4 sec spill every 4 seconds.

Flux set for 1 SEL every five spills so no more than one SEL occurred in a pulse.
Example 4: Results Compared

Results of low energy heavy ion tests [2, 3] are compared to results of VDBP tests for all latches (sum of analog and digital latches).

The cross-section as a function of LET(Si) data measured with the VDBP method for the sum of the digital and analog latches falls between the two sets of data measured previously with low energy heavy ions.

This demonstrates the measurement of the response of part that exhibits non-destructive latches with the VDBP method with the pulsed NSRL beam.


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Discussion

• There are other ways to use the method and the high energy heavy ion beams at NSRL that were not described. Some have been explored and some have not.
• There are no known reasons why the VDBP method can not be used to test at angle provided the range of the ions is adequate.
• The method has not been demonstrated for testing “3D” parts, but a demonstration experiment is planned.
• A VDBP test is planned to study the effects of heavy metals near the sensitive volume of a device.
• Clever testers will likely invent other uses of the method and of the beams of the NASA Space Radiation Lab.

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Questions?

For additional information see:

Buchner et al., IEEE Transactions on Nuclear Science, December 2011

Foster et al., IEEE Transactions on Nuclear Science, December 2012