Capacitor Tasks 2024

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Abstract

This presentation gives updates on three types of new technology capacitors evaluated in 2024:

- Feed-Through Polymer Tantalum Capacitors
- Thin Dielectric Metallized Polymer Film Capacitors
- Chip Aluminum Polymer Capacitors

Results of construction analysis, performance, potential reliability issues and approaches for assessments of reliability acceleration factors are discussed.

List of Acronyms

AC	alternative current	**NLE**	NanoLam Element
ACC	anomalous charging current	**PCA**	PolyCharge America
APC	aluminum polymer capacitor	**RH**	relative humidity
DC	direct current	**RMS**	root mean square
DCL	DC leakage	**SST**	step stress testing
ESR	equivalent series resistance	**TDDB**	time dependent dielectric breakdown
HALT	highly accelerated life testing	**TPC**	tantalum polymer capacitor
HTS	high temperature storage	**TTF**	time to failure
IM	infant mortality	**VBR**	voltage breakdown
LF	lead frame	**VR**	voltage rating
LIBC	low inductance bulk capacitor	**WO**	wear-out
MPFC	metallized polymer film capacitor		

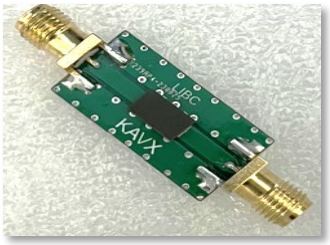
Outline

- Feed-Through Polymer Tantalum Capacitors
- Thin Dielectric Metallized Polymer Film Capacitors
- Chip Aluminum Polymer Capacitors

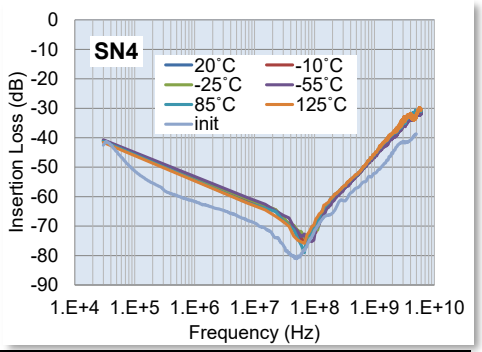
Each task included:

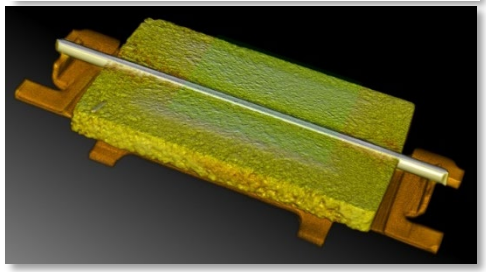
- Literature analysis on reliability and acceleration factors.
- Construction Analysis to better understand design, materials, and vulnerabilities of the parts.
- Performance characterization and development of methods to evaluate reliability acceleration factors.
- Reliability assessments.
- Recommendations for screening and qualification tests.

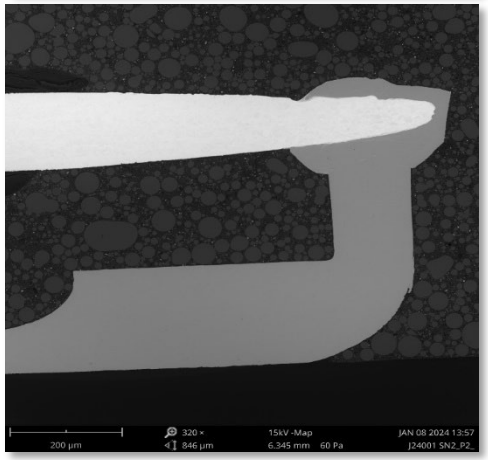
Feed-Through (LIBC) Capacitors



- Benefits of LIBC compared to ceramic feed-through:
  - wider range of frequencies,
  - no piezoelectric and bias effects,
  - no cracking issues,
  - higher RMS currents,
  - temperature stability.
- Potential reliability issues:
  - quality of welding that might limit DC currents,
  - anomalous transients and ACC,
  - long-term stability at high temperatures,
  - IM and WO failures.

