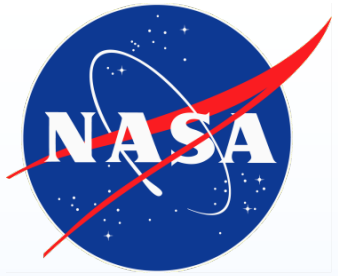


# Schottky Diode Derating for Survivability in a Heavy Ion Environment

Megan C. Casey[1], Jean-Marie Lauenstein[1], Raymond L. Ladbury[1], Edward P. Wilcox[2], Alyson D. Topper[2], Anthony Phan[2], Hak Kim[2], and Kenneth A. LaBel[1]

NASA Goddard Space Flight Center
ASRC Federal Space and Defense, Inc. (AS&D, Inc.)

To be presented by Megan Casey at the IEEE Nuclear and Space Radiation Effects Conference (NSREC), Boston, MA, July 13-17, 2015 and published on nepp.nasa.gov.

# List of Acronyms and Symbols

- SEE – Single Event Effects
- NEPP – NASA Electronic Parts and Packaging Program
- $V_R$ – Reverse Voltage
- $V_F$ – Forward Voltage
- $I_R$ – Reverse Current
- $I_F$ – Forward Current
- LBNL – Lawrence Berkeley National Laboratory
- DUT – Device Under Test
- LET – Linear Energy Transfer
- MOSFET – Metal Oxide Semiconductor Field Effect Transistor
- $\phi_B$ – Schottky Barrier Height

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# Introduction

- In 2011/2012, Bob Gigliuto of GSFC observed failures in the output Schottky diodes of DC/DC converters
  - Independent testing of the diodes was undertaken to determine their vulnerability to heavy ions
- Until this point, diodes generally were not considered to be susceptible to SEEs
  - These diode failures could be catastrophic to scientific instruments, or even entire spacecraft
- Power MOSFETs are derated when operating in radiation environments
  - Would a similar approach work for Schottky diodes?

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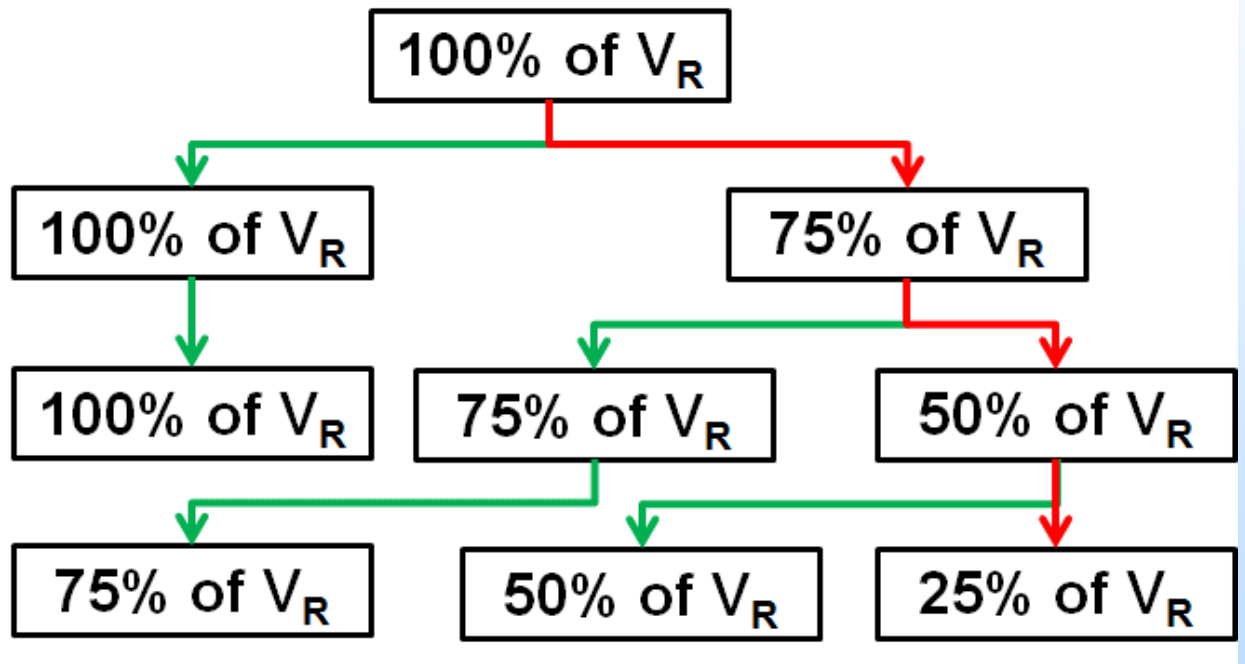
# Test Facilities and Technique

- All parts were tested at Lawrence Berkeley National Laboratory's (LBNL) 88" cyclotron with 1233 MeV Xe (LET = 58.8 MeV-cm$^2$/mg)
- All diodes were reverse biased while irradiated
- After each beam run, $V_F$, $V_R$, and $I_R$ were measured

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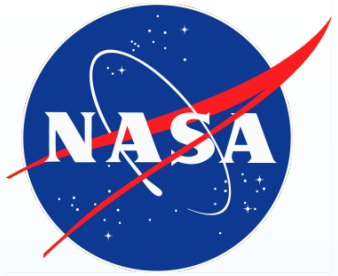
# Parts Tested




- 38 Schottky diodes from 8 manufacturers (See the paper for details.)
- Reverse voltages range from 40 V to 200 V
- Forward currents (per diode) from 5 A to 30 A
- Within the manufacturers, high temperature, high forward voltage lines are compared to low temperature, low forward voltage and low barrier height lines

