Device Reliability

TCG-XIV – Munitions Reliability and Lifecycle Technology

Sandia National Laboratories

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‘TCG XIV COTS Reliability’ Key Personnel

Name	Org	Role
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Andrew Sandoval asando1@sandia.gov 505-844-5588		Electrical Device Measurement

240K project (120K from DOD)

Outline

- Project Overview
- FY19-23: Five Year Plan
- Technical Update

'Device Reliability' Goal & Objectives

Goal:

Develop Physics-of-failure (PoF) approaches to verify, validate and reliably model aging and the long-term behavior of COTS electrical components.

Objectives:

- **Evaluate failure modes for new or changed device technologies, capacitors, plastic encapsulated magnetics, lead free solder, devices with copper wirebonds.**
- **Investigate novel, non-destructive techniques to detect failure precursors and an improved understanding of degradation processes in COTS electronic devices resulting in a predictive assessment of device behavior.**
- **Develop, calibrate, verify and validate compact lifetime prediction models (small number of input parameters, coarse component description) using long-term dormant storage (LTDS) data and available stress-test and field results.**

‘Device Reliability’
DOE/DoD Gaps, Needs, Challenges

- COTS components are designed to last the lifetime of a cell phone or an automobile. DOD and DOE applications need 20-30 lifetimes with a significant dormant storage requirement and single use high reliability component to that requirement.

- Specifications are forgiving, often devices function within a narrow region of their specified range. They can change behavior over time or exposure, impacting the performance of a circuit yet still operate within their specified requirement.

- Devices (and device lots) exhibit variability. Separating out the lot variability from change in device behavior due to aging can be difficult.

‘Device Reliability’ Impact

Will provide:

- Non-destructive techniques to detect failure precursors for predictive assessment of electrical components.
  - Statistical analyses
    - Power Spectrum Analysis/Principle Component Analysis of aging or defective components.
    - Functional Statistics Methodology for characterizing device variability
  - Parameter Extraction used as model inputs for circuit analysis.

- physics-based reliability assessments (this includes models!), applicable to current and emerging technologies, for mission critical components and systems.

- Improved understanding of component degradation in field and storage environments.

Information to get to Dsktl

Buchheit, T.E., Wilcox, I.Z., Sandoval, A.J. and Reza, S. “Zener Diode Parameter Extraction Using Xyce-Dakota Optimization”, SAND2017-1370

Tangyunyong,Paiboon (SNL); Cole, Edward I. (SNL); Loubriel, Guillermo M. (SNL); Beutler, Joshua (SNL); Udoni, Darlene Meloche (SNL); Paskaleva, Biliana Stefanova (SNL); Buchheit, Thomas E. (SNL), Power Spectrum Analysis (PSA), 43rd International Symposium for Testing and Failure Analysis (ISTFA).

Tangyunyong P., Paskaleva, B. S., Udoni, D. M., Buchheit, T. E., Loubriel, G. M., Stinnett, R.W., Cole, E. I.,”Aging Detection in Zener Diodes Using Power Spectrum Analysis (PSA)”, in GOMACTech 2016 conference proceedings.

Buchheit, T.E., Lopez, J.R. et al. “Evaluation of the Mechanical Reliability of a single axis MEMS Gyroscope”, SAND2018-XXXX

FY19 – FY23 Five Year Plan: List of Milestones/Deliverables

Subtask	Milestones / Deliverables	Completion Date (FY)
06.1	SAND Report on statistical approach for diode data analysis	Q1-FY19
06.02	Documentation of Results from diode copper wire bond study Begin follow-up testing on different data code zener diodes	FY19
06.03	Ta Capacitor study begins	FY19
06.04	2nd report on results from Diode study	FY20
06.05	Results from Ta capacitor study passed to AMRDEC	FY20
06.06	Guidance provided based on Ta Capacitor study results	FY21
06.07	Report on Ta capacitors Study	FY22
06.08	Information generated from both studies to provide guidance for aging, trust and circuit modeling of COTS electronics	FY18-23

U.S. DEPARTMENT OF ENERGY

Technical Update 'Device Reliability'

- Aging and assessment of 3 diodes with Copper Wire-bonds:
  - MMSZ5221BT1-D Zener Diode
  - BAS20LT1G Schottky Barrier Diode
  - BAT54ALT1G High Voltage Diode

- Interrogation of LM2940-N Voltage regulator with PSA / Decap of 'faulty' devices *(off line)*

- Ta Capacitors

Aging and Copper wire bond assessment of three diodes

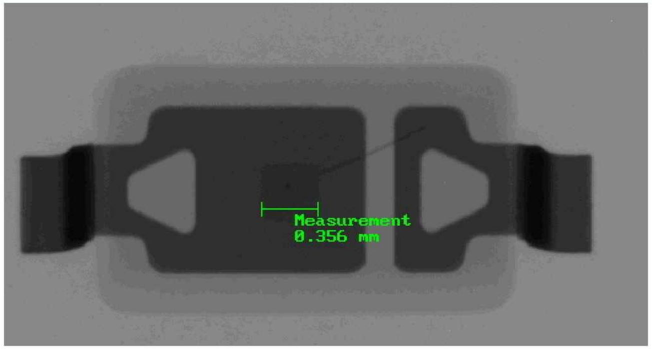
Device	Sample Size	Test Cycle	Aging Time (Intervals)	Characterization			
				SEM	TEM	PSA/ PCA	Elec. Meas.
BAS20LT1G **High Voltage Diode**	100-120	Age 140ºC	500,1000,1500,2000 hrs.	x	x	x	
	100-120	Age 150ºC	500,1000,1500,2000 hrs.			x	x
	100-120	Precondition + Age 150ºC	500,1000,1500,2000 hrs.				x
MMSZ5239BT1 **Zener Diode**	100-120	Age 140ºC	500,1000,1500,2000 hrs.	x	x	x	
	100-120	Age 150ºC	500,1000,1500,2000 hrs.	x		x	x
	100-120	Precondition + Age 150ºC	500,1000,1500,2000 hrs.	x			x
BAT54 ALT1G **Schottky Diode**	100-120	Age 140ºC	500,1000,1500,2000 hrs.	x	x	x	
	100-120	Age 150ºC	500,1000,1500,2000 hrs.			x	x
	100-120	Precondition + Age 150ºC	500,1000,1500,2000 hrs.				x

