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Destructive Single-Event Failures in Schottky Diodes

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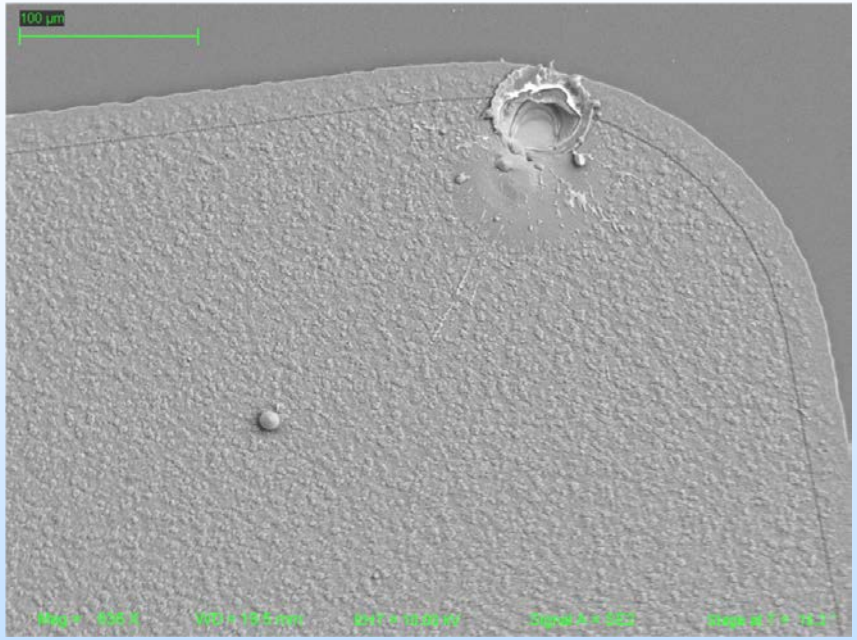
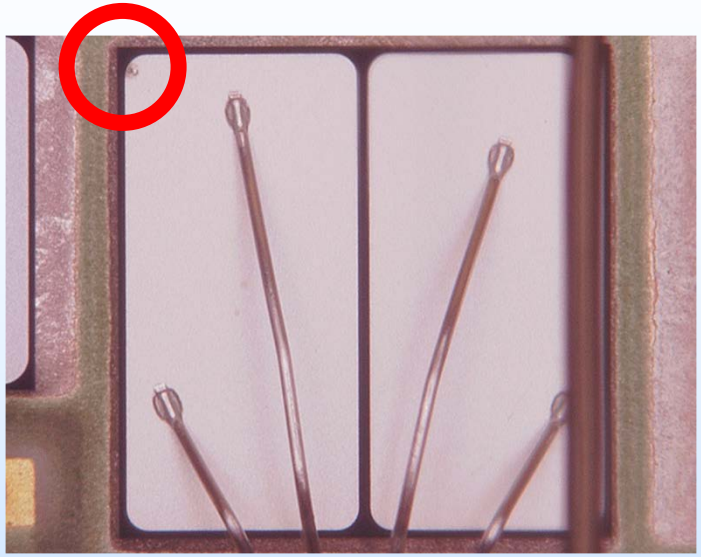
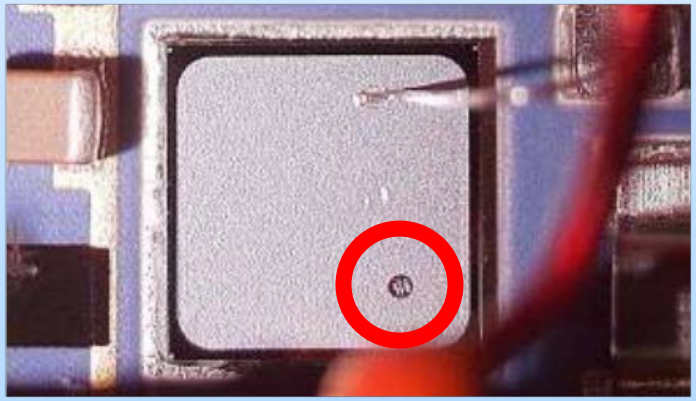