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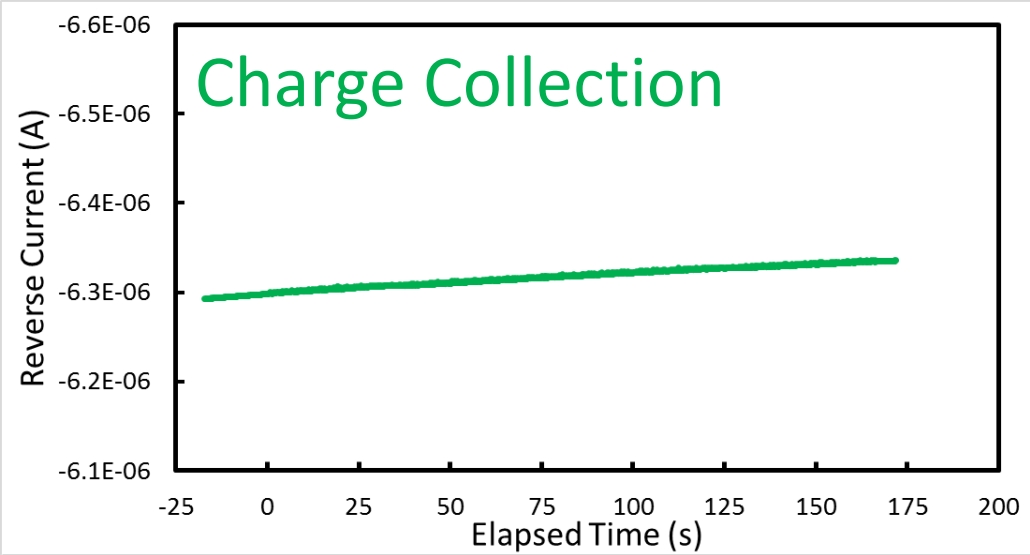
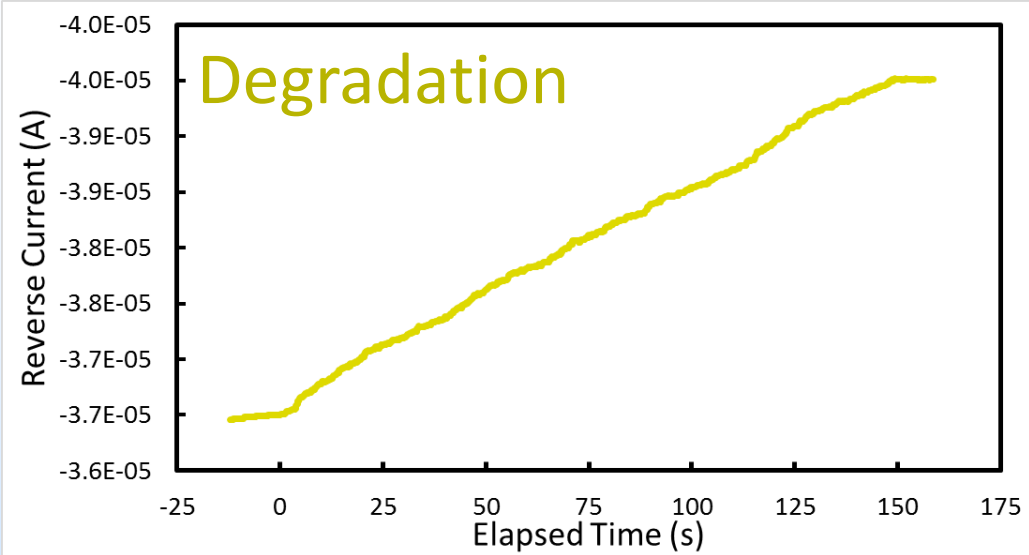
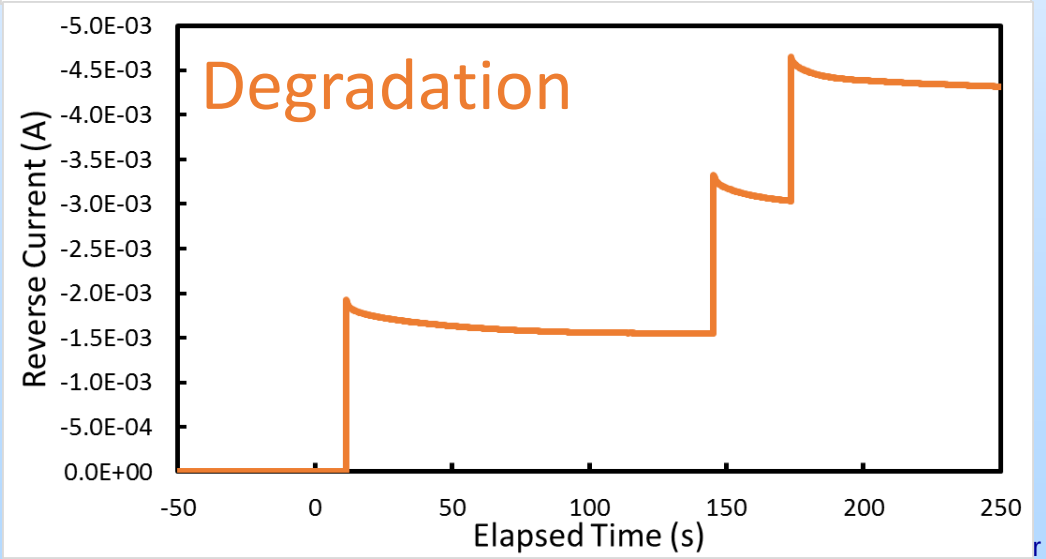
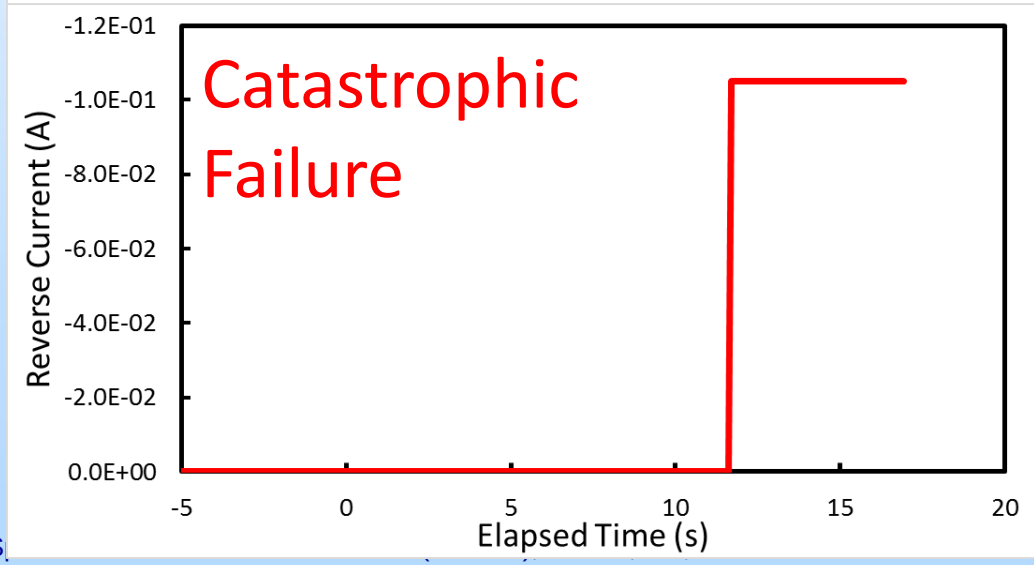
# Observed Radiation Responses