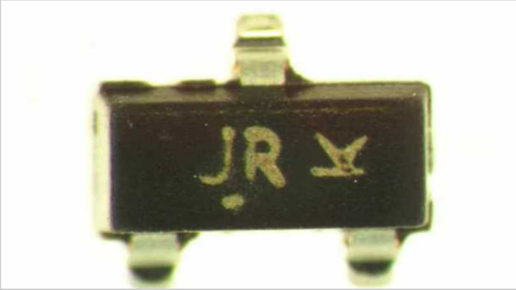
Preconditioning: 30ºC 60%R.H. 192 Hrs.
Reflow: 3 cycles at 260ºC

- Schottky Diode aging and characterization
- Functional data analysis on Zener diode

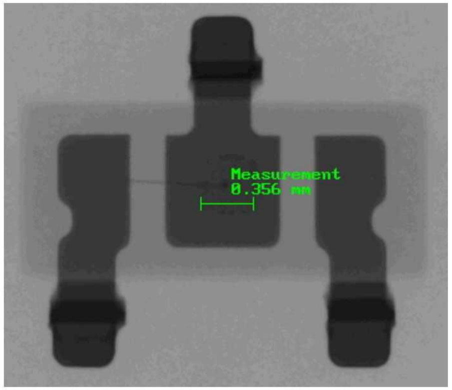
COTS Diodes – Simple, small and cheap devices

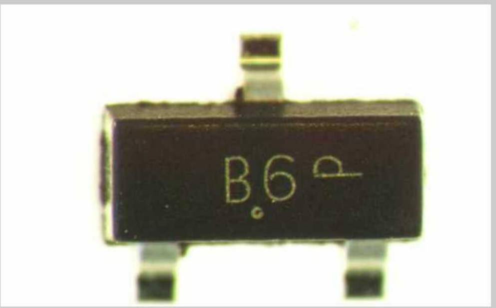
MMSZ5239BT1G
Zener Diode
9.1V 500 mW,
SOD123,
Cu wire bond



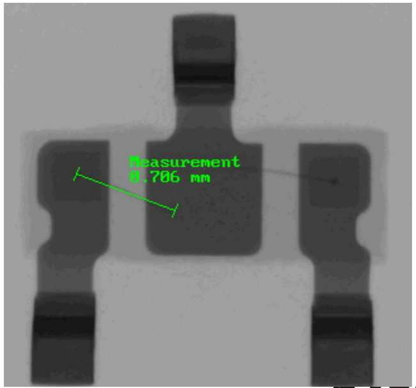


BAS20LT1G
High Voltage
Switching Diode
200V
SOT23
Cu wire bond



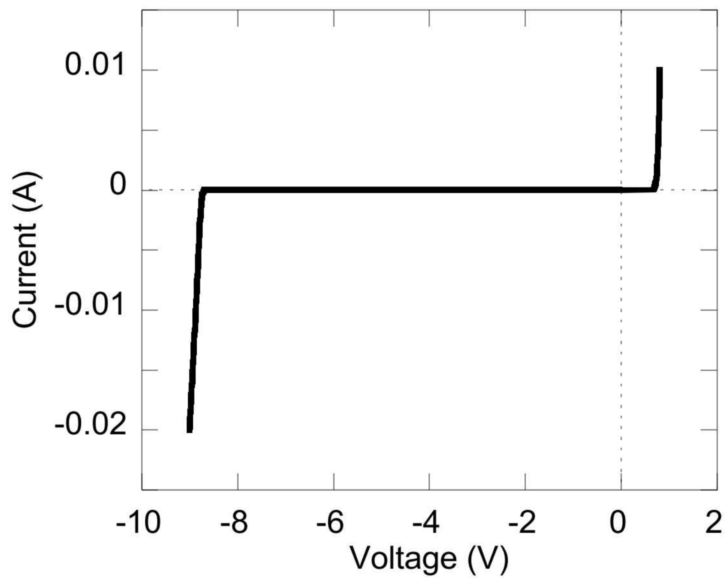


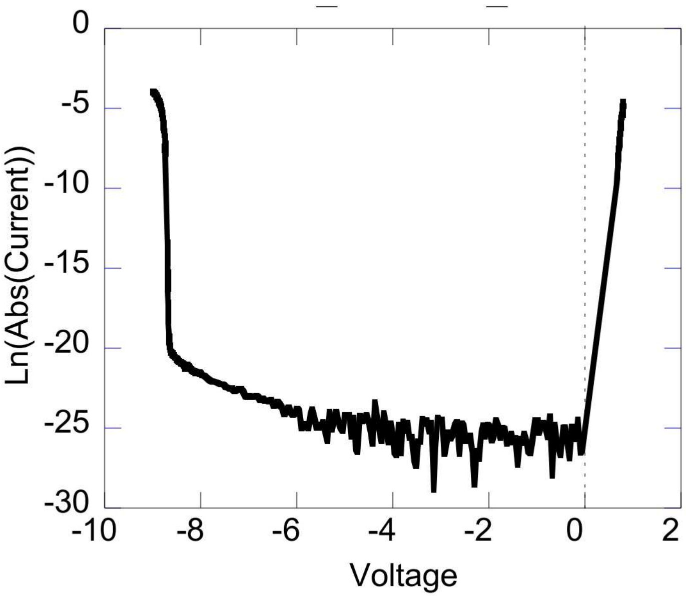
BAT54ALT1G
Schottky Diode
30V 200 mA SOT23
Cu wire bond



