SAND2018-13548PE

JOINT DOD/DOE MUNITIONS PROGRAM

COTS Device Reliability

TCG-XIV – Munitions Reliability and Lifecycle Technology

Sandia National Laboratories

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Fall Technical Update
Nov. 2019

'TCG XIV COTS Reliability' Key Personnel

Name	Org	Role
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Kenny Leeson asando1@sandia.gov 505 844-5588	Sandia DOE Lab	Electrical Device Measurement

240K project (120K from DOD)

‘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’ 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.**

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

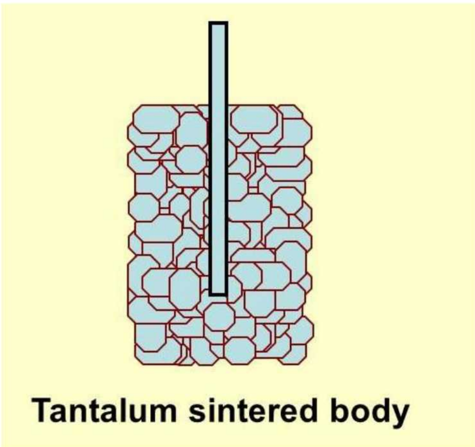
Technical Update ‘Device Reliability’

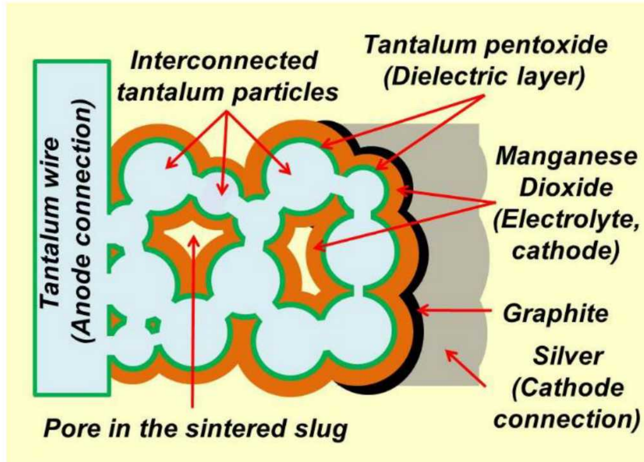
- Tantalum Capacitors
  - Results from small study on VISHAY T97Z476 and KEMET T541X226 capacitors
  - Follow up with AMRDEC and KEMET

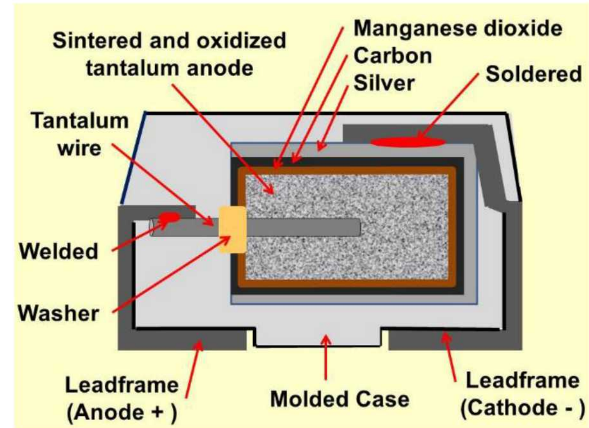
- Aging and assessment of diodes with Copper Wire-bonds:
  - MMSZ5221BT1-D Zener Diode
    - Comparison between automotive grade and standard COTS grade devices
    - 'Selection of a Nominal Device Using Functional Data Analysis'

- Selection of a Nominal Device Using Functional Data Analysis

Ta Capacitor – General Construction







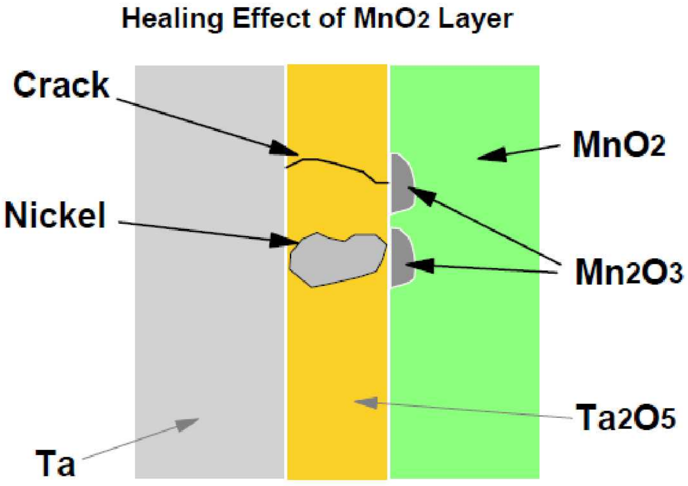
- Thin, 0.1-1 µm, well adhered oxide (Ta_2O_5) on all surfaces of the sintered Ta body acts as the dielectric.
- MnO_2 coating on Ta-oxide body acts as cathode.
- Alternatively, an Organic conductive polymer (PEDOT given as an example) is used as a cathode

[Prymark, IEEE, 1998]

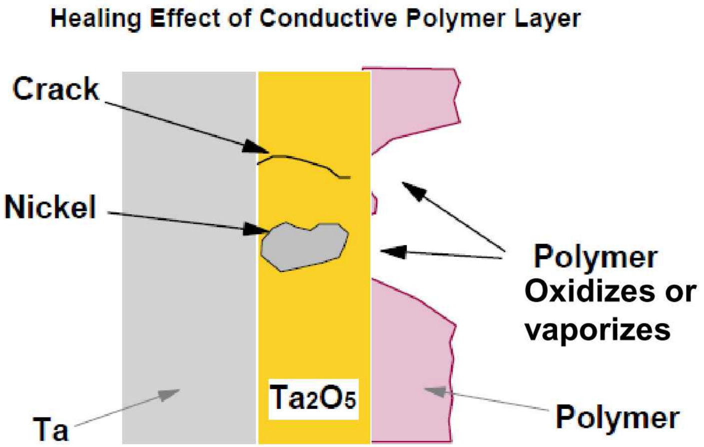
Self-Healing Mechanisms in Ta capacitors

An important characteristic – often associated with the reliability of Ta capacitors

MnO_2 cathode capacitors



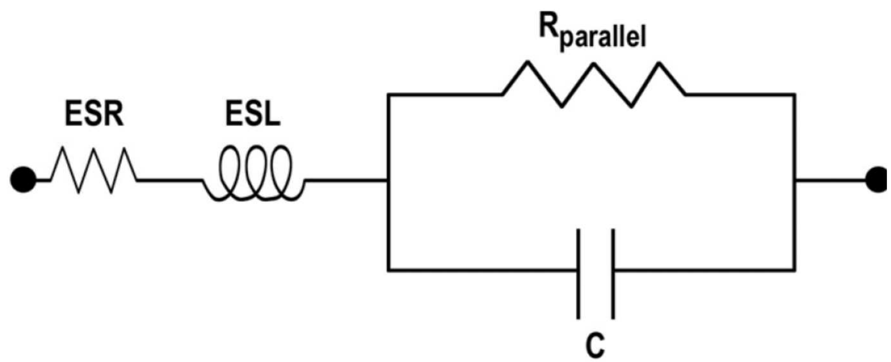
Polymer cathode capacitors



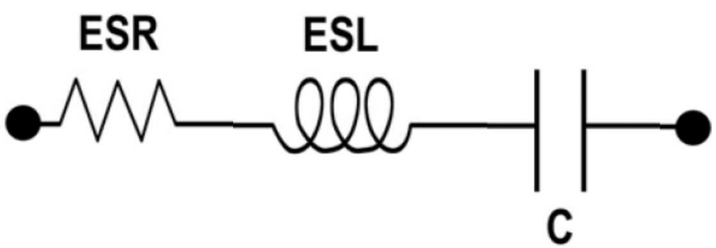
- **MnO_2 - Mn_2O_3 phase change is regarded as key self healing mechanism**
- **Ta capacitors are usually conditioned to grow Mn_2O_3 or vacate the polymer near defects in the dielectric layer.**

