Destructive Single-Event Failures in Schottky Diodes

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List of Acronyms

- DUT – Device Under Test
- EEE Parts – Electrical, electronic, and electromechanical parts
- EEE-INST-002 – Instructions for EEE Parts Selection, Screening, Qualification, and Derating
- GSFC – Goddard Space Flight Center
- IEEE – Institute of Electrical and Electronics Engineers
- $I_R$ – Reverse Current
- IR – International Rectifier
- LBNL – Lawrence Berkeley National Laboratory Facility’s 88-Inch Cyclotron
- LET – Linear Energy Transfer
- MOSFET – Metal-oxide-semiconductor field-effect transistor
- NEPP – NASA Electronic Parts and Packaging program
- NSREC – Nuclear and Space Radiation Effects Conference
- REDW – IEEE Radiation Effects Data Workshop
- SEE – Single-Event Effect
- STMicro – STMicroelectronics
- TAMU – Texas A&M University’s Radiation Effects Facility
- $V_R$ – Reverse Voltage
- $V_F$ – Forward Voltage
Outline

• Introduction
  – Destructive Failures in DC-DC Converters

• Test Facilities and Set-Up

• Test Results
  – ON Semiconductor MBR20200CT
  – Sensitron SD125SB45A
  – STMicroelectronics STPS20100

• Path Forward

• Conclusions
Introduction: Destructive Failures in DC-DC Converters

• Destructive SEEs observed in DC-DC converters by two different manufacturers, IR and Crane Aerospace
  – Attributed to the shorting of the anode and the cathode of the output diodes

• Diodes generally are not considered to be susceptible to SEEs
  – Implication of these diode failures could be catastrophic to scientific instruments, or even entire spacecraft

• Under NEPP, the diodes are independently irradiated to identify and understand the failure mechanism, and the severity of the potential impact to NASA missions


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Parts Tested and Test Set-Up

• Diodes Tested
  – ON Semiconductor MBR20200CT
    • Dual 200 V, 10 A Schottky diode
    • 45 diodes were irradiated
  – Equivalent to Sensitron SD125SB45A
    • 45 V, 15 A Schottky diode
    • 4 diodes were irradiated
  – ST Micro STPS20100
    • Dual 100 V, 10 A Schottky diode
    • 3 diodes were irradiated

• Test Set-Up
  – Experiments were conducted using GSFC High-Voltage Power MOSFET Motherboard

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## Test Facilities and Beam Conditions

<table>
<thead>
<tr>
<th>Facility</th>
<th>Ion</th>
<th>Energy (MeV)</th>
<th>LET at Normal Incidence (MeV-cm²/mg)</th>
<th>Range in Si (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAMU</td>
<td>Ar</td>
<td>944</td>
<td>5.60</td>
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<tr>
<td></td>
<td>Kr</td>
<td>1032</td>
<td>27.80</td>
<td>170</td>
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<tr>
<td></td>
<td>Xe</td>
<td>1512</td>
<td>51.5</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>Ta</td>
<td>2076</td>
<td>77.3</td>
<td>119</td>
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<tr>
<td>LBNL</td>
<td>O</td>
<td>183</td>
<td>2.19</td>
<td>226</td>
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<tr>
<td></td>
<td>Ne</td>
<td>216</td>
<td>3.49</td>
<td>175</td>
</tr>
<tr>
<td></td>
<td>V</td>
<td>508</td>
<td>14.59</td>
<td>113</td>
</tr>
<tr>
<td></td>
<td>Ag</td>
<td>10</td>
<td>48.15</td>
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<tr>
<td></td>
<td>Xe</td>
<td>1232</td>
<td>58.78</td>
<td>90</td>
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All parts were only found to be susceptible when reverse biased
- EEE-INST-002 states that all diodes should be derated to 75% of rated voltage, so in theory, these diodes could be used up to a voltage of 150 V
- When irradiated with 508 MeV V, failed at voltages greater than 150 V
- When irradiated with 1032 MeV Kr, failed below derated voltage threshold