Introduction: Destructive Failures in DC-DC Converters

- **At 2012 Nuclear and Space Radiation Effects Conference, O'Bryan et al. highlighted destructive single-event effects (SEEs) observed in DC-DC converters by two different manufacturers, International Rectifier (IR) and Crane Aerospace**
  - **Attributed to the shorting of the anode and the cathode of the output diodes**



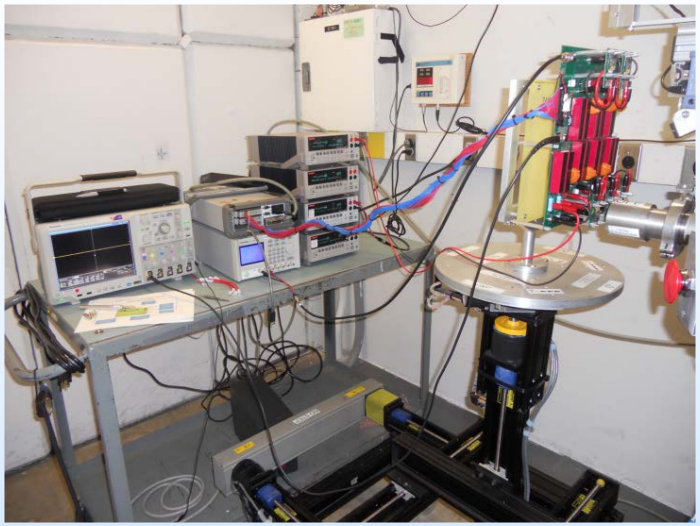
- **Diodes generally are not considered to be susceptible to single-event effects**
  - **Implication of these diode failures could be catastrophic to scientific instruments, or even entire spacecraft**



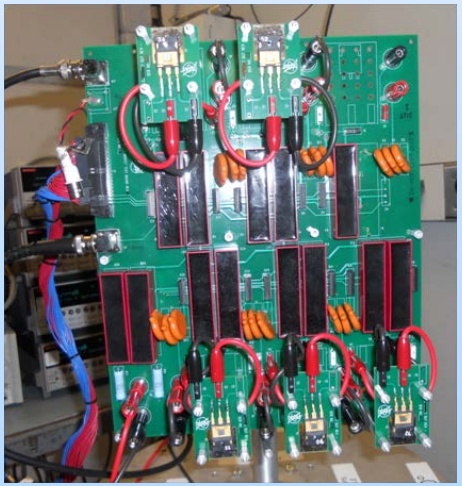
- **In this work, the diodes are independently irradiated to identify and understand the failure mechanism, and the severity of the potential impact to NASA missions**

Parts Tested and Test Set-Up

- **Diodes Tested**
  - **IR DC-DC converter**
    - **ON Semiconductor MBR20200CT**
    - **Dual 200 V, 20 A Schottky diode**
    - **45 diodes were irradiated**
  - **Crane DC-DC converter**
    - **Equivalent to Sensitron SD125SB45A**
    - **45 V, 15 A Schottky diode**
    - **4 diodes were irradiated**



- **Test Set-Up**
  - **Experiments were conducted using GSFC High-Voltage Power MOSFET Motherboard**
  - **Equipment used:**
    - **Keithley 2410 SourceMeter; Agilent 34907A Data Acquisition unit (DAQ); Tektronix MSO5104 1 GHz mixed-signal oscilloscope; Keithley 2400 SourceMeter; Personal computer (PC); custom LabView programs**