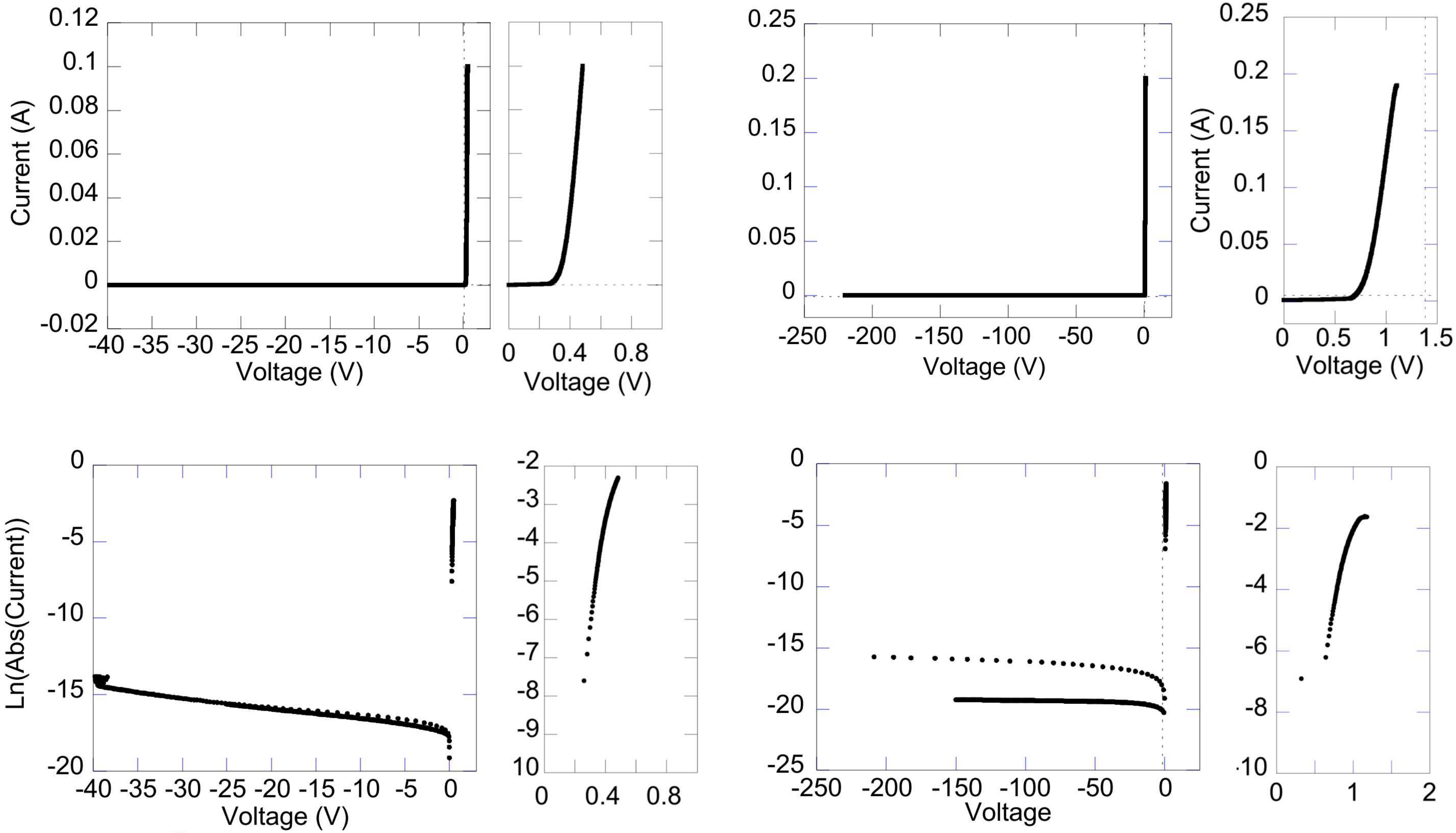
U.S. DEPARTMENT OF ENERGY

Typical Diode Behavior (Measured) - Zener Diode





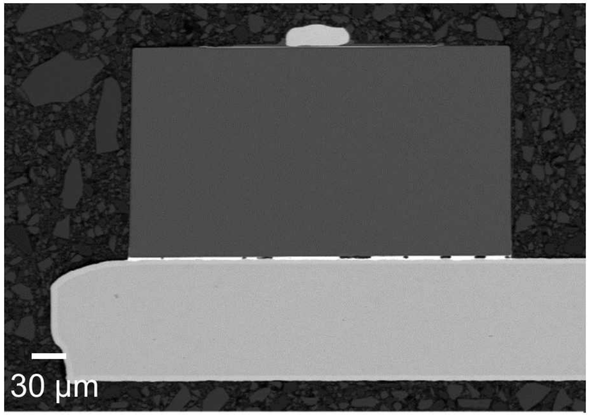
Typical Diode Behavior – Schottky and HV Diodes