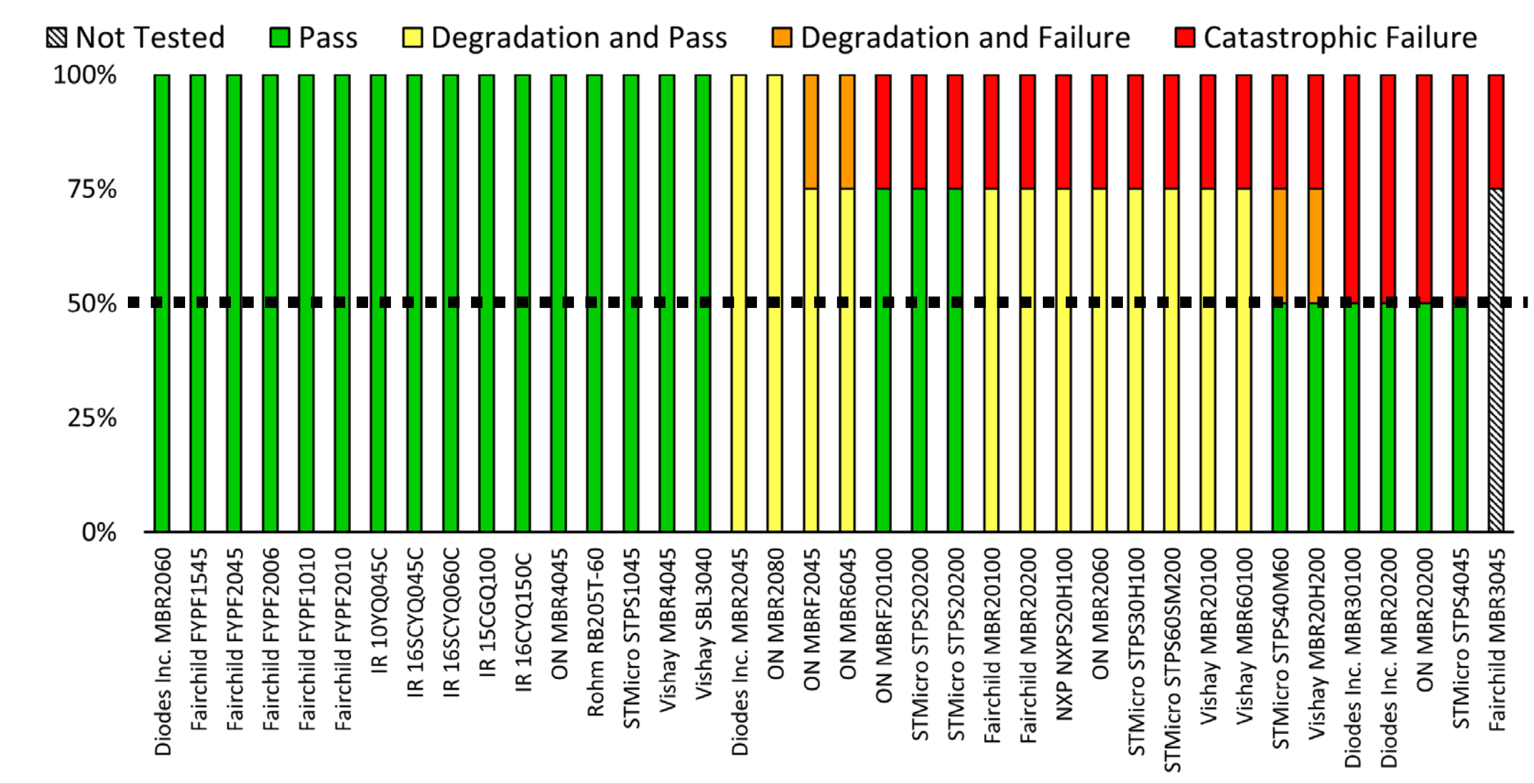


# Results

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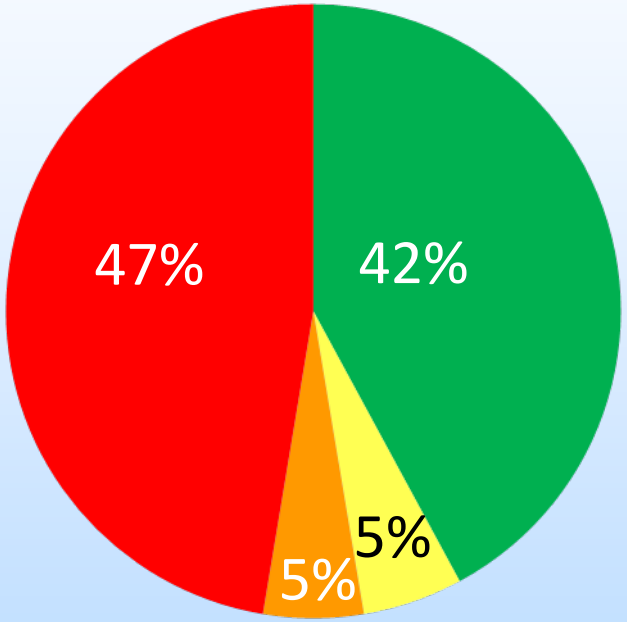
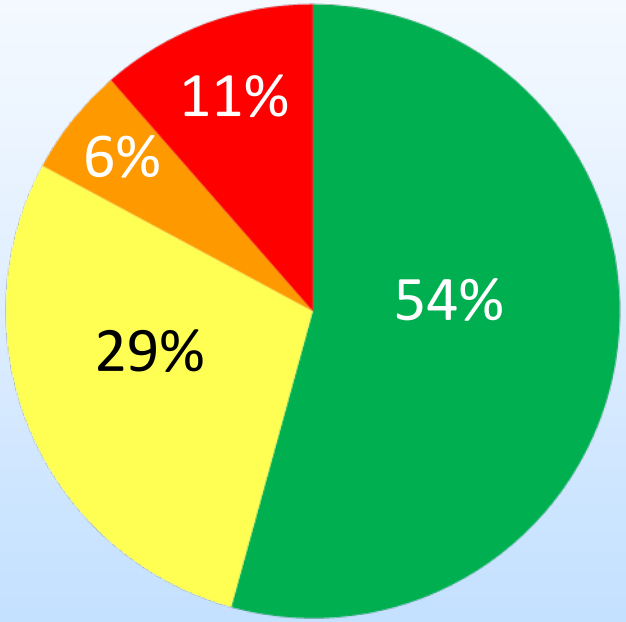
# Results