Capturing the behavior of a real capacitor with an electrical model

Capacitor Model

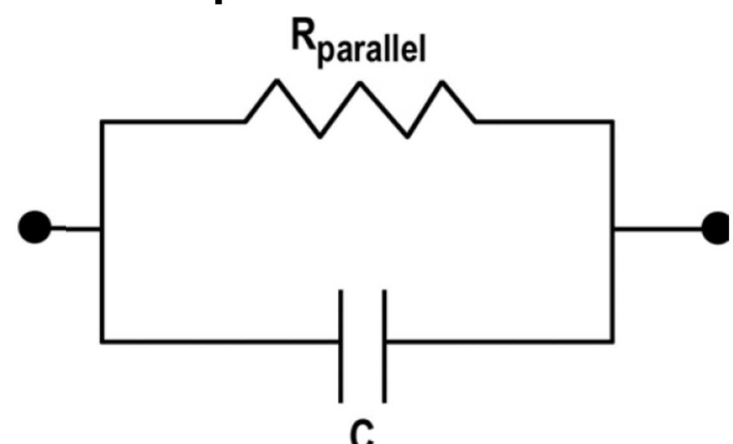


AC signal isolates this portion of the circuit



Series RLC circuit

DC signal isolates this portion of the



Provides a measure of the current leakage through the Dielectric

Capacitors tested as part of the APBA board study

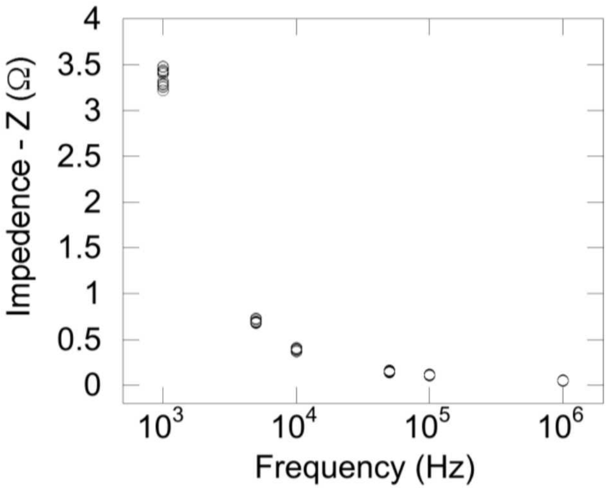
Capacitor Type	Lot ID	No. of Samples tested	Voltage Rating	Capacitance	Max Leakage at 25C	Max DF at 25C 120Hz	Max ESR at 25C 100 kHZ
VISHAY **T97Z476**	11667169 **17Nov**	16	50	47 ± 4.7 µF	23.5 uA	6%	0.24
	11667169 **1746**	16					
	11755887 **1747**	16					
	11841192 **1807**	16					
KEMET **T541X226**	1637DK30E -DC-**1637**	28 10	50	22 ± 4.4 µF	110 uA	10%	0.75
	1720CJ91B	28 10					

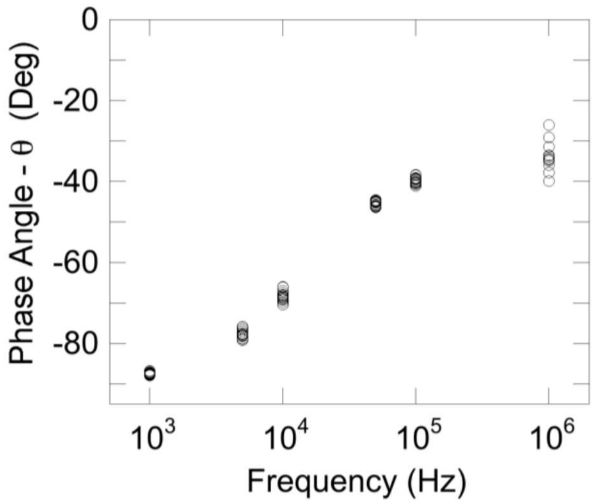
- **VISHAY T97 Capacitors –** Production 'Lot to Lot' variability across 4 lots
- **KEMET T541 Capacitors –** Comparison of 2 different lots and the effect of additional 'burn in'

Example: AC measurement results on a capacitor (16 capacitors 'T97-17Nov')

35 V Bias applied across each capacitor
Frequency is logarithmically stepped from 10^3 Hz – 10^6 Hz

Measured Results





Measured Results ➔ Calculated Values

$$Z = -\frac{j}{2\pi fC} \qquad Z\sin\theta = -\frac{1}{2\pi fC}$$

Pure capacitance- Voltage lags current by $\pi/2$
$-\pi/2$ to 0 – capacitive circuit

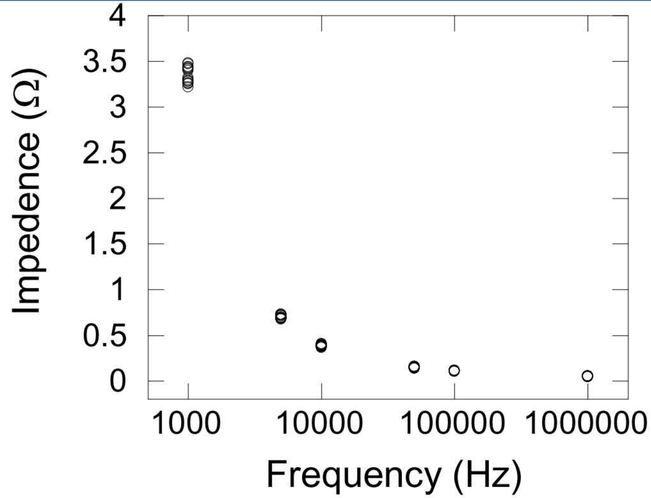
$$Z = j2\pi fL \qquad Z\sin\theta = 2\pi fL$$

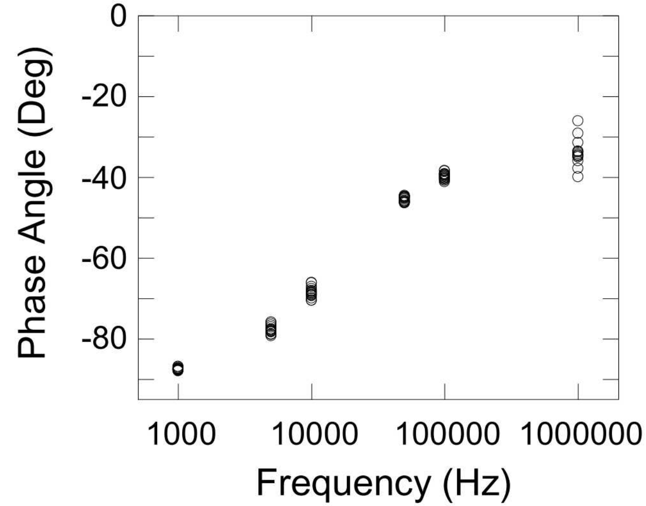
Pure inductance- Voltage leads current by $\pi/2$
0 to $+\pi/2$ – inductive circuit