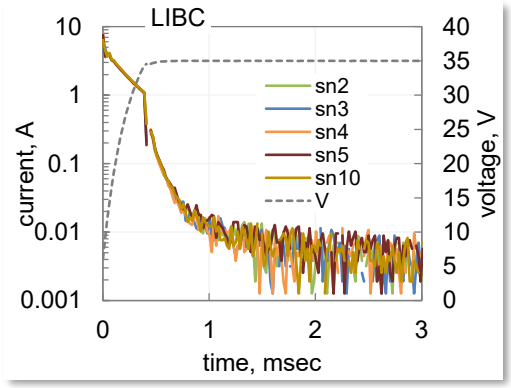


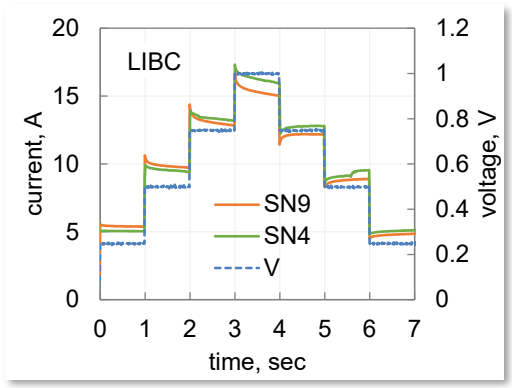


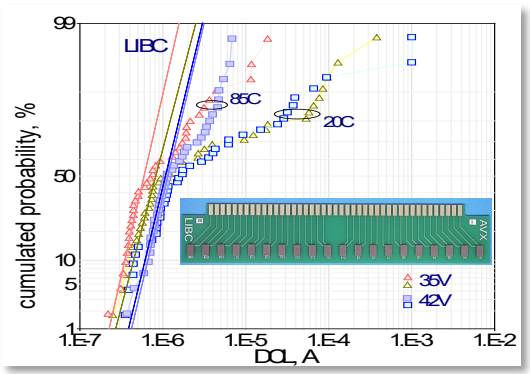


- ✓ The parts has reproducible characteristics.
- ✓ The insertion losses, S21, in the range 30kHz to 6GHz is below -40 dB, which exceeds characteristics of ceramic feedthrough capacitors.

LIBC, Cont'd

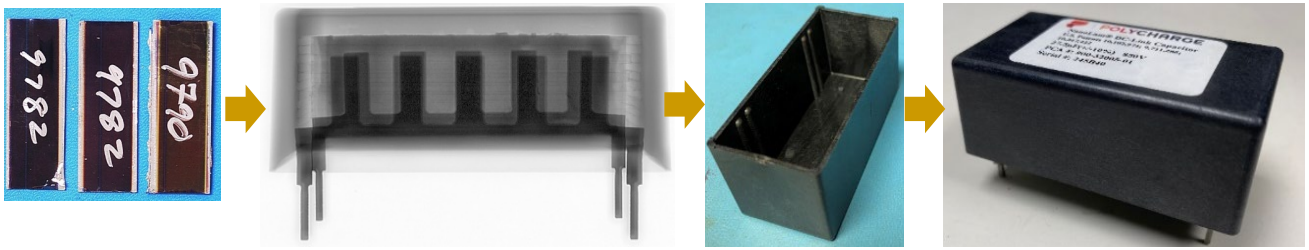






- Low level of ACC determined by the power surge testing.
- R_{DC} = 50 ±10 mohm and the parts can operate at 3A ($\Delta T \approx$ 15C).
- Leakage currents at 20C were greater than at 85C indicating anomalous transients.
- Approximately 10% of the parts had currents exceeding 0.1CV indicating a need for DCL screening.
- Breakdown voltages are ~ 2VR allowing HALT up to 1.7VR.
- Leakage currents degrade gradually during HALT resulting in parametric failures.