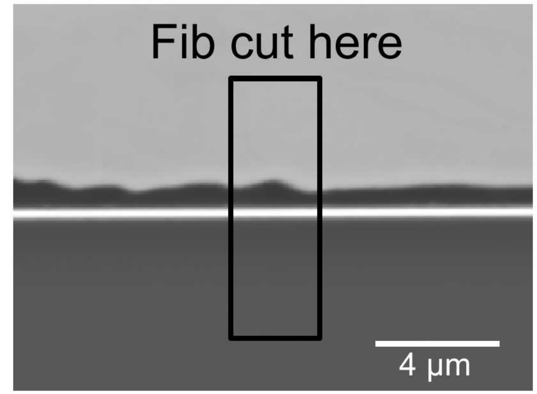


Cross sectioning and characterizing Diode wirebonds

Cross section of the Schottky Diode wirebond

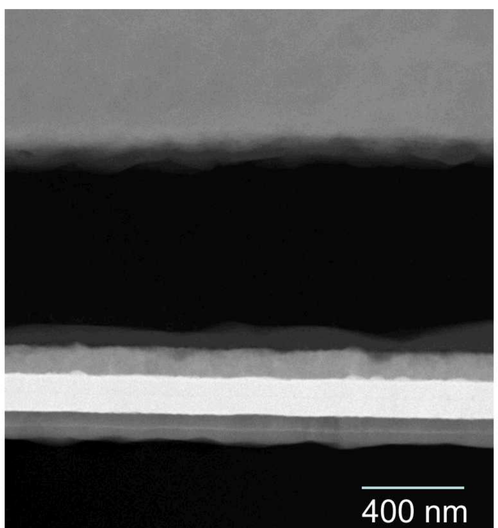
SEM images



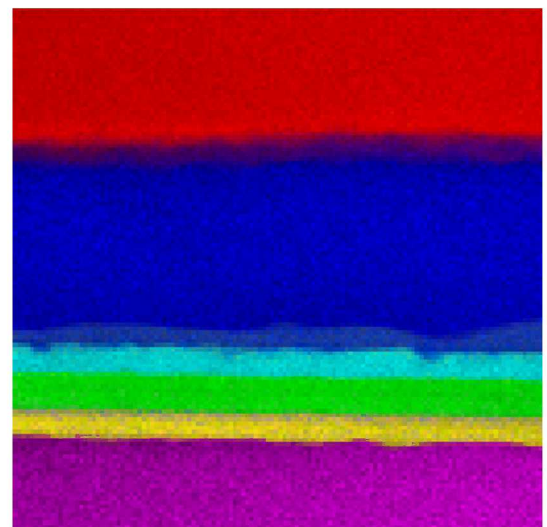


TEM images

Annular dark-field STEM image

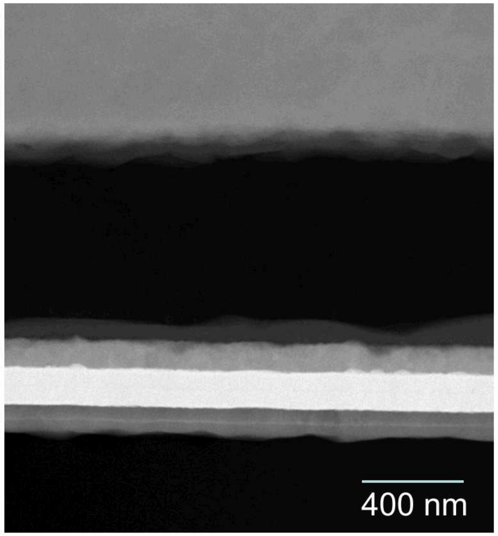


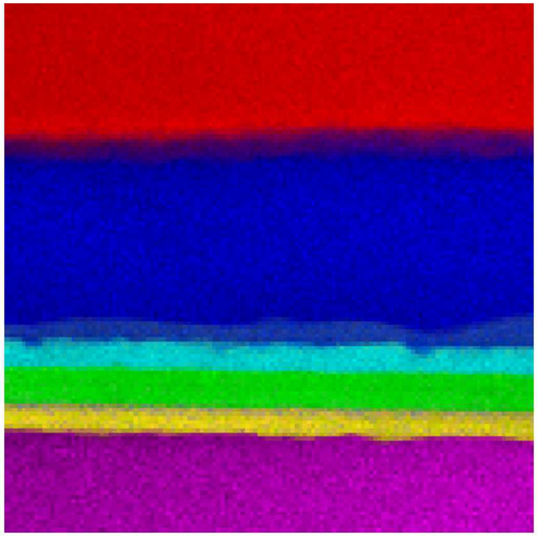
Energy Dispersive X-ray spectroscopy map



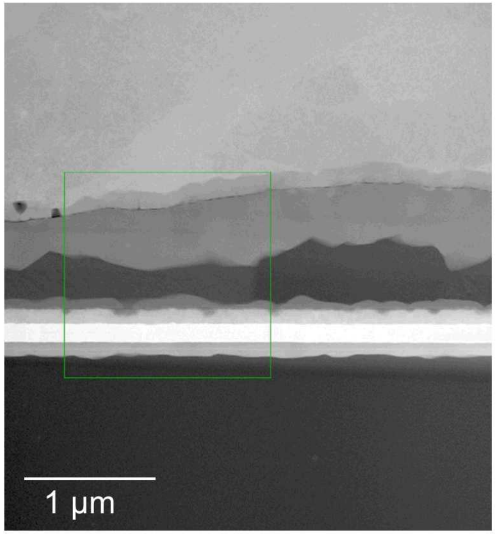
Changes in Cu/Al wirebond and Schottky Barrier due to aging