ESR = $Z\cos\theta$ *Equivalent Series Resistance*

DF = $\cot\theta$ *Dissipation Factor*

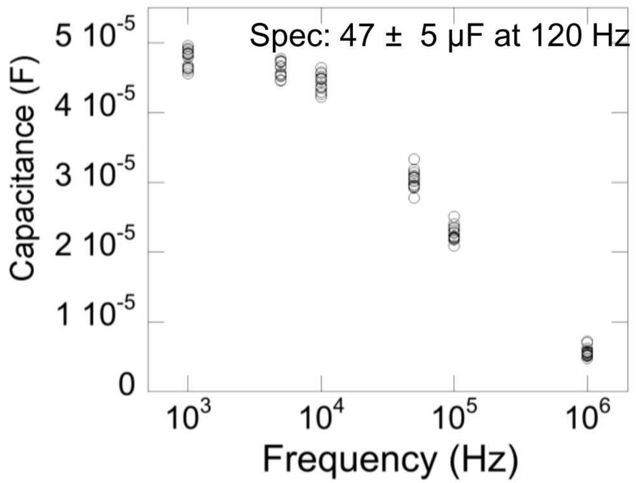
Variability exhibited on 16 devices from the same production lot (T97-17Nov)

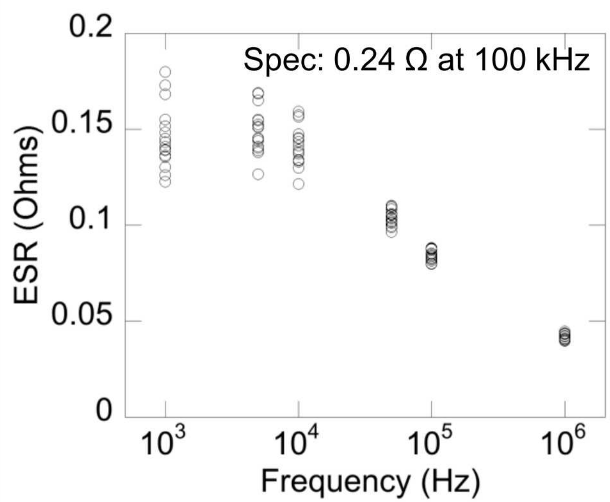


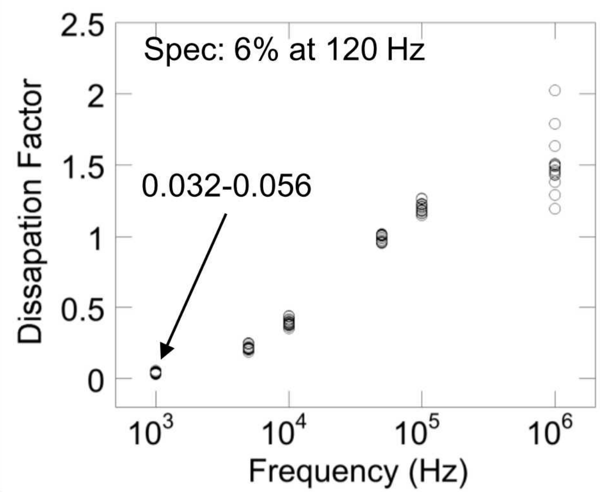


Measured

Calculated

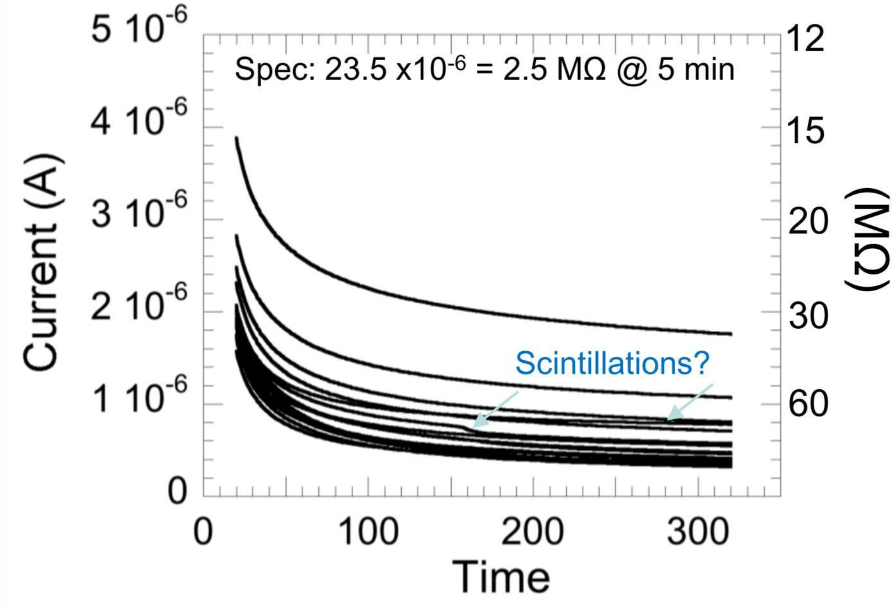






Isolating Device to Device variability

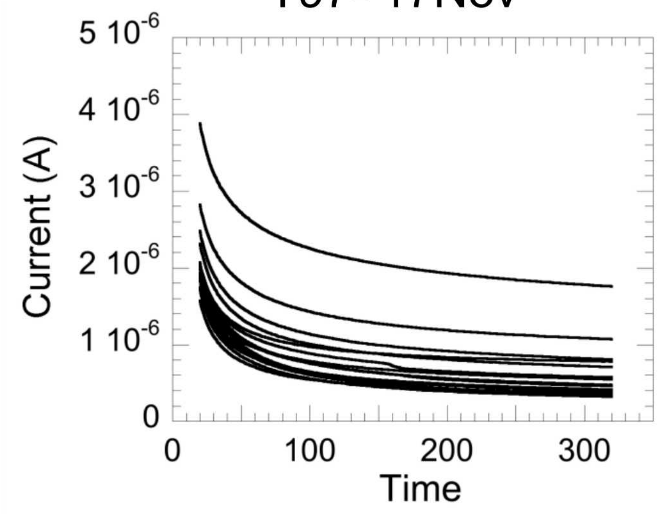
Example: DC Measurement Results across a capacitor (16 capacitors T97-17Nov)



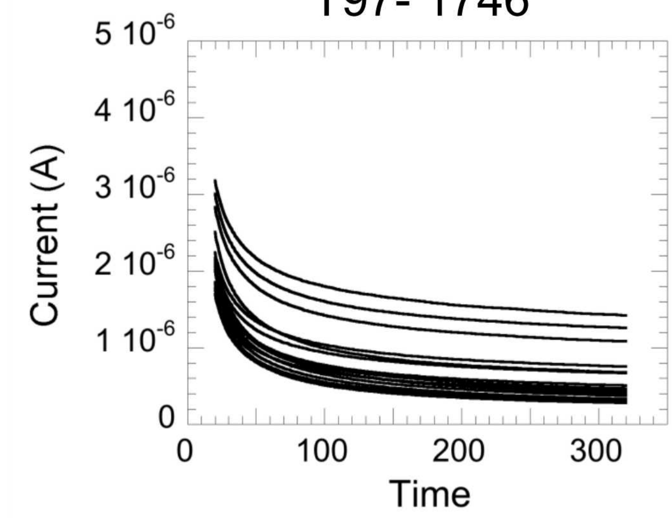
- Devices held at 60 V for 5 min
- Evaluation of *current leakage* across the dielectric
- Series RC circuit, expect an exponential decay in the DC current vs. time signal.
- Can estimate dielectric resistance using these measurements