NanoLam MPFC



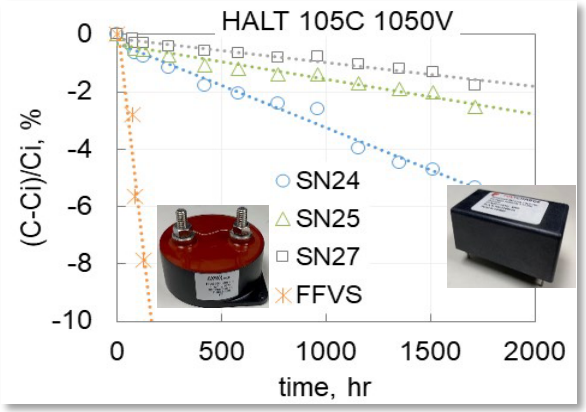
- Manufacturing: formation of NLEs on drums in a single vacuum process (deposition of acrylate-based monomer -> e-beam curing -> deposition of Al.
- Dielectric thickness 200-300 nm, Al – 5 nm. Thousands of layers in NLE.
- Assembled parts can have *C* up to 1 mF and *VR* up to 5kV (dozens of elements connected in series) and T_{op} > 125C.

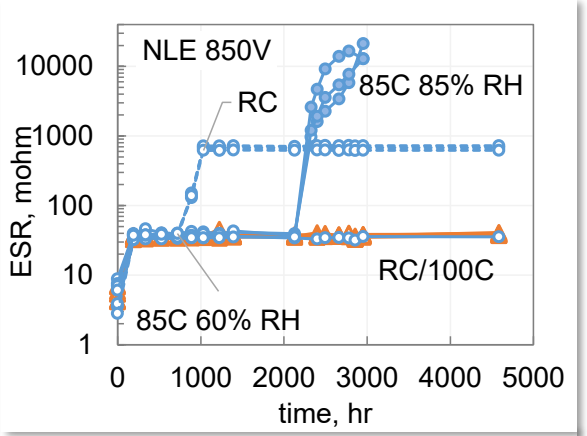
- ✓ 2023 task was limited to analysis of NLEs rated to 50V (NASA/TM—20230014257).
  - Good radiation tolerance, > 5 Mrad Si.
  - No significant degradation during 4000 hours of HTS at 125C.
  - Only parametric failures were observed during HALT.
  - Reliability acceleration factors: 2.6 < *n* < 8.6, $E_a < 0.5$ eV.
  - Useful life at 65 ºC and 0.6VR varies for different lots from 9.6 to 5800 years.
- ✓ Performance and reliability of NLEs are highly sensitive to presence of moisture.

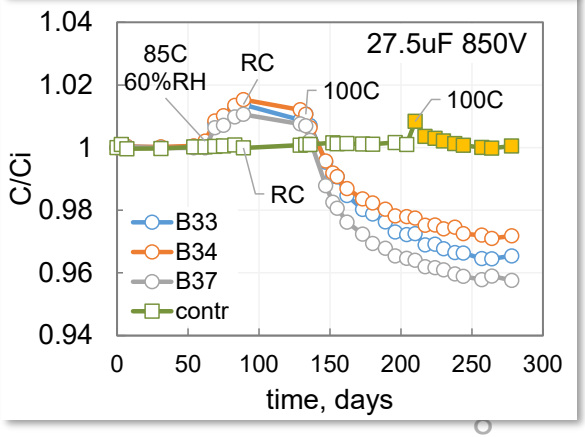
NanoLam MPFC, Cont'd

- 2024 task is focused on NLEs and assembled parts (PCA) rated to 850V.

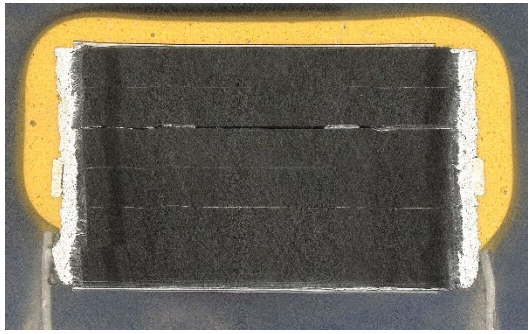
- ✓ PCA caps have better reliability compared to a standard technology capacitors.
- ✓ 850V NLEs degrade substantially after ~100 hrs at 85C and 60% RH and failed catastrophically after 200 hrs at 85C 85% RH.
- ✓ Even a relatively small amount of moisture can result in lasting (thousands of hours) degradation during unbiased storage.
- ✓ Estimations show that at operating conditions (60C and 600V) TTF exceeds 70 years.