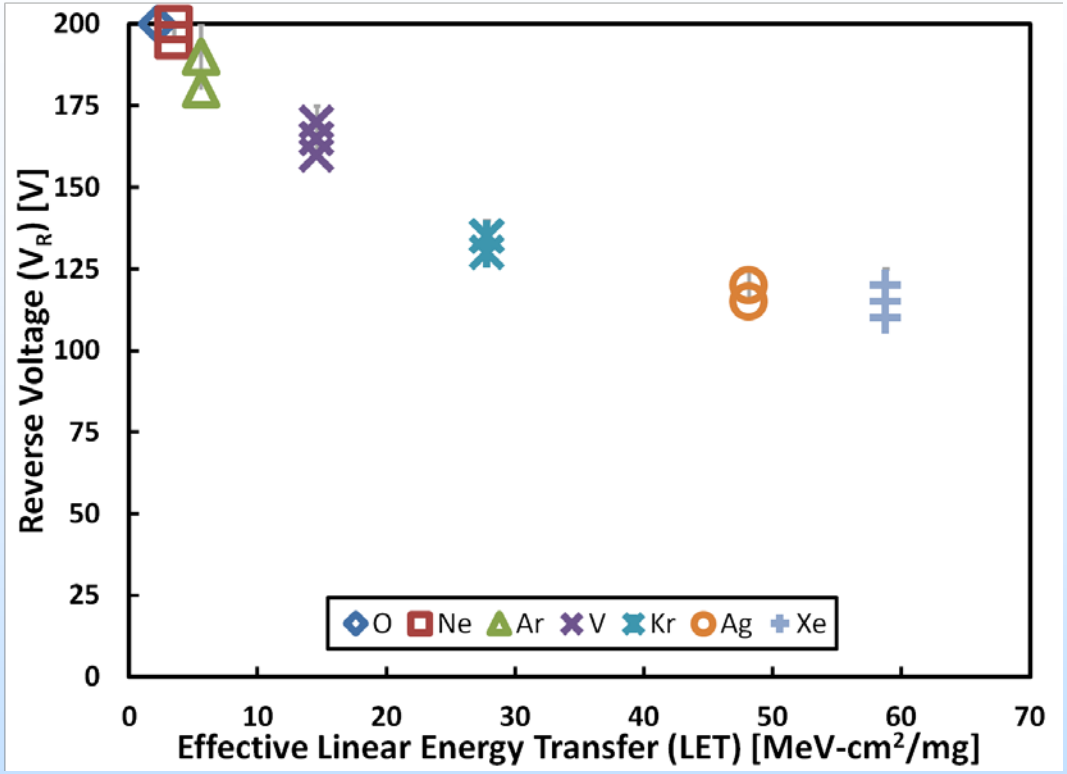
Test Facilities

Facilities used were Lawrence Berkeley National Laboratory (LBNL) BASE Facility's 88-Inch Cyclotron and Texas A&M University's (TAMU) Radiation Effects Facility at the Cyclotron Institute

Facility	Ion	Energy (MeV)	Linear Energy Transfer (LET) at Normal Incidence (MeV-cm^2/mg)	Range in Si (µm)	Parts Tested	Angles (°)
TAMU	Ar	944	5.60	193	MBR20200CT	0
	Kr	1032	27.80	170	MBR20200CT	0
LBNL	O	183	2.19	226	MBR20200CT	0
	Ne	216	3.49	175	MBR20200CT	0
	V	508	14.59	113	MBR20200CT	0
	Ag	10	48.15	90	MBR20200CT	0, 10, 30
	Xe	1232	58.78	90	MBR20200CT, SD125SB45A	0, 10, 30, 45, 60