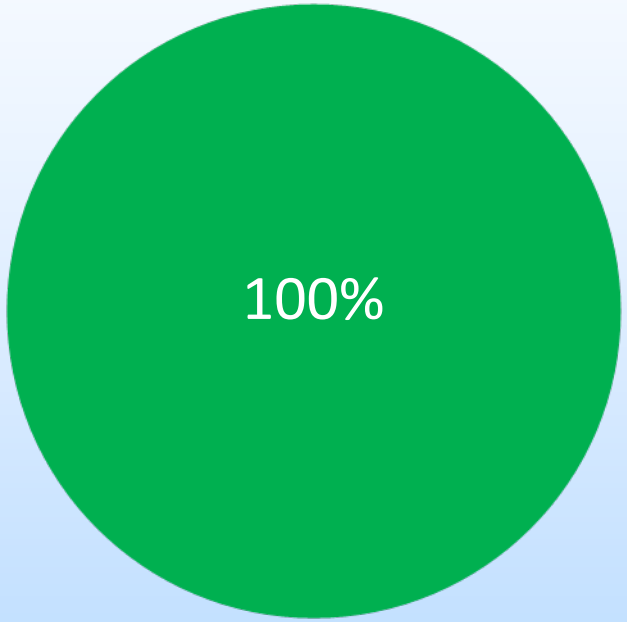
100% of Reverse Voltage




75% of Reverse Voltage




50% of Reverse Voltage




By derating to 50% of the reverse voltage, all failures are eliminated for the parts tested

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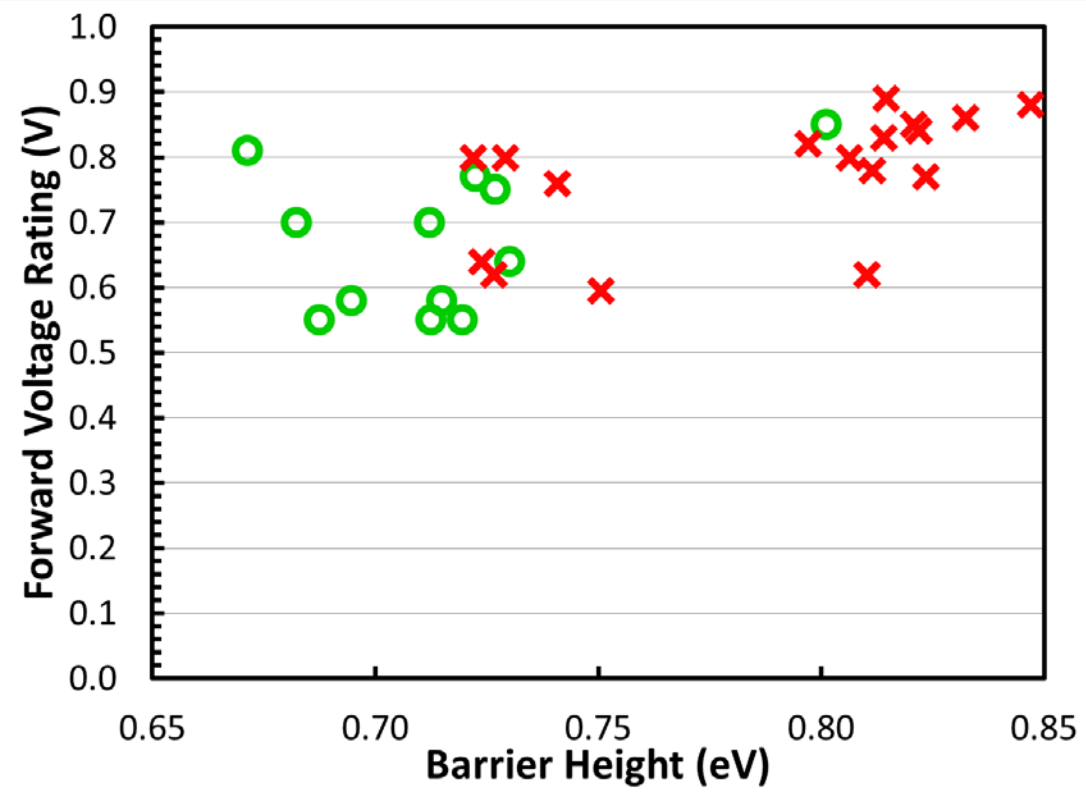
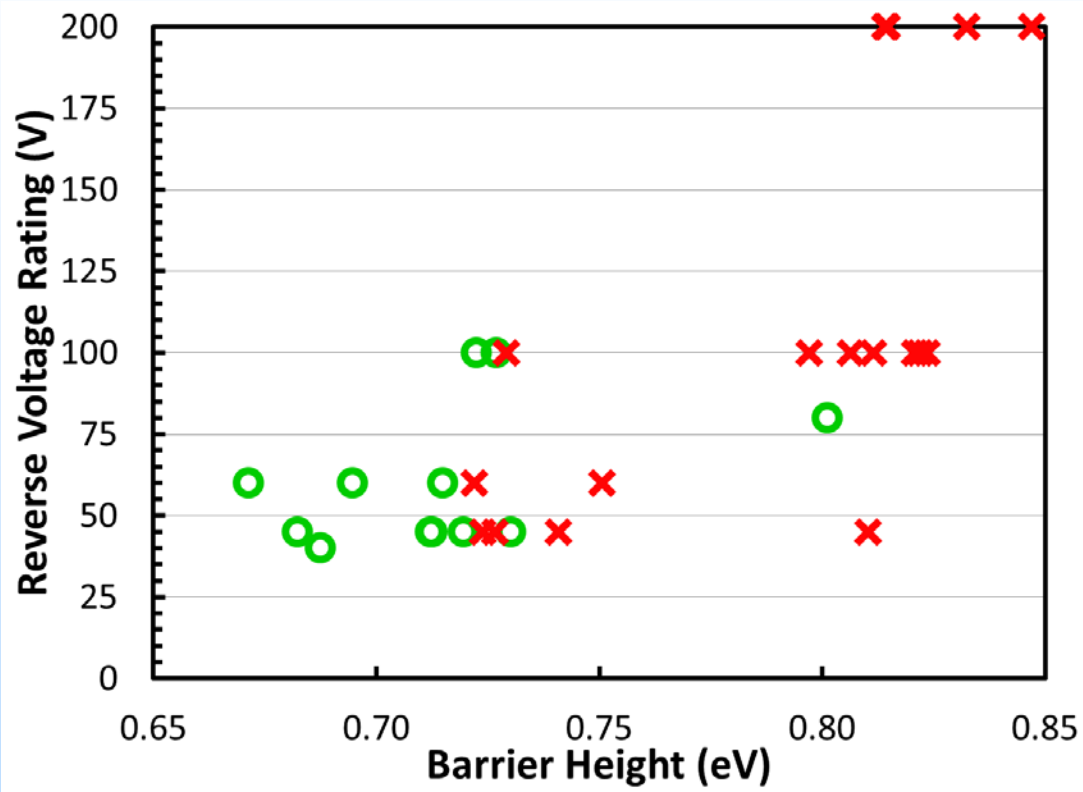
# Failures as a Function of Barrier Height