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Test Results
Sensitron SD125SB45A

- Schottky diodes were irradiated with 1232 MeV Xe (LET = 58.8 MeV-cm$^2$/mg) at LBNL and with 2076 MeV Ta (LET = 77.3 MeV-cm$^2$/mg) at TAMU
  - No failures were observed with either ion, including at full rated voltage of 45 V
- Failure in the MTR28515 may be due to something other than burnout in the diode
  - Location of the failure was not along the guard ring in the DC-DC converter test
  - No failures observed in these parts independent of the converter


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Test Results
STMicro STPS20100

- Full rated voltage (100 V) was applied during irradiation
- Current increased in steps during irradiation with Xe, but did not fail
  - May have exceeded datasheet specification for reverse current (30 μA) if fluence had been higher (3×10^5 particles/cm^2)
- Diode failed short as soon as the beam was turned on with Ta
  - Failure rate would be very low

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## Additional Parts Tested

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Part Number</th>
<th>Reverse Voltage (V)</th>
<th>Number of Parts Tested (#)</th>
<th>Xe Energy (MeV)</th>
<th>Xe LET (MeV-cm²/mg)</th>
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<tbody>
<tr>
<td>STMicro</td>
<td>1N5819</td>
<td>45</td>
<td>3</td>
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<td>3</td>
<td>1512</td>
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<tr>
<td>IR/Vishay</td>
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<td>45</td>
<td>3</td>
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<td>4</td>
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<td>53.1</td>
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<td>95-9942</td>
<td>150</td>
<td>3</td>
<td>1366</td>
<td>53.1</td>
</tr>
</tbody>
</table>

* Part irradiated at 100 V

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Path Forward

• Recently procured 23 different Schottky diodes
  – Variety of manufacturers, reverse voltage ratings, and forward current ratings

• DUTs will be tested at LBNL June 29-July 1
  – 12 hrs to irradiate 46 DUTs

• Test plans are go/no-go testing
  – Will irradiate with Xe at 100% of rated voltage
    • If pass, test two more under same conditions
    • If fail, test at 75%, 50%, 25%...
  – Intent is to identify what parameters determine failure
  – Derating guideline would be next step using failing parts
### Path Forward

**Investigating Effect of Manufacturer**

**Investigating Effect of Forward Current**

**Investigating Effect of Reverse Voltage**

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Manufacturer</th>
<th>Reverse Voltage</th>
<th>Forward Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>MBR20200CTTU</td>
<td>Fairchild Semiconductor</td>
<td>200</td>
<td>10</td>
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<tr>
<td>FYPF2010DNTU</td>
<td>Fairchild Semiconductor</td>
<td>100</td>
<td>20</td>
</tr>
<tr>
<td>MBR20100CTTU</td>
<td>Fairchild Semiconductor</td>
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<tr>
<td>MBR2060CT</td>
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<td>MBR3045PT</td>
<td>Fairchild Semiconductor</td>
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<td>FST30100</td>
<td>Microsemi</td>
<td>100</td>
<td>15</td>
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<tr>
<td>NXPS20H100CX,127</td>
<td>NXP Semiconductor</td>
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<td>10</td>
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<tr>
<td>MBRF20100CTG</td>
<td>ON Semiconductor</td>
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<td>MBR20100CT-E3/4W</td>
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<tr>
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<td>Vishay Semiconductor</td>
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Conclusions

• We have shown that Schottky diodes are susceptible to destructive single-event effects
  – Failures only occur when diodes are reverse biased
  – Failures visible along guard ring in parts with no current limiting

• Future work will be completed to identify parameter that determines diode susceptibility
  – Manufacturer(s)? Reverse voltage? Forward Current?

• By determining the last passing voltages, a safe operating area can be derived
  – If these values are used for derating, rather than the rated voltage we can work to ensure the safety of future missions
    • This is currently done with power MOSFETs

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