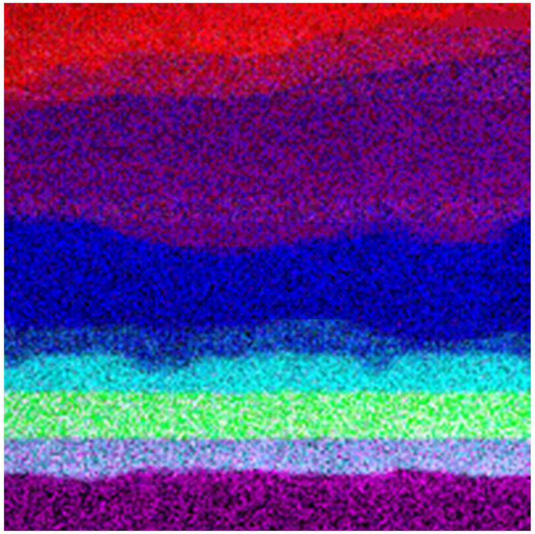
Pristine



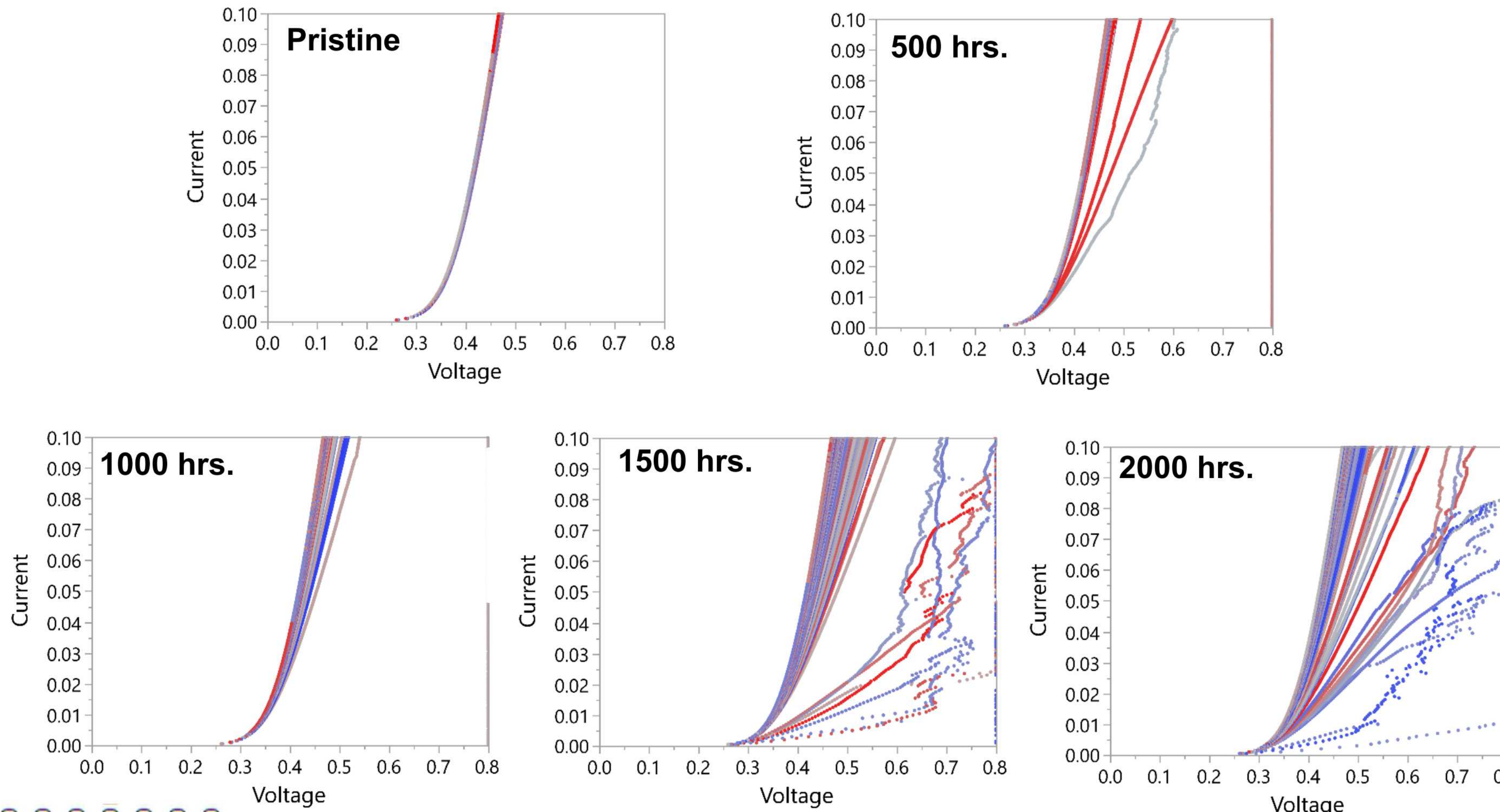


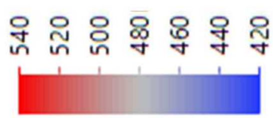
Aged 2000hrs./140ºC





Forward behavior of Schottky Diodes as a function of aging

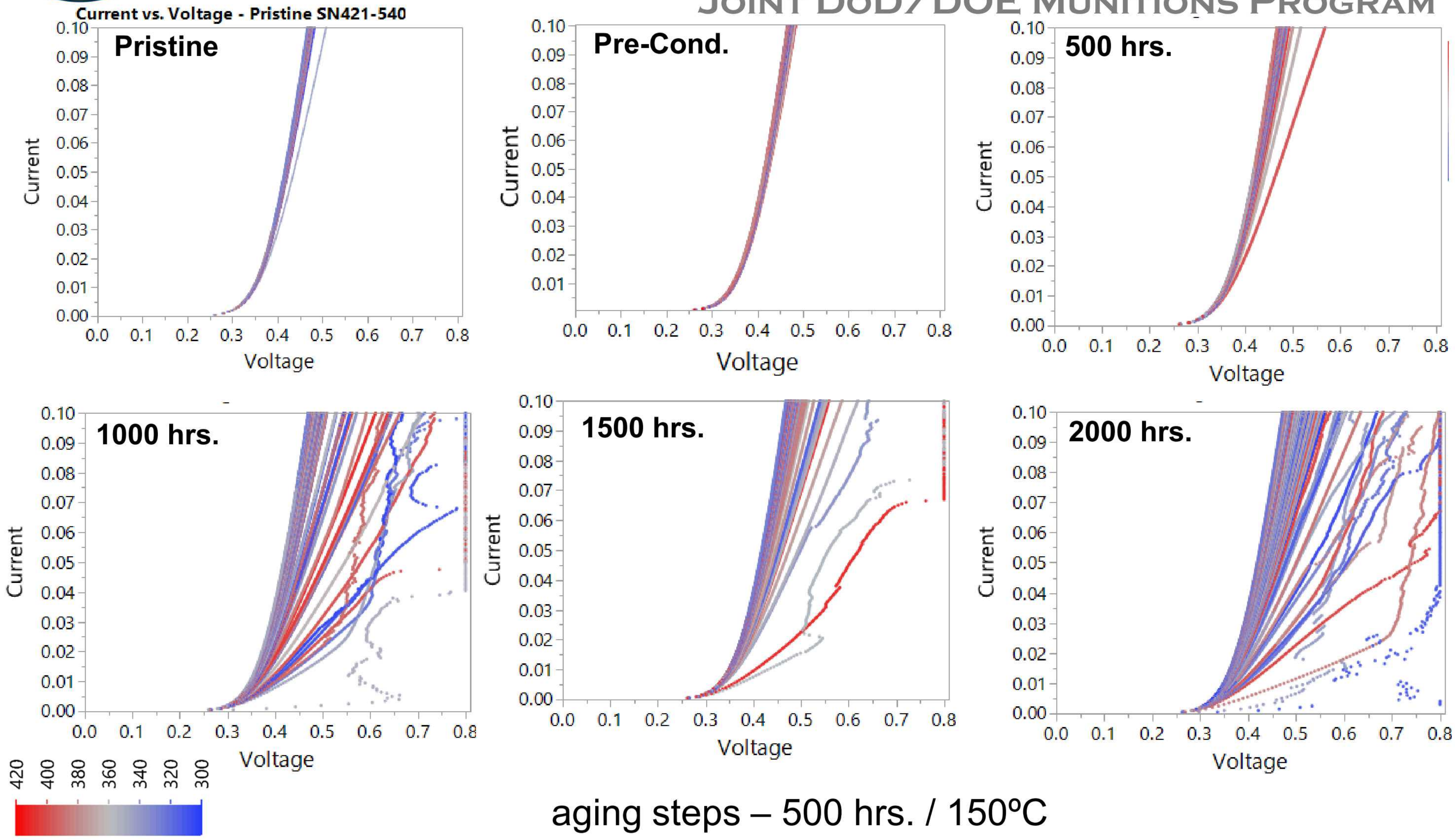




SN#

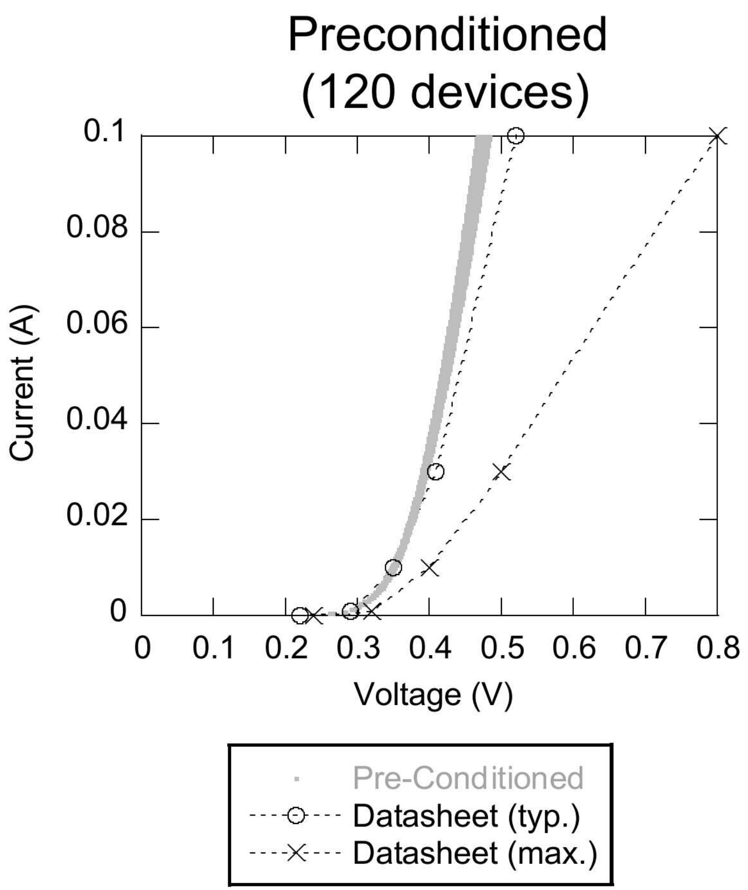
aging steps – 500 hrs. / 150ºC

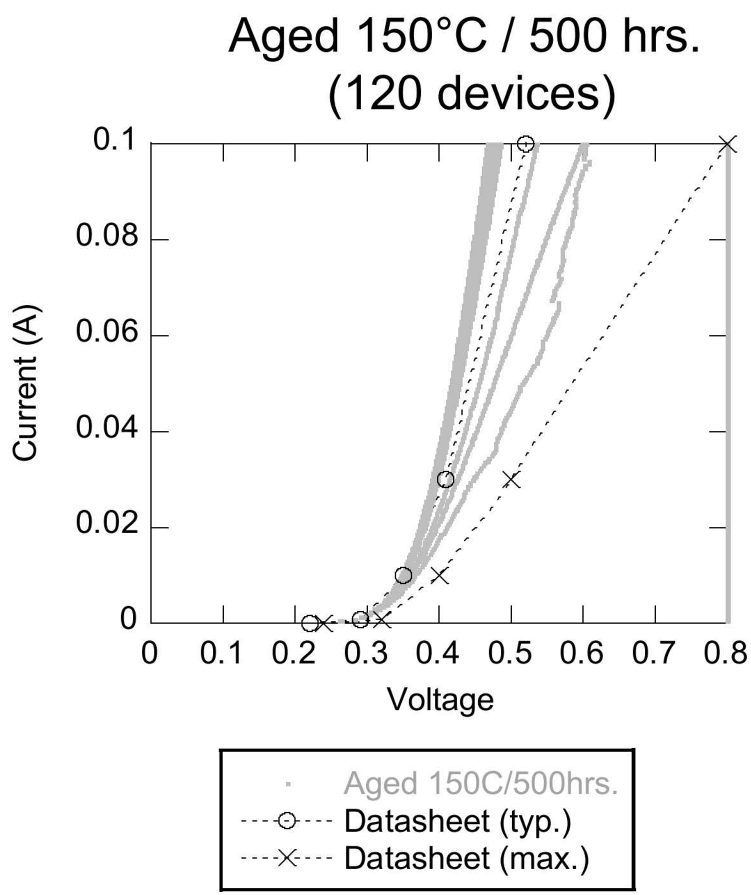