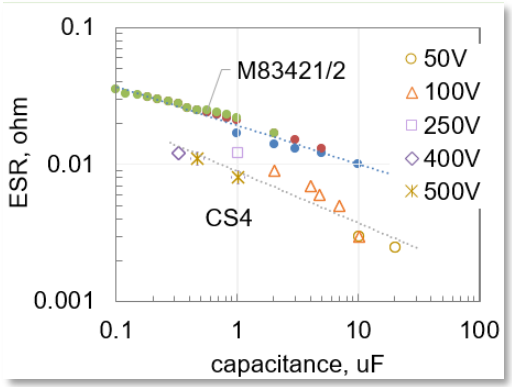


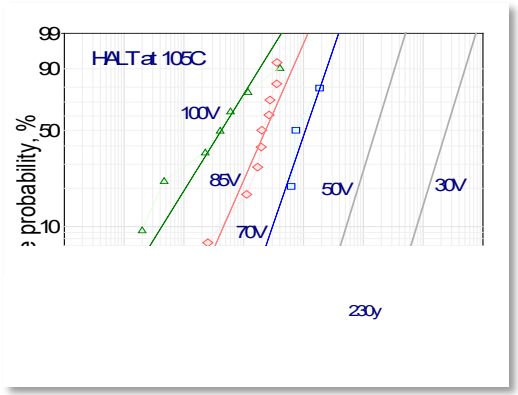


Paktron CS4 MPFC



- Benefits compared to M83421 caps:
  lower ESR, operation at high frequencies and ripple currents, smaller volume, (no need for voltage derating???).
- Aluminum instead of Zn is used to form contacts to internal Al electrodes.
- Polyester dielectric thickness ~ 2um.
- No short circuit failures and no significant variations of AC characteristics during SST from 70 to 110V.
- Moisture (85/85) increases capacitance by ~5%, while DF and ESR remain stable.

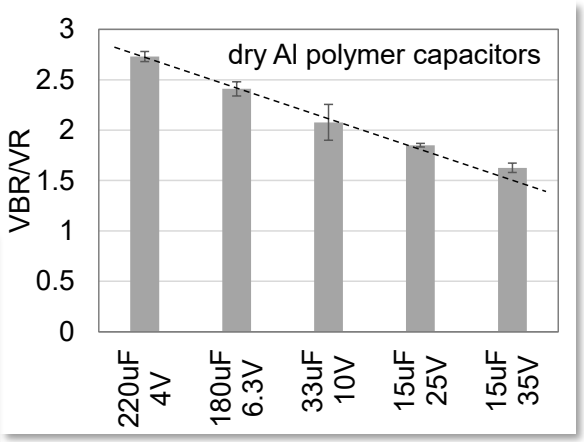




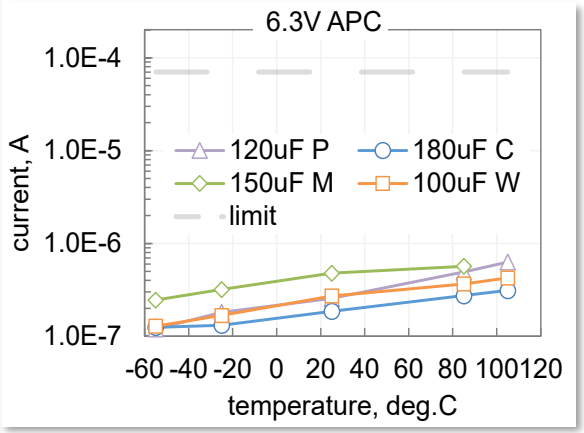
- ✓AC characteristics were within the limits after 560hr of storage at 85/85.
- ✓Design might need improvements to assure a better moisture resistance and stability after reflow soldering.
- ✓ Capacitance degradation during HALT results in parametric wear-out failures.
- ✓ Preliminary estimations: 230 years of useful life at 105C and voltage derated to 0.6VR.

Chip Aluminum Polymer Capacitors

- Chip layered APCs have similar size and can be interchangeable with PTCs.
- Benefits compared to TPCs: lower ESR and mass, higher tolerance to reverse bias.