No failures observed in parts with ϕB less than 0.72 eV

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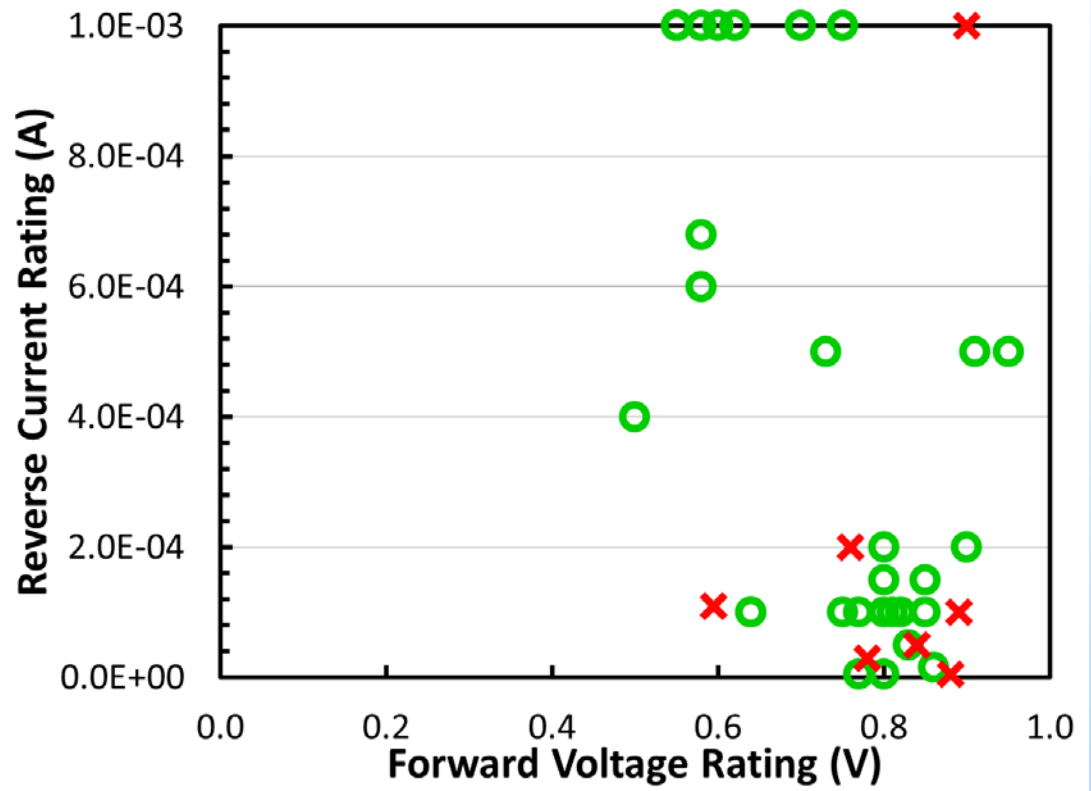
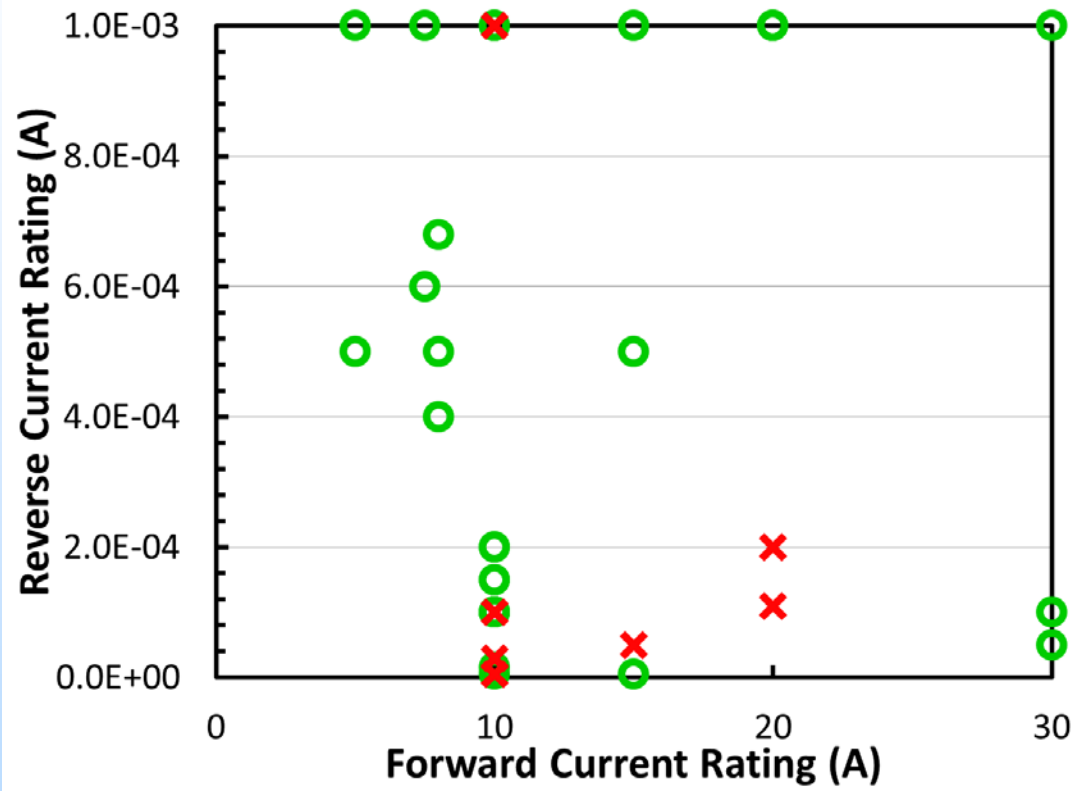
# Failures as a Function of Reverse Current