Observed variability in leakage measurements across four production lots – 16 devices from each lot

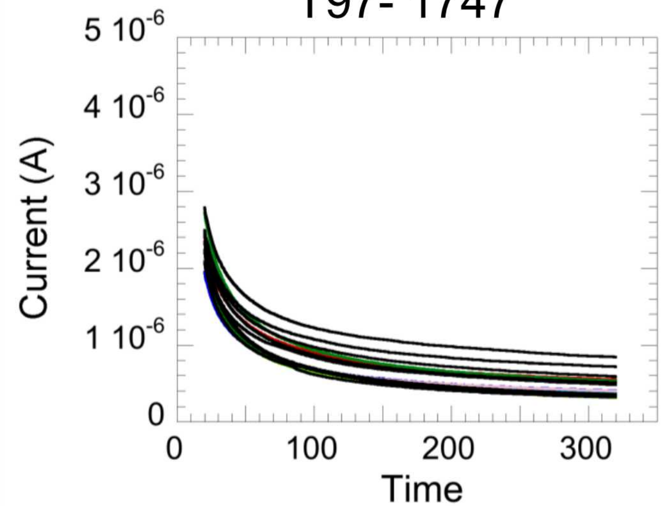
T97- 17Nov



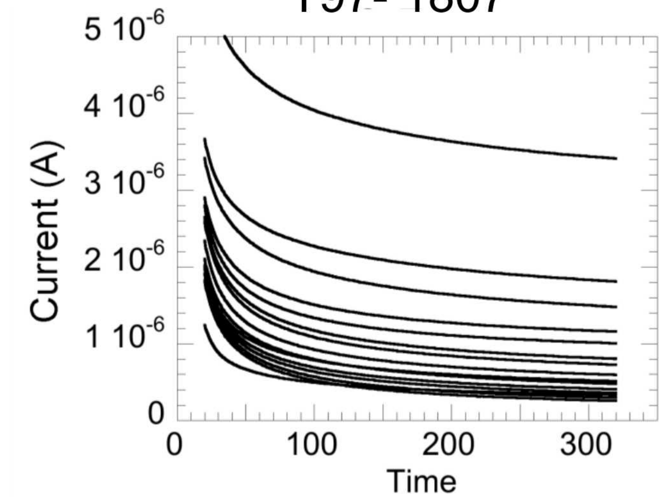
T97- 1746



T97- 1747



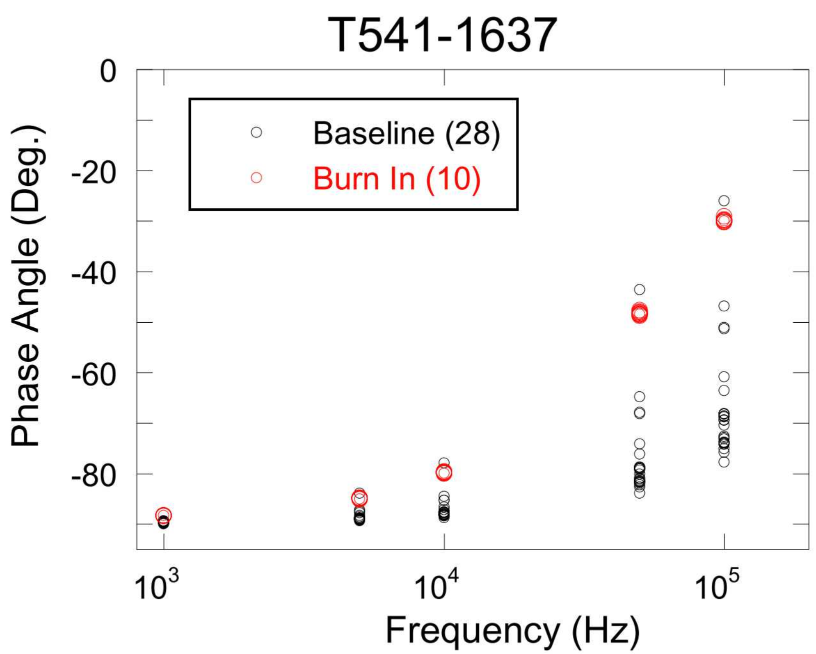
T97- 1807

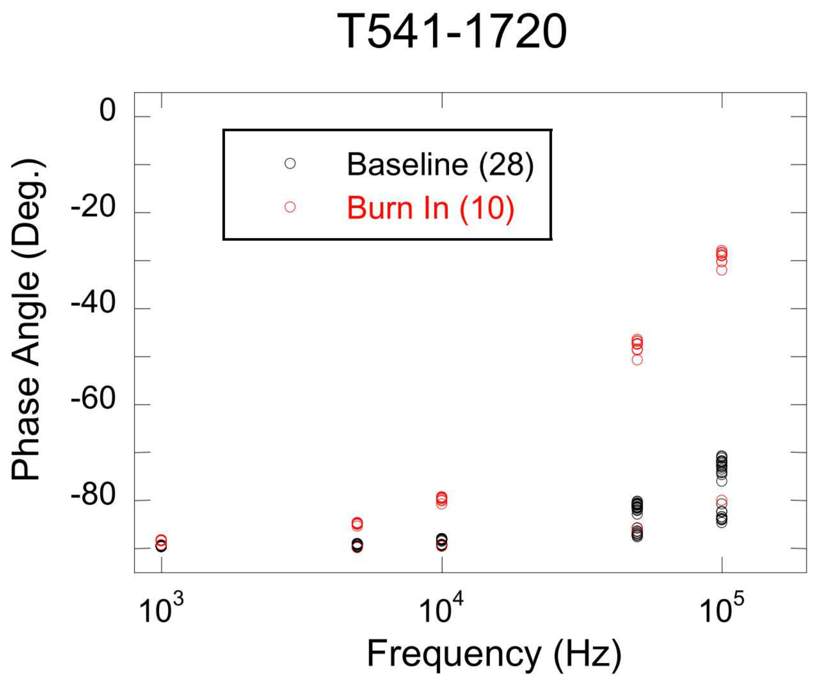


Spec: 23.5×10^{-6} = 2.5 MΩ @ 5 min

T541 capacitor testing - additional 'burn-in' revealed a significant change in their electrical behavior

- 28 devices each from 2 separate lots were tested
- 10 devices from each lot were subjected to 'additional burn-in' then retested.
- 'additional burn-in' - Device held at their rated voltage and 85°C for 20 hrs





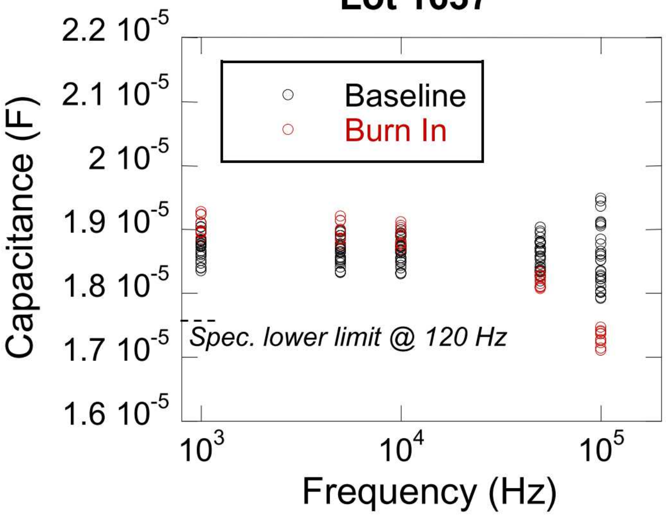
Burn-in provides an opportunity to improve the integrity of the dielectric layer by invoking the healing mechanism at any processing defects or by annealing within the layer.