Test Results

ON Semiconductor MBR20200CT



- 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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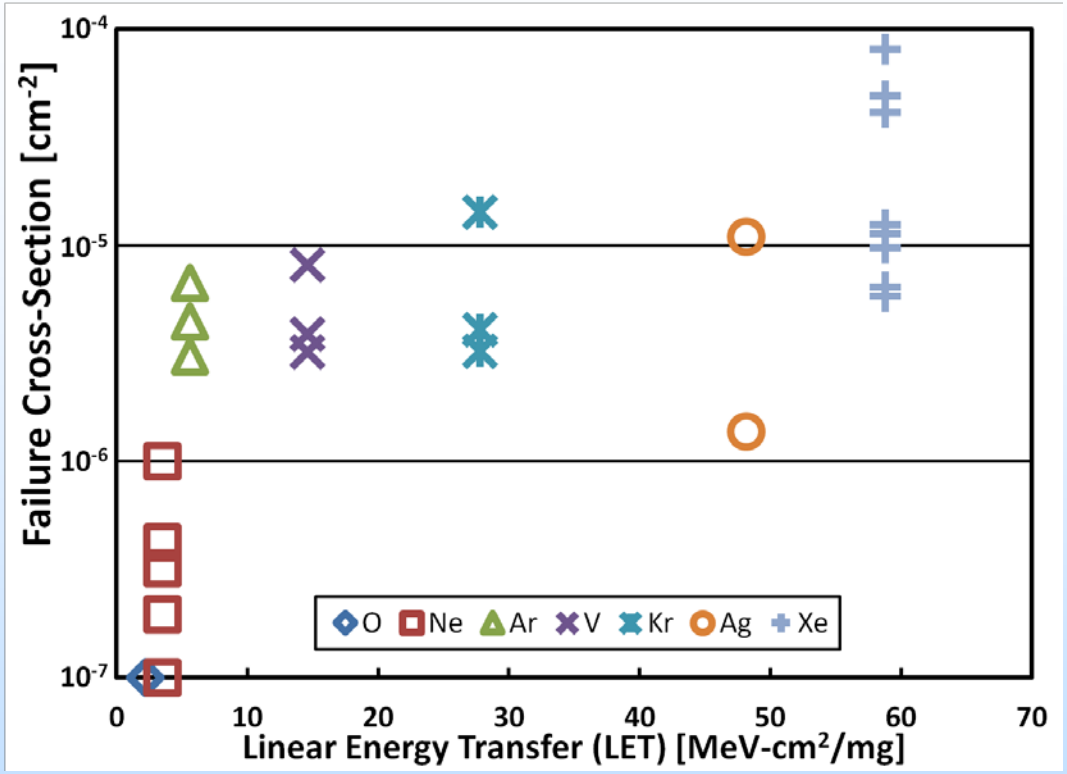
Test Results

ON Semiconductor MBR20200CT



- Difficult to accurately calculate **destructive** SEE cross-sections
- Diodes have a clear onset threshold and seem to saturate at ~1×10^{-5} cm^2
  - No failures were observed with 183 MeV O (LET = 2.19 MeV-cm^2/mg)
  - Failures were observed at 195 V and 200 V with 216 MeV Ne (LET = 3.49 MeV-cm^2/mg)

Test Results
ON Semiconductor MBR20200CT

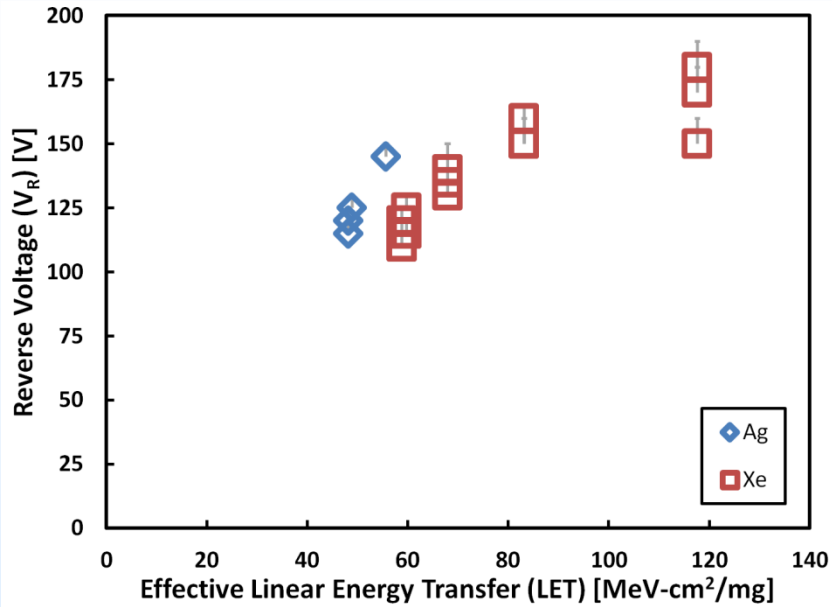
- Using data from the cross-section curve and Cosmic Ray Effects on Micro-Electronics Monte Carlo Code (CRÈME-MC), failure rates can be calculated for different solar conditions in a near-Earth interplanetary/geosynchronous orbit behind 100 mils of Al shielding