Strong correlation in susceptibility and low $I_R$ rating

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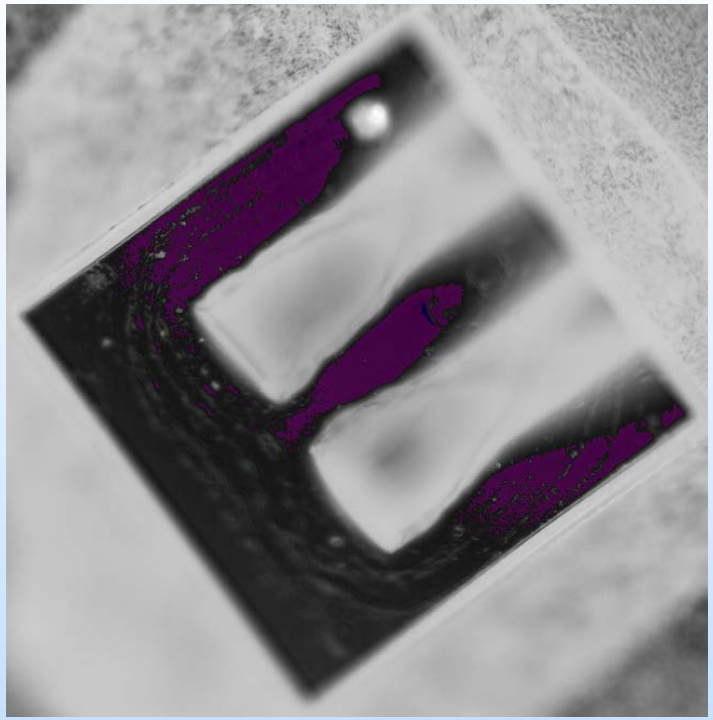
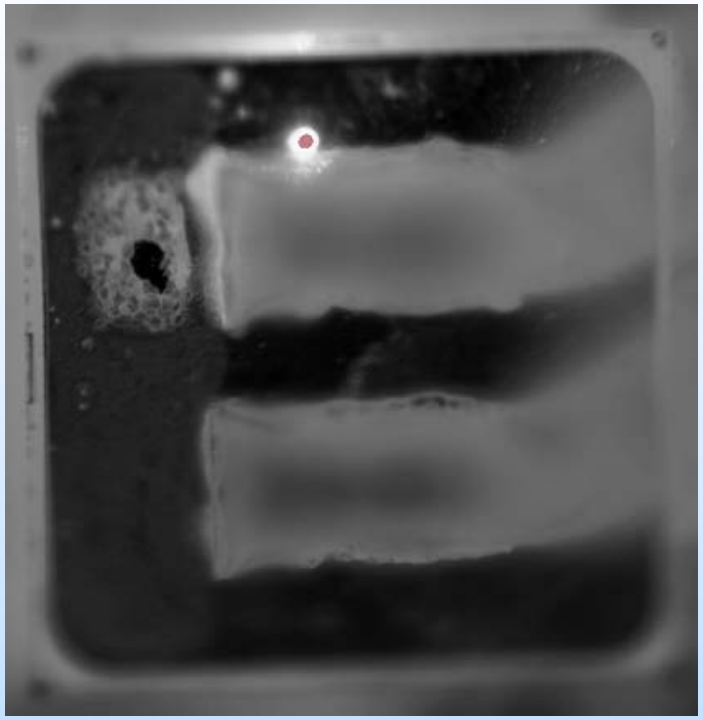
# Thermal Imaging of Failed Schottky Diodes





Failure locations are hundreds of microns away from guardring

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# Conclusions

- Schottky diodes are susceptible to destructive SEEs
  - Failures only occur when diodes are reverse biased
  - Thermal images show failures are not located solely along guardring
- Failures are much more widespread than originally suspected
  - Failures observed across manufacturers, reverse voltages, and forward current ratings tested
- No failures observed at 50% (or below) of rated reverse voltage
- There appears to be a strong correlation between failures and barrier height, as well as reverse current rating
  - SEE testing should be considered when selecting parts with $\phi_B > 0.72$ eV or with $I_R \leq 200$ µA
  - Correlation also exists between failures and forward voltage

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# Acknowledgments


- This work was sponsored by the NASA Electronic Parts and Packaging Program.

- The authors gratefully acknowledge members of the Radiation Effects and Analysis Group who contributed to the test results presented here.

- The authors would also like to acknowledge the staff at the LBNL cyclotron for their support during these tests.

# Parts Tested

| Part Number | Manufacturer | Reverse Voltage (V) | Forward Current (A) | Reverse Current (A) | Forward Voltage (V) |
|---|---|---|---|---|---|
| MBR2045 | Diodes Inc. | 45 | 10 | 1.00E-04 | 0.64 |
| MBR2060 | Diodes Inc. | 60 | 10 | 1.00E-04 | 0.81 |
| MBRF30100 | Diodes Inc. | 100 | 15 | 5.00E-05 | 0.84 |
| MBR20200 | Diodes Inc. | 200 | 10 | 1.00E-04 | 0.89 |
| FYPF1545 | Fairchild Semiconductor | 45 | 7.5 | 1.00E-03 | 0.55 |
| FYPF2045 | Fairchild Semiconductor | 45 | 10 | 1.00E-03 | 0.55 |
| FYPF2006 | Fairchild Semiconductor | 60 | 10 | 1.00E-03 | 0.58 |
| FYPF1010 | Fairchild Semiconductor | 100 | 5 | 1.00E-03 | 0.75 |
| FYPF2010 | Fairchild Semiconductor | 100 | 10 | 1.00E-04 | 0.77 |
| MBR3045 | Fairchild Semiconductor | 45 | 15 | 1.00E-03 | 0.62 |
| MBR20100 | Fairchild Semiconductor | 100 | 10 | 2.00E-04 | 0.8 |
| MBR20200 | Fairchild Semiconductor | 200 | 10 | 2.00E-04 | 0.9 |
| 10YQ045C | International Rectifier | 45 | 5 | 5.00E-04 | 0.73 |
| 16SCYQ045C | International Rectifier | 45 | 8 | 4.00E-04 | 0.5 |
| 16SCYQ060C | International Rectifier | 60 | 8 | 6.80E-04 | 0.58 |
| 15CGQ100 | International Rectifier | 100 | 15 | 5.00E-04 | 0.95 |
| 16CYQ150C | International Rectifier | 150 | 8 | 5.00E-04 | 0.91 |
| NXPS20H100 | NXP Semiconductor | 100 | 10 | 4.50E-06 | 0.77 |
| RB205T-60 | Rohm Semiconductor | 60 | 7.5 | 6.00E-04 | 0.58 |