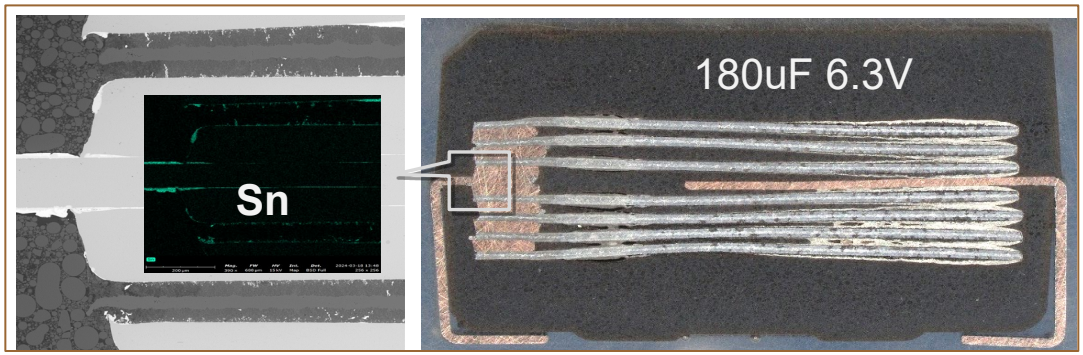
- ✓ Contrary to PTC, APCs do not have ACC effect.
- ✓ Similar to other types of capacitors, normalized breakdown voltages are increasing for lower voltage ratings.
- ✓ Operational leakage currents are more than 100 times less than the specified DCL and have a relatively weak temperature dependence.
- ✓ Potential reliability issues: degradation and failures in humid environments and during storage at high temperatures; current spiking due to poor self-healing.

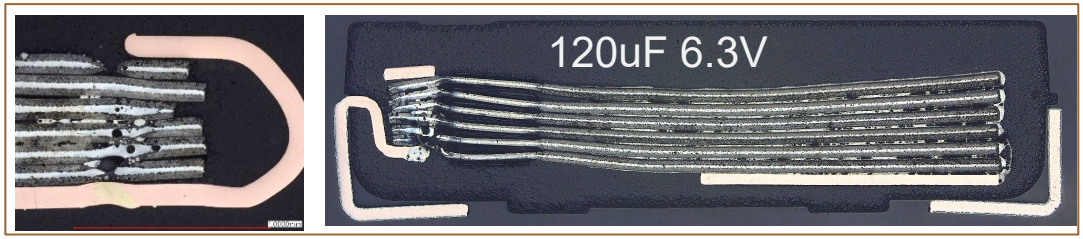


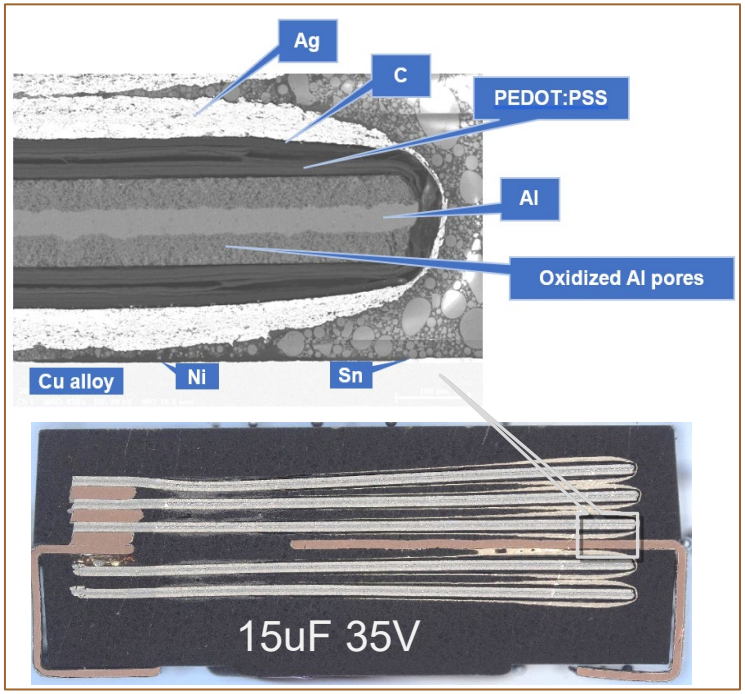
APC, Construction Analysis

APCs used in this study

Gr.	Mfr	C, uF	VR, V	ESR, mohm	DF, %	DCL, uA	T_{max}, C	H, mm
1	A	120	6.3	9	6	75	105	1.9
2	B	180	6.3	10	6	45	125	2.8
3	C	150	6.3	15	6	94.5	105	1.9
4	D	100	6.3	15	6	63	105	1.9
5	B	33	10	18	6	13	125	2
6	B	15	25	40	6	15	125	2
7	B	15	35	40	6	53	125	2.8