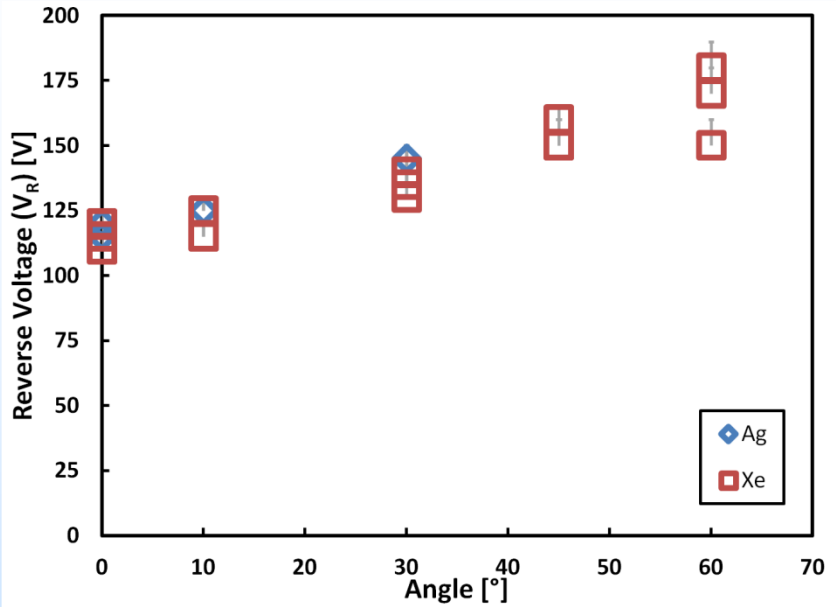
Errors/device-day	
Solar Min	1.66×10^{-5}
Solar Max	4.36×10^{-6}
Worst Week	9.26×10^{-3}
Worst Day	4.64×10^{-2}
Worst Five Minutes	1.74×10^{-1}

Based on the sheer number of diodes flying on any given spacecraft and the length of NASA missions, single-event-induced diode failures could become a serious issue

Test Results

ON Semiconductor MBR20200CT





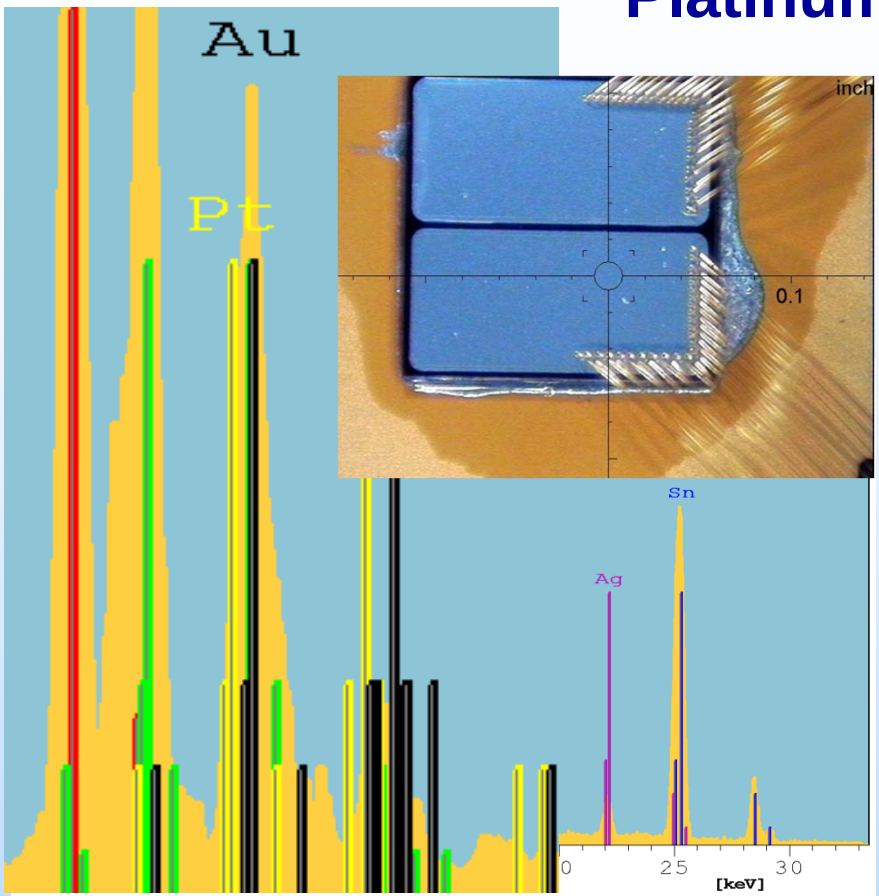
- Last passing voltage does not improve rapidly with increasing angle of incidence
- Data up to and including 45° points follow the cosine law
  - 60° points make trend appear linear