| Part Number | Manufacturer | Reverse Voltage (V) | Forward Current (A) | Reverse Current (A) | Forward Voltage (V) |
|---|---|---|---|---|---|
| MBRF2045 | ON Semiconductor | 45 | 10 | 1.00E-04 | 0.64 |
| MBR4045 | ON Semiconductor | 45 | 20 | 1.00E-03 | 0.7 |
| MBR6045 | ON Semiconductor | 45 | 30 | 1.00E-03 | 0.62 |
| MBR2060 | ON Semiconductor | 60 | 10 | 1.50E-04 | 0.8 |
| MBR2080 | ON Semiconductor | 80 | 10 | 1.00E-04 | 0.85 |
| MBRF20100 | ON Semiconductor | 100 | 10 | 1.50E-04 | 0.85 |
| MBR20200 | ON Semiconductor | 200 | 10 | 1.00E-03 | 0.9 |
| STPS1045 | STMicroelectronics | 45 | 10 | 1.00E-04 | 0.75 |
| STPS4045 | STMicroelectronics | 45 | 20 | 2.00E-04 | 0.76 |
| STPS40M60 | STMicroelectronics | 60 | 20 | 1.10E-04 | 0.595 |
| STPS20100 | STMicroelectronics | 100 | 10 | 3.00E-05 | 0.78 |
| STPS30H100 | STMicroelectronics | 100 | 15 | 5.00E-06 | 0.8 |
| STPS20200 | STMicroelectronics | 200 | 10 | 1.50E-05 | 0.86 |
| STPS60SM200 | STMicroelectronics | 200 | 30 | 5.00E-05 | 0.83 |
| MBR4045 | Vishay Semiconductor | 45 | 20 | 1.00E-03 | 0.6 |
| MBR20100 | Vishay Semiconductor | 100 | 10 | 1.00E-04 | 0.8 |
| MBR60100 | Vishay Semiconductor | 100 | 30 | 1.00E-04 | 0.82 |
| MBR20H200 | Vishay Semiconductor | 200 | 10 | 5.00E-06 | 0.88 |
| SBL3040 | Vishay Semiconductor | 40 | 15 | 1.00E-03 | 0.55 |

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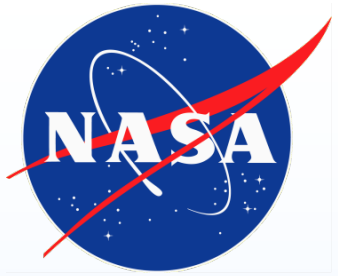
# Results




| Part Number | Manufacturer | Reverse Voltage (V) | Forward Current (A) | Reverse Current (A) | Forward Voltage (V) | 100% | 75% | 50% |
|---|---|---|---|---|---|---|---|---|
| MBR2045 | Diodes Inc. | 45 | 10 | 1.00E-04 | 0.64 | D | NT | NT |
| MBR2060 | Diodes Inc. | 60 | 10 | 1.00E-04 | 0.81 | P | NT | NT |
| MBRF30100 | Diodes Inc. | 100 | 15 | 5.00E-05 | 0.84 | CF | CF | P |
| MBR20200 | Diodes Inc. | 200 | 10 | 1.00E-04 | 0.89 | CF | CF | P |
| FYPF1545 | Fairchild Semiconductor | 45 | 7.5 | 1.00E-03 | 0.55 | P | NT | NT |
| FYPF2045 | Fairchild Semiconductor | 45 | 10 | 1.00E-03 | 0.55 | P | NT | NT |
| FYPF2006 | Fairchild Semiconductor | 60 | 10 | 1.00E-03 | 0.58 | P | NT | NT |
| FYPF1010 | Fairchild Semiconductor | 100 | 5 | 1.00E-03 | 0.75 | P | NT | NT |
| FYPF2010 | Fairchild Semiconductor | 100 | 10 | 1.00E-04 | 0.77 | P | NT | NT |
| MBR3045 | Fairchild Semiconductor | 45 | 15 | 1.00E-03 | 0.62 | CF | NT | NT |
| MBR20100 | Fairchild Semiconductor | 100 | 10 | 2.00E-04 | 0.8 | CF | D | NT |
| MBR20200 | Fairchild Semiconductor | 200 | 10 | 2.00E-04 | 0.9 | CF | D | NT |
| 10YQ045C | International Rectifier | 45 | 5 | 5.00E-04 | 0.73 | P | NT | NT |
| 16SCYQ045C | International Rectifier | 45 | 8 | 4.00E-04 | 0.5 | P | NT | NT |
| 16SCYQ060C | International Rectifier | 60 | 8 | 6.80E-04 | 0.58 | P | NT | NT |
| 15CGQ100 | International Rectifier | 100 | 15 | 5.00E-04 | 0.95 | P | NT | NT |
| 16CYQ150C | International Rectifier | 150 | 8 | 5.00E-04 | 0.91 | P | NT | NT |
| NXPS20H100 | NXP Semiconductor | 100 | 10 | 4.50E-06 | 0.77 | CF | D | NT |
| RB205T-60 | Rohm Semiconductor | 60 | 7.5 | 6.00E-04 | 0.58 | P | NT | NT |

| Part Number | Manufacturer | Reverse Voltage (V) | Forward Current (A) | Reverse Current (A) | Forward Voltage (V) | 100% | 75% | 50% |
|---|---|---|---|---|---|---|---|---|
| MBRF2045 | ON Semiconductor | 45 | 10 | 1.00E-04 | 0.64 | DF | D | NT |
| MBR4045 | ON Semiconductor | 45 | 20 | 1.00E-03 | 0.7 | P | NT | NT |
| MBR6045 | ON Semiconductor | 45 | 30 | 1.00E-03 | 0.62 | DF | D | NT |
| MBR2060 | ON Semiconductor | 60 | 10 | 1.50E-04 | 0.8 | CF | D | NT |
| MBR2080 | ON Semiconductor | 80 | 10 | 1.00E-04 | 0.85 | D | NT | NT |
| MBRF20100 | ON Semiconductor | 100 | 10 | 1.50E-04 | 0.85 | CF | P | NT |
| MBR20200 | ON Semiconductor | 200 | 10 | 1.00E-03 | 0.9 | CF | CF | P |
| STPS1045 | STMicroelectronics | 45 | 10 | 1.00E-04 | 0.75 | P | NT | NT |
| STPS4045 | STMicroelectronics | 45 | 20 | 2.00E-04 | 0.76 | CF | CF | P |
| STPS40M60 | STMicroelectronics | 60 | 20 | 1.10E-04 | 0.595 | CF | CF | P |
| STPS20100 | STMicroelectronics | 100 | 10 | 3.00E-05 | 0.78 | CF | CF | P |
| STPS30H100 | STMicroelectronics | 100 | 15 | 5.00E-06 | 0.8 | CF | D | NT |
| STPS20200 | STMicroelectronics | 200 | 10 | 1.50E-05 | 0.86 | CF | P | NT |
| STPS60SM200 | STMicroelectronics | 200 | 30 | 5.00E-05 | 0.83 | CF | D | NT |
| MBR4045 | Vishay Semiconductor | 45 | 20 | 1.00E-03 | 0.6 | P | NT | NT |
| MBR20100 | Vishay Semiconductor | 100 | 10 | 1.00E-04 | 0.8 | CF | D | NT |
| MBR60100 | Vishay Semiconductor | 100 | 30 | 1.00E-04 | 0.82 | CF | D | NT |
| MBR20H200 | Vishay Semiconductor | 200 | 10 | 5.00E-06 | 0.88 | CF | DF | P |
| SBL3040 | Vishay Semiconductor | 40 | 15 | 1.00E-03 | 0.55 | P | NT | NT |