T541 AC measurements

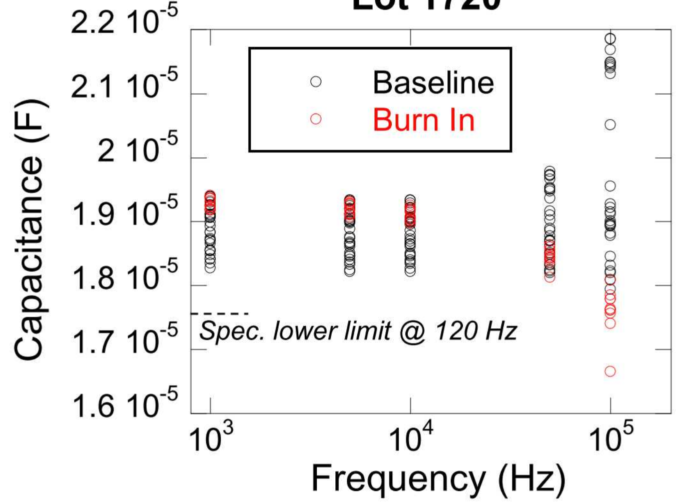
Rated Capacitance = 22 µF

Capacitance vs. Frequency

Lot 1637

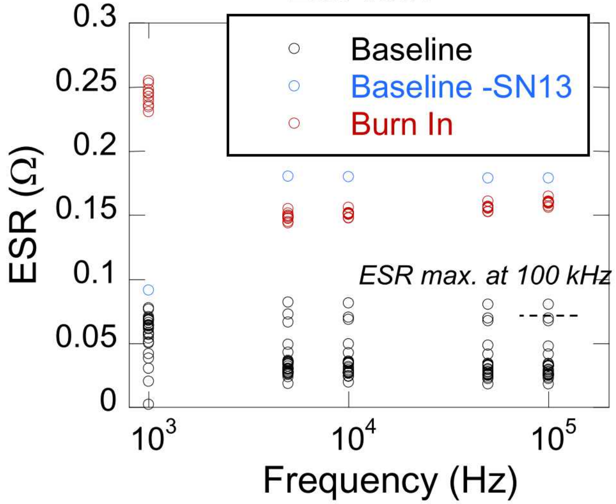


Lot 1720

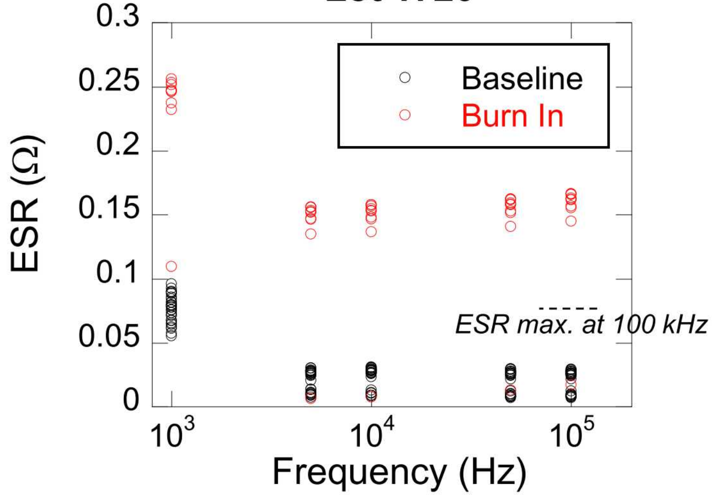


ESR vs. Frequency

Lot 1637



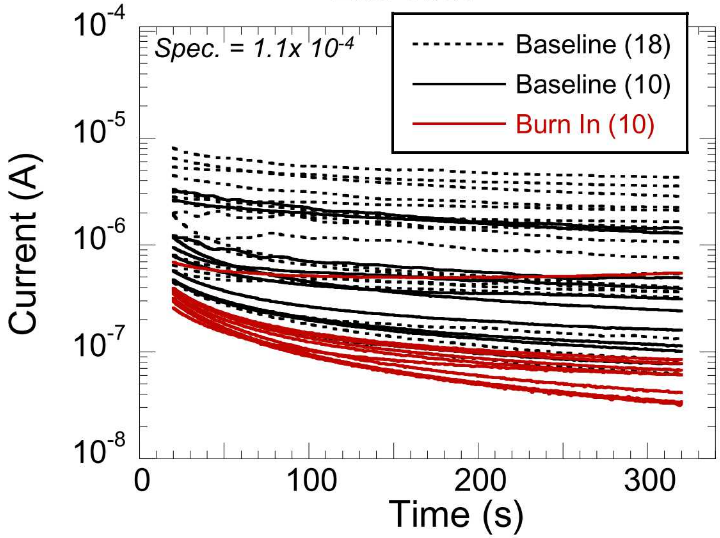
Lot 1720



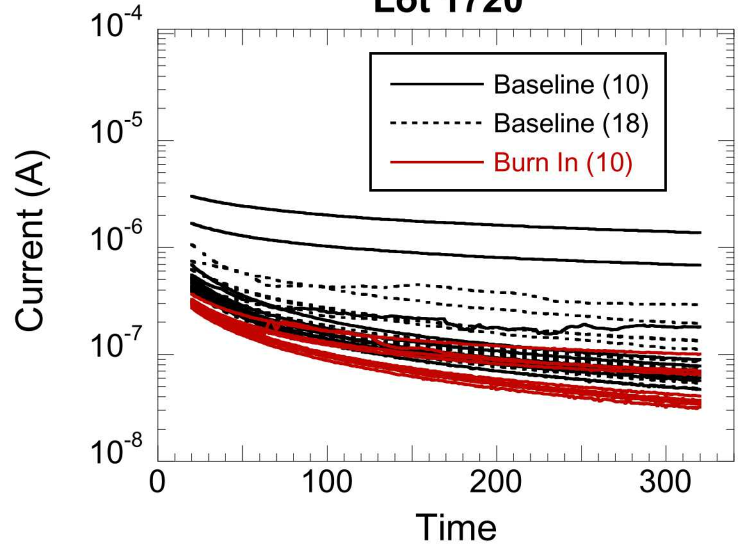
T541 DC Leakage measurements

Specification = 110 μA

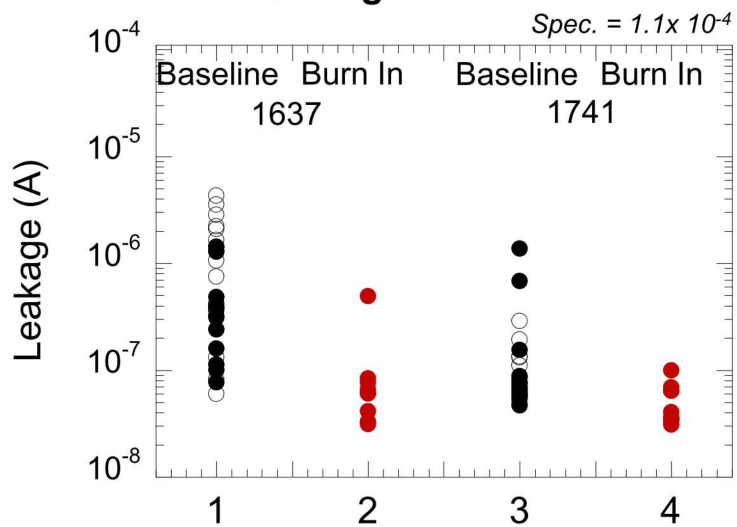
Lot 1637



Lot 1720



Leakage after 320 sec



One possible approach for coupling electrical measurements with Ta Capacitor Reliability

Surge Step Stress Test

-as a tool to evaluate production lot reliability

Typical Result

- Subject capacitors from a specific lot or after a specific aging condition to voltage pulses of increasing magnitude