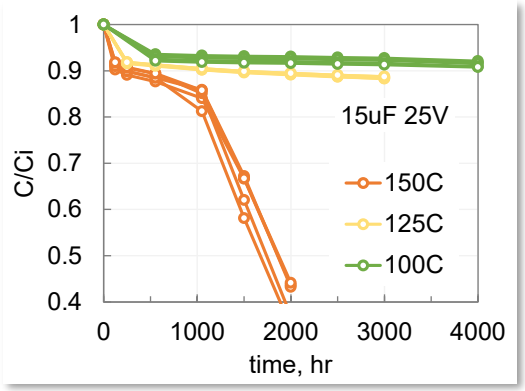


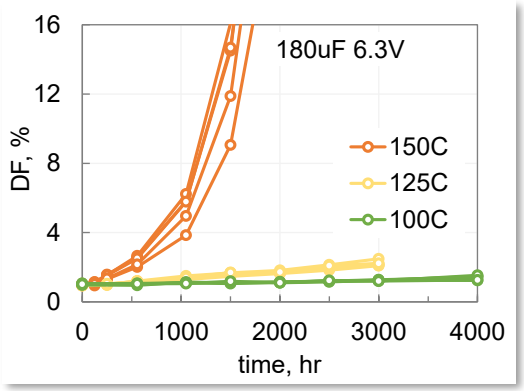
✓ APCs use multilayer Al foil, but differ by shape and position of the cathode LF, anode construction (spacer) and welding.

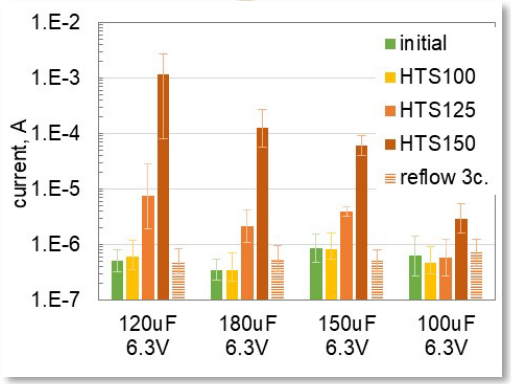
✓ Oxide layers at the edges of Al plates might differ from oxide in the pores.

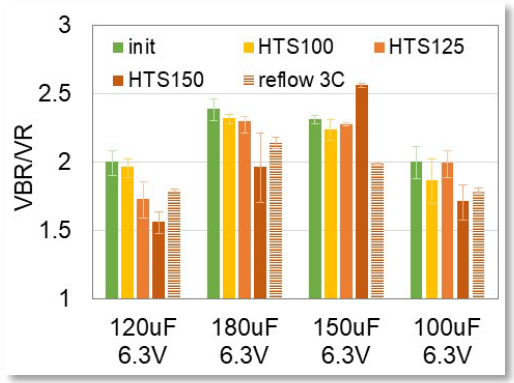
APC: High Temperature Storage

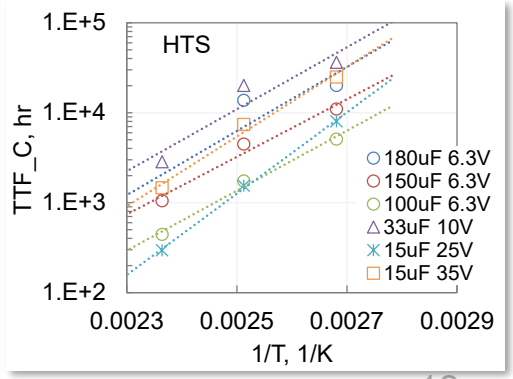