Forward behavior of Schottky Diodes as a function of aging *(includes pre-conditioning cycle)*



aging steps – 500 hrs. / 150ºC

COTS device specifications are very forgiving



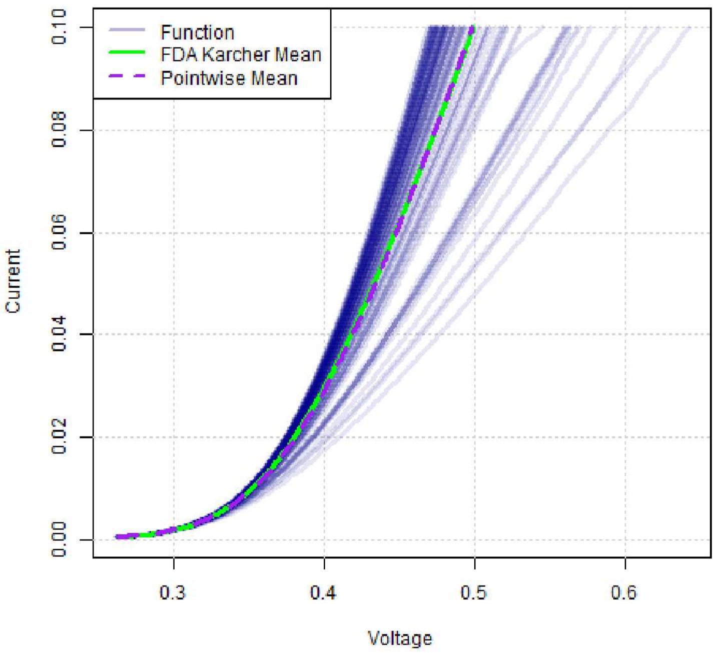


- *Reverse leakage behavior*
- How do we screen for 'future' outliers?
- How do we characterize the distribution for circuit modeling?