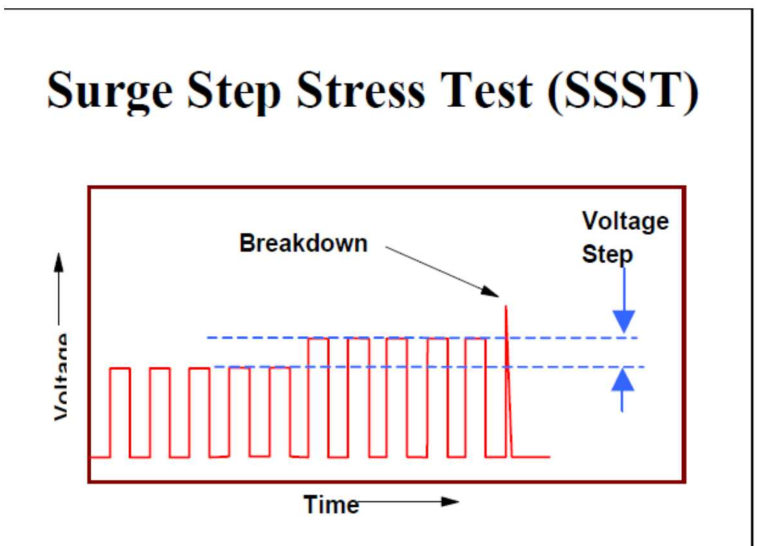
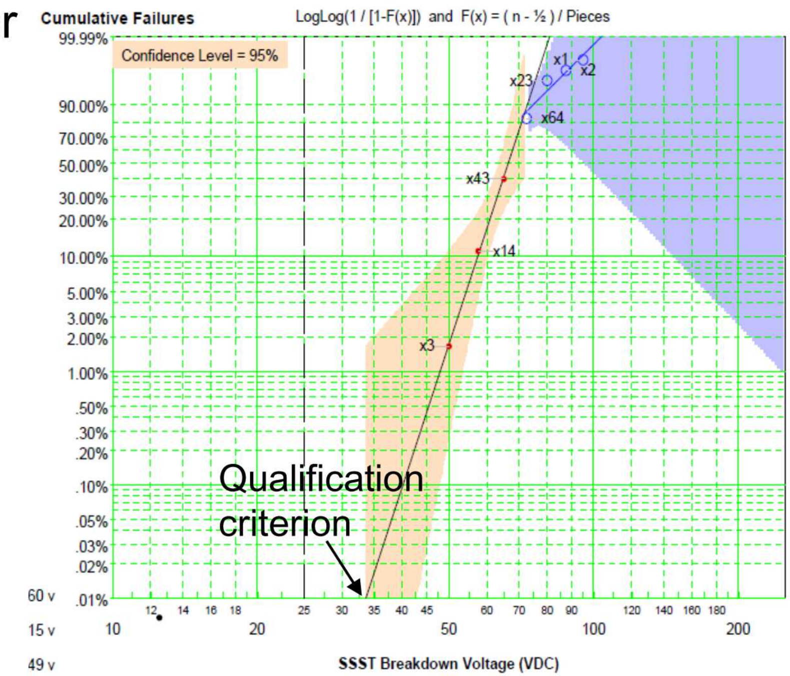


Fig. 3. Increasing voltage pulses of SSST test.



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

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

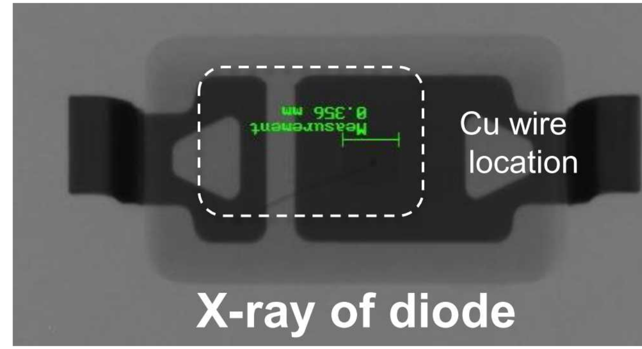
Aging and Copper wire bond assessment of three diodes

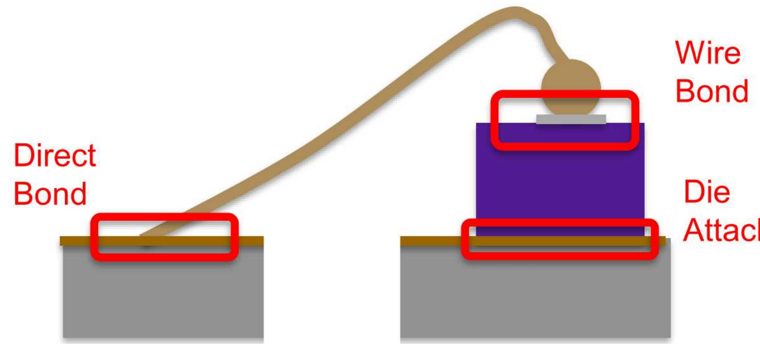
Device	Sample Size	Test Cycle	Aging Time (Intervals)	Characterization			
				SEM	TEM	PSA/ PCA	Elec. Meas.
BAS20LT1G **High Voltage Diode**	100-120	Age 140ºC	500,1000,1500,2000 hrs.	x	x	x	
	100-120	Age 150ºC	500,1000,1500,2000 hrs.			x	x
	100-120	Precondition + Age 150ºC	500,1000,1500,2000 hrs.				x
MMSZ5239BT1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