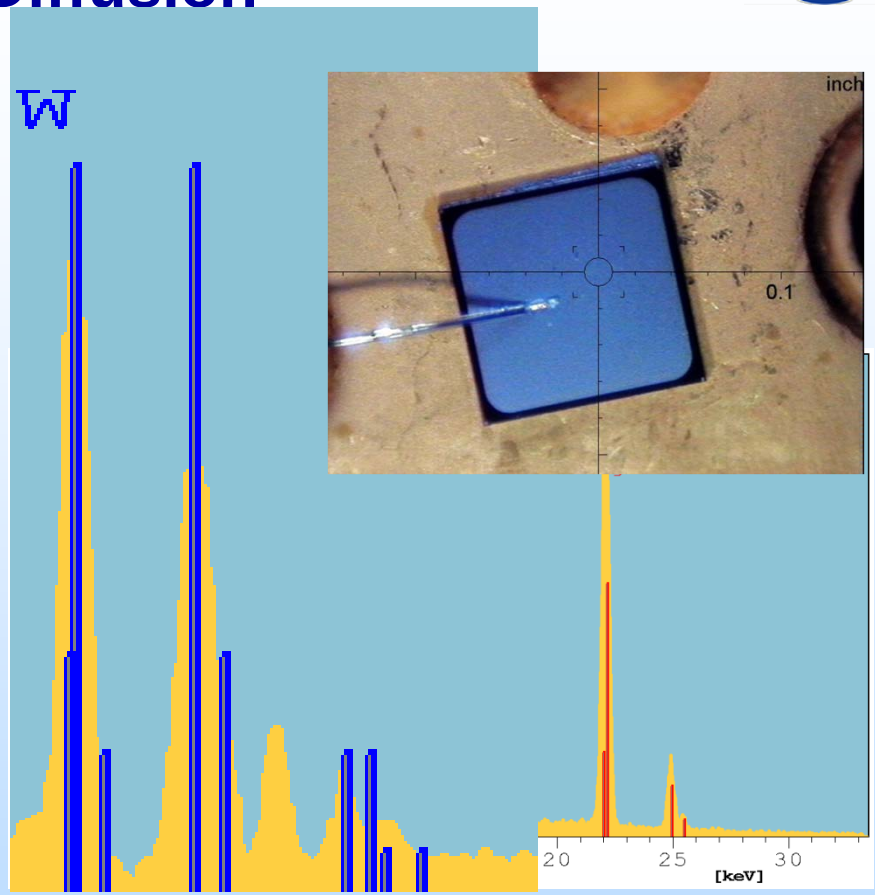
Test Results
Sensitron SD125SB45A

- Schottky diodes were irradiated with 1232 MeV Xe (LET = 58.8 MeV-cm^2/mg) at LBNL and no failures were observed
- During original MTR28515 experiments, the converters saw no destructive failures with TAMU's 1934 MeV Xe (LET = 51.5 MeV-cm^2/mg)
  - Failure occurred in the converter when irradiated with 2714 MeV Ta (LET = 77.3 MeV-cm^2/mg)
- Could indicate:
  - Minimum LET threshold was not met
  - Effect is not a function of LET, but atomic number
  - Something other than an SEE failure was observed in the diode in the converter, latent ESD damage for instance

Possible Source of Failure

Platinum Diffusion





- Learned the 200 V ON Semi parts are diffused with Pt, and found through x-ray flourescence (XRF) that the 45 V parts were not
- Other diode manufacturers have confirmed Pt and Au diffusions in some Schottky diodes

Conclusions and Open Questions

- We have shown that diodes are susceptible to destructive single-event effects
  - Failures occur along guard ring
- 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
- There are still open questions about these failures
  - Are they limited to a single manufacturer, a small number, or all of them?
  - Is there a threshold rated voltage that must be exceeded to see these failures?
  - Are high-Z metal diffusions the cause of the failures?