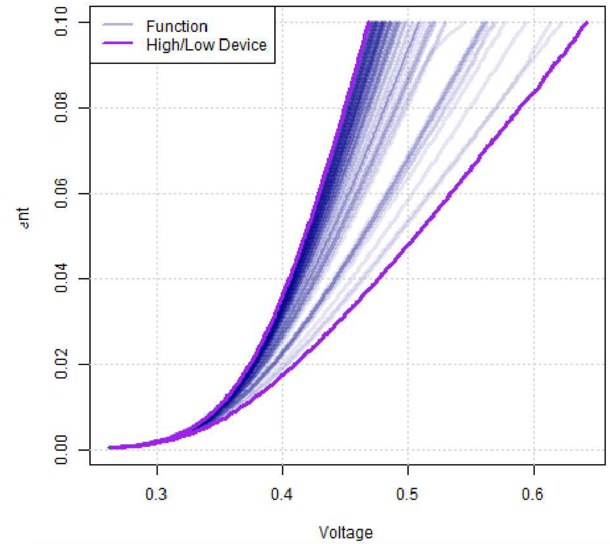
Statistically analyzing the Schottky Diode Data <u>Aged 150°C 2000 hours</u>

FDA- Functional Data Analysis

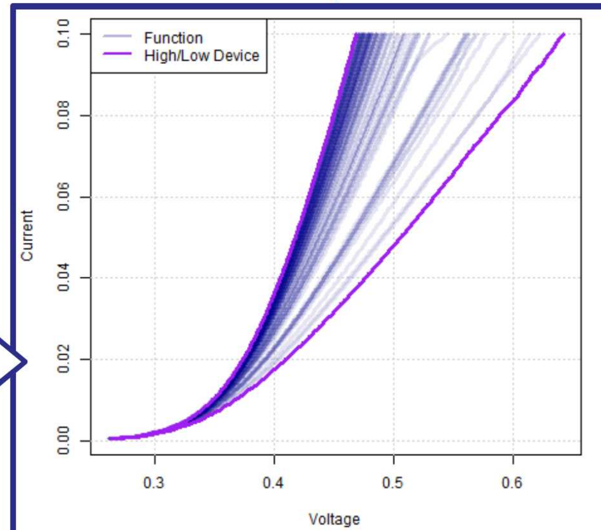
Comparison of Karcher and pointwise means



Simple high/low chosen as highest/lowest voltage at max current

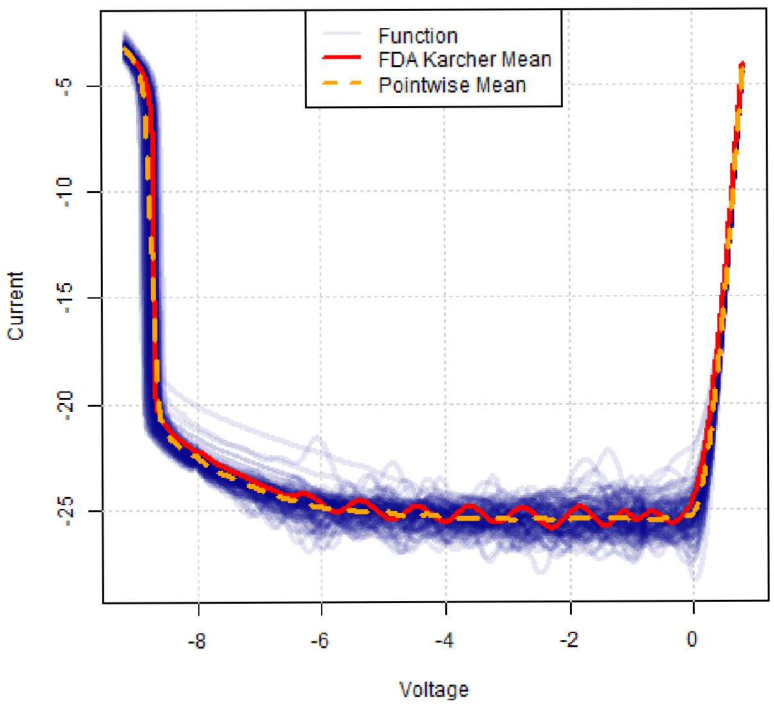


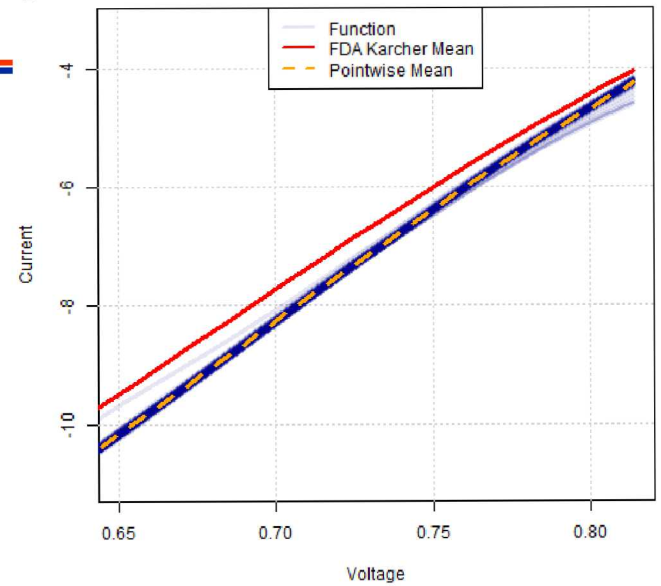
FDA high/low chosen devices with largest distance from Karcher mean