Catastrophic Failure | Degradation and Failure | Degradation and Pass | Pass | Not Tested

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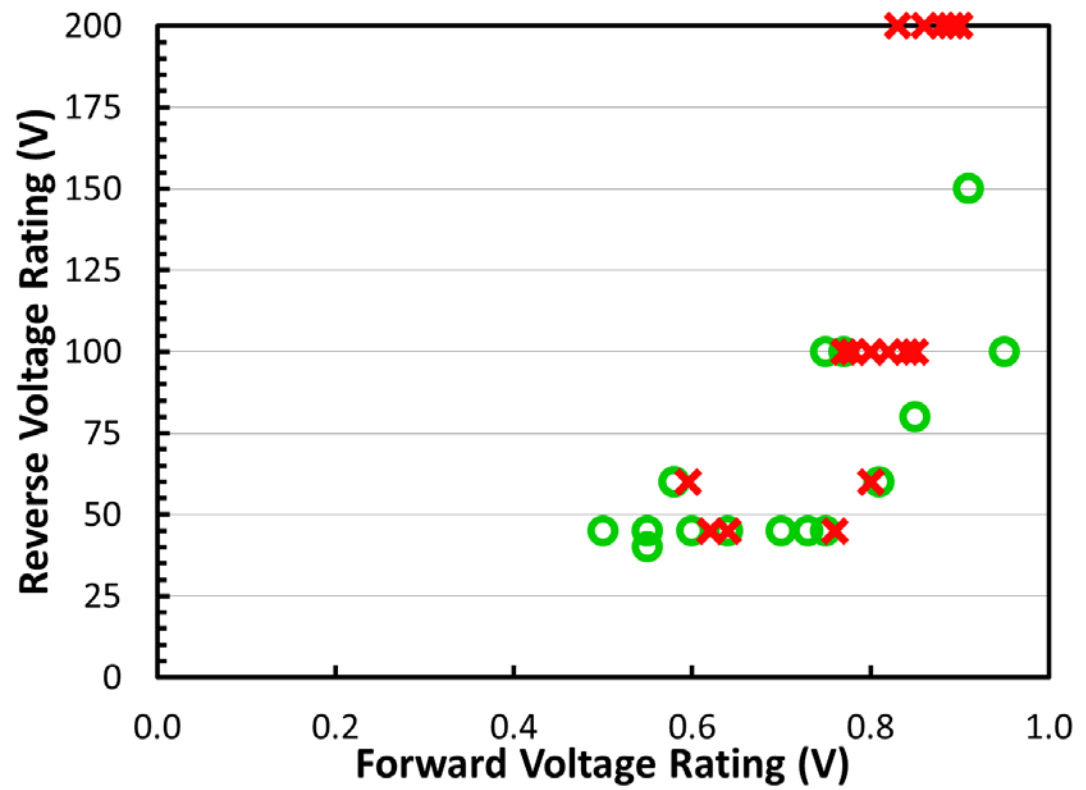
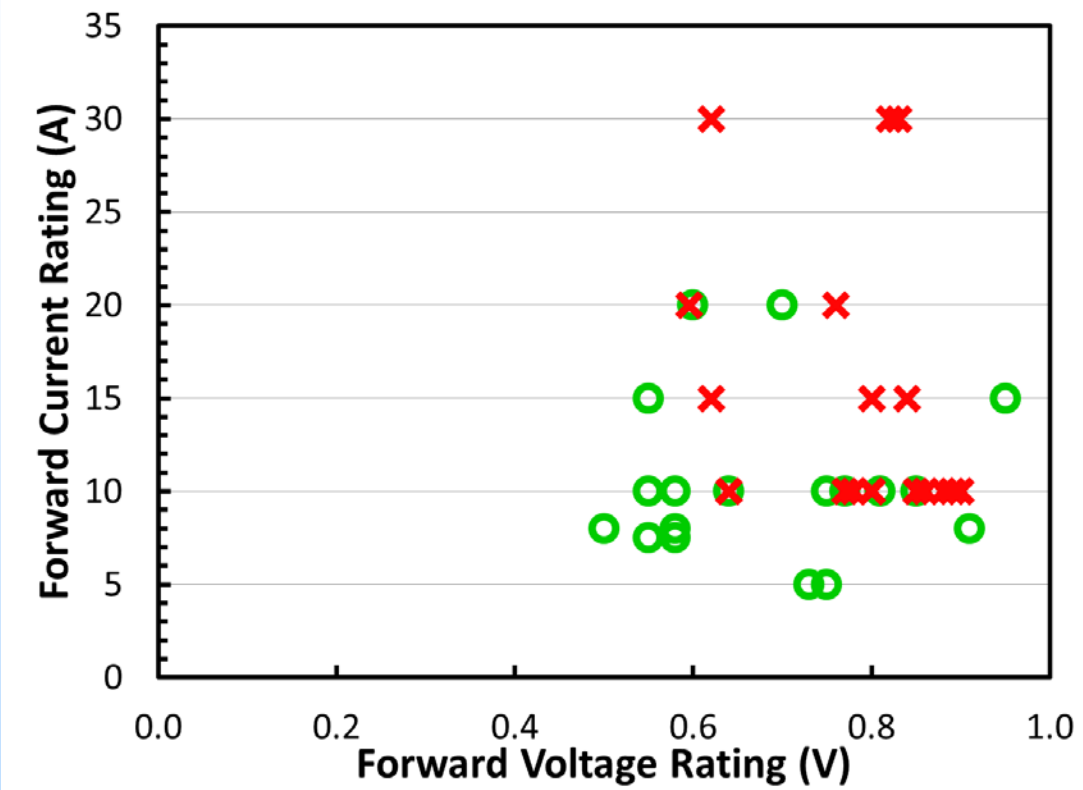
# Failures as a Function of Forward Voltage




Weaker correlation in susceptibility and high $V_F$ rating

However, product lines billed as low $V_F$ or low $\phi_B$ show very little susceptibility

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