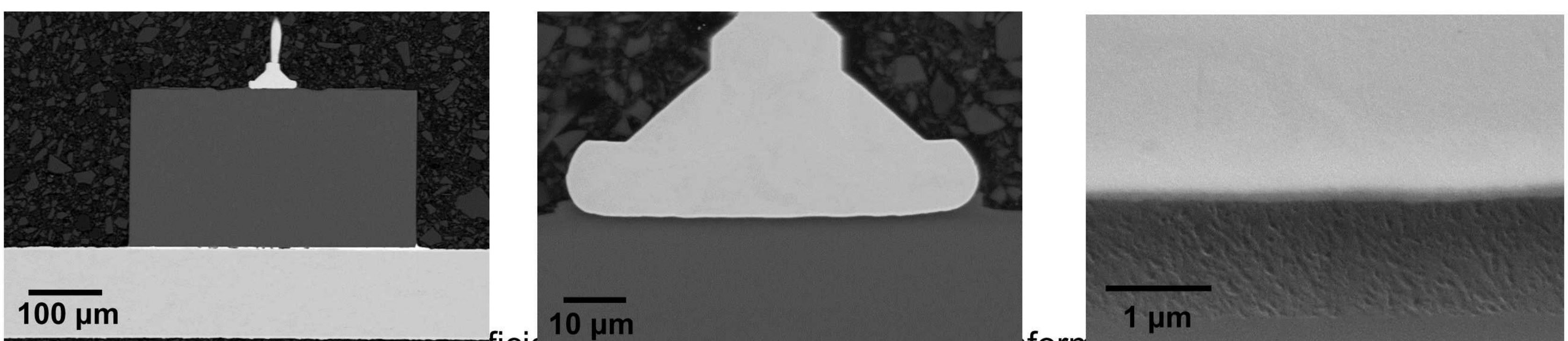
The Copper Wire-Bond in a Zener Diode

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





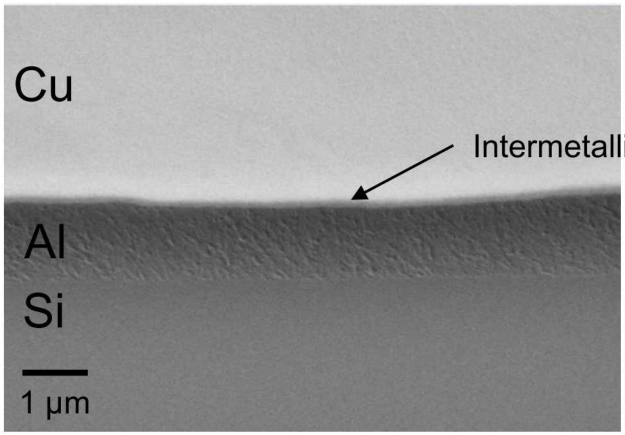
Cross-sections of Zener-Diode wire bond



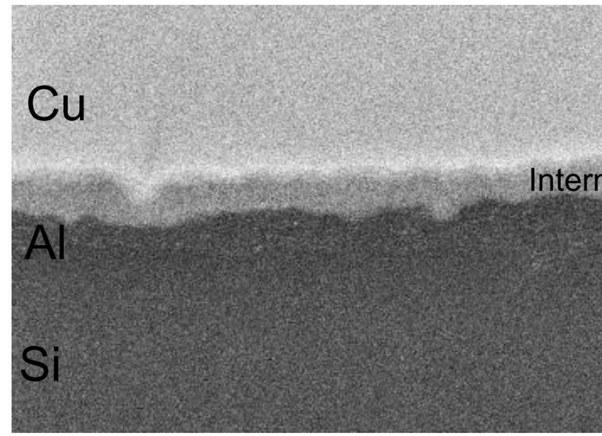
Diode wirebond changes during aging

SEM images

-secondary electron imaging condition



Pristine

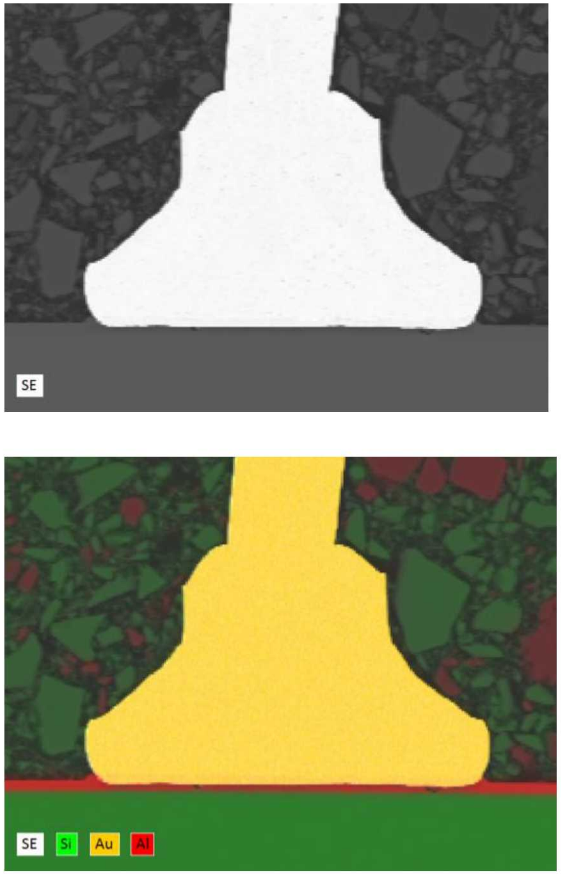


Aged 150°C/2000hr.

- Intermetallic layers at copper wirebond interface thickens and PSA measurement changes during aging.
- Documented changes at the wirebond interface with SEM and TEM (140°C only). Changes elsewhere in the diodes were not observed.

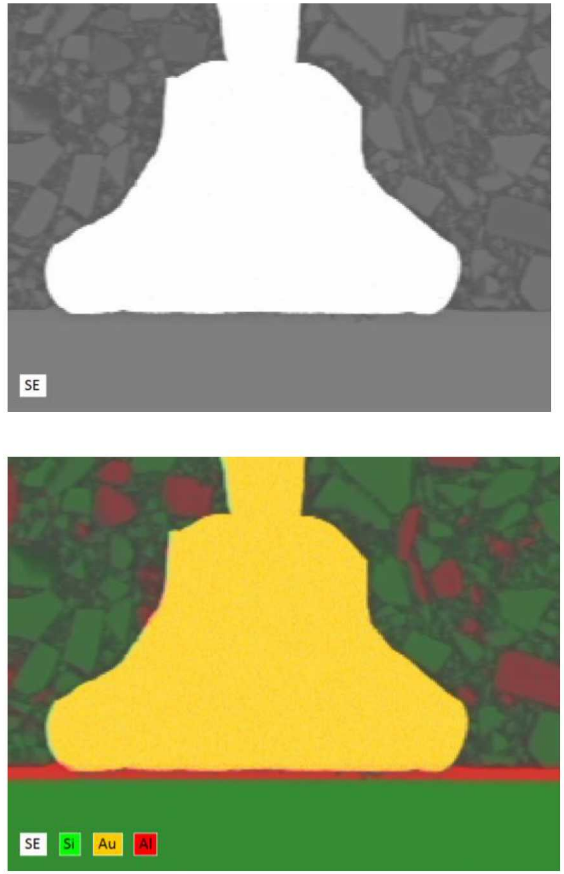
Are automotive grade MMSZ532x series Zener diodes different?