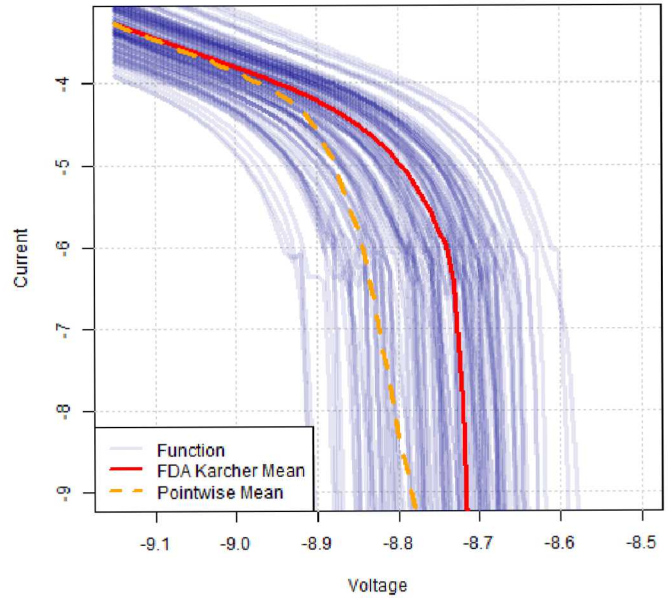


FDA On Spline Fit

Karcher vs. Pointwise Mean







Surge Step Stress Test on Ta Capacitors -as a failure analysis method

- Assumed mechanism is voltage breakdown of dielectric
- Voltage pulses of increasing magnitude

**Typically Mounted on a circuit board using IR-reflow solder process*

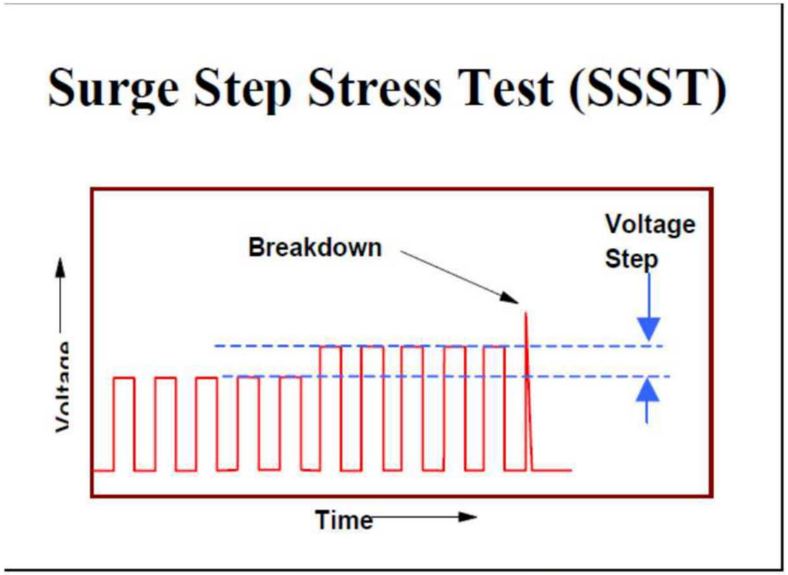
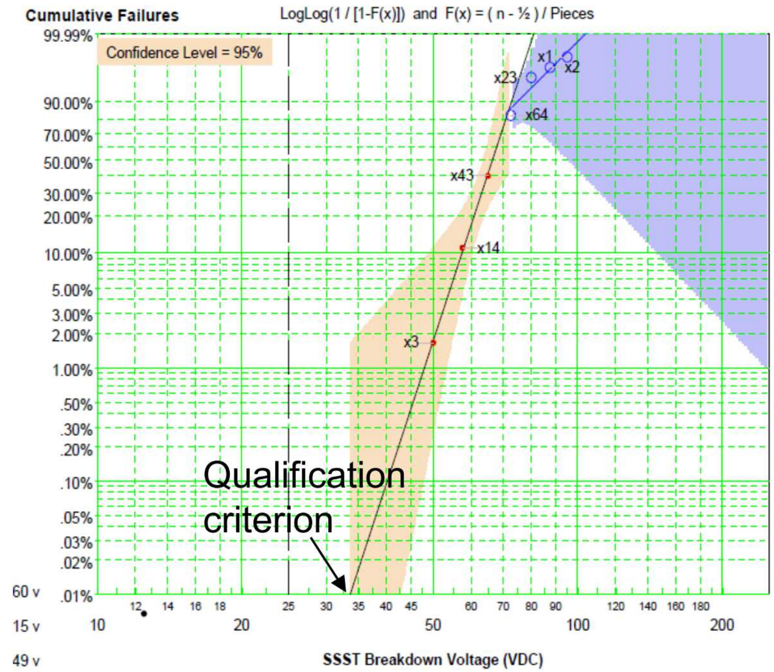


Fig. 3. Increasing voltage pulses of SSST test.

Typical Result



VDC	%Cumulative Fail
6.25	0 PPM
12.50	0 PPM
18.75	0 PPM
25.00	2 PPM
35.45	200 PPM
38.04	500 PPM
40.12	1000 PPM

What do SSST distributions reveal?

Proposed Test Plan: SSST

Ta Capacitors

Part Number:

T409H156K025BC4251 (T409) 25V, 15 uF

2 grades: MIL SPEC and F-TECH

(CWR09KC156KBB)

Reference Measurements

No. of Devices	Meas.
20	Electrical testing
20	Electrical testing
20	Electrical testing

Test Measurements

No. of Devices	Test Step	Measurements	Devices consumed
480	Pristine	Electrical testing + SSST	80
400	Pre-cond.	Electrical testing + SSST	80
320	Age Step #1	Electrical testing + SSST	80

Electrical Testing: Leakage, Capacitance, Dissipation

SSST: Statistical Voltage vs. Breakdown data

Summary

- **Project Overview**

  Reviewed a set of programmatic slides following JMP template

- **FY19-23: Five Year Plan**

  Listed a set of milestones/deliverables which will anchor the five year plan document

- **Technical Update**
- **Schottky Diode wirebond characterization and forward sweep results due to aging**
  - **Degradation of bond, increase in spread of forward sweep as a function of aging**
  - **Statistical analysis of electrical behavior, forward sweep of**