CR16



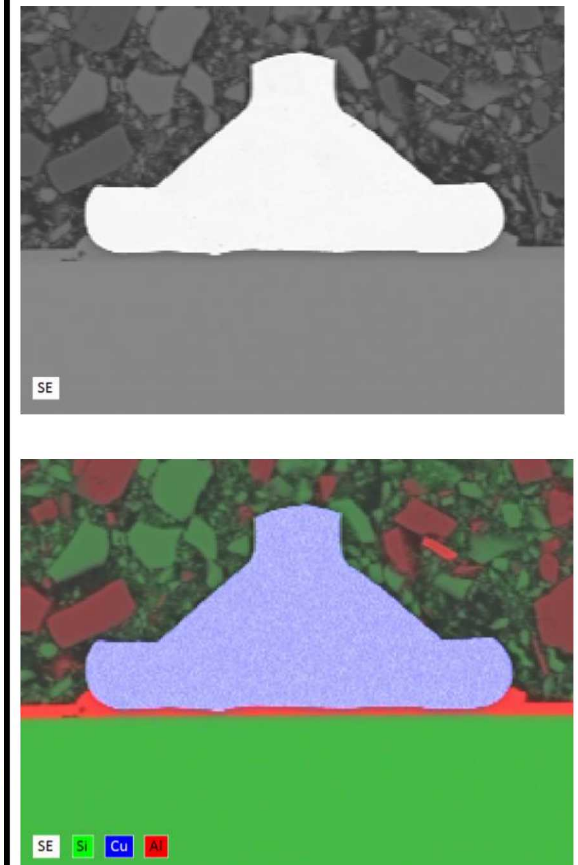
Gold wirebond

CR25



Gold wirebond

CR18

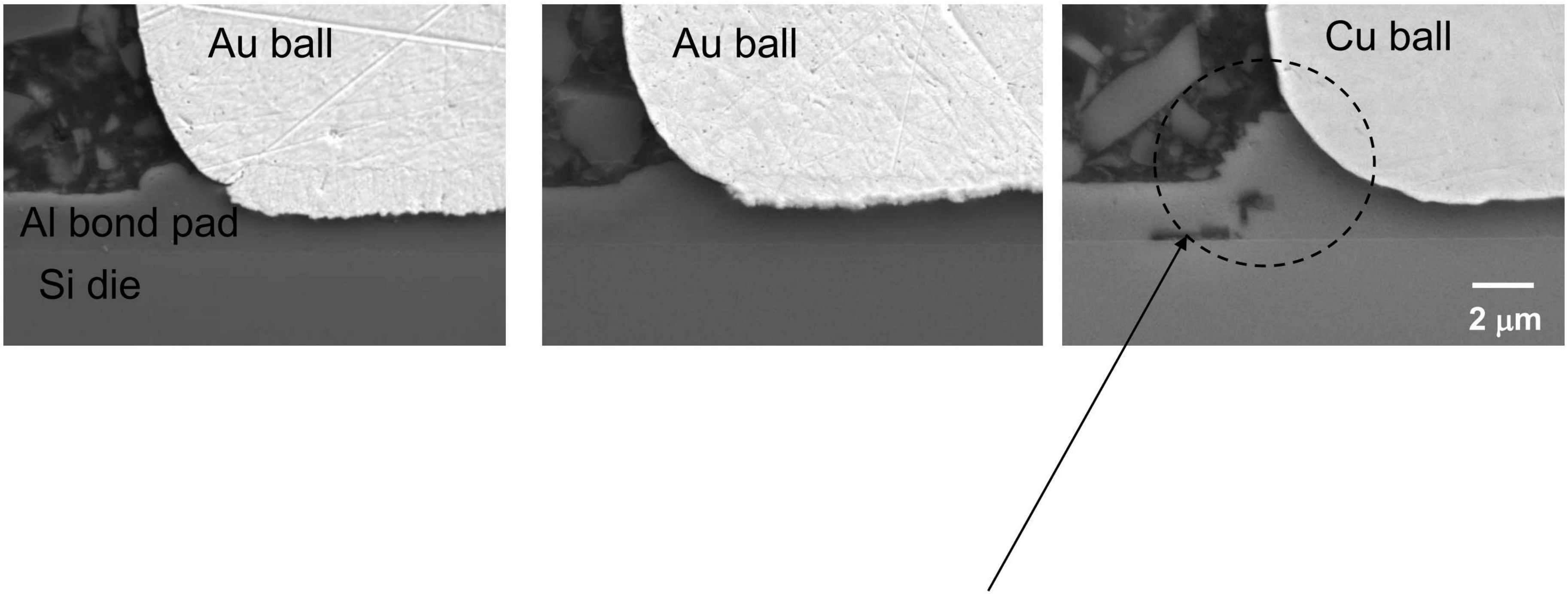


Copper wirebond

PPAP (Production Part Approval Process) – a standardized process in the automotive and aerospace industries that helps manufacturers and suppliers communicate and approve production designs and processes before, during, and after manufacture. *Independent of MIL-SPEC qualification.*

Pressing the copper into the Aluminum bond pad with more force evident

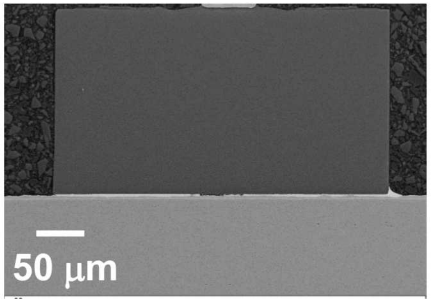
CR16 CR25 CR18

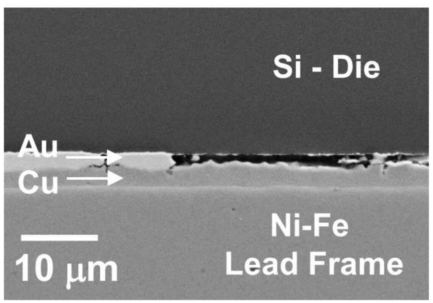


Hillock and voiding in Al bond pad at the edge of the bond is evidence of more pressure applied to form wirebond

Difference in die attach layers not detected

MMSZ5239BT1G



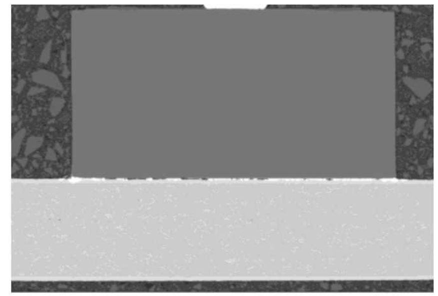


Cu wire bond

Normal COTS

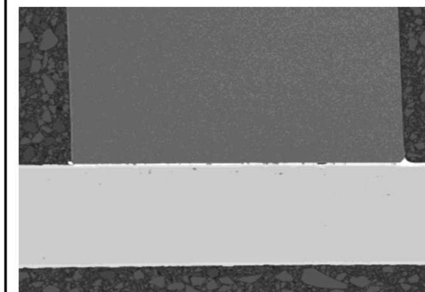
CR16

CR25



Au wire bond

CR18



Cu wire bond

Automotive Grade COTS

Information to get to Dsktl

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

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

Martin, N.S., Buchheit T.E. and Reza S. "Selection of a Nominal Device Using Functional Data Analysis", Proceedings from the IEEE Conference On Data Science and Advanced Analytics, Oct. 2018.

Summary

- Ta Capacitors
  - Results from small study on VISHAY T97Z476 and KEMET T541X226 capacitors
  - Follow up with AMRDEC and KEMET

- Aging and assessment of diodes with Copper Wire-bonds:
  - MMSZ5221BT1-D Zener Diode
    - Comparison between automotive grade and standard COTS grade devices
    - 'Selection of a Nominal Device Using Functional Data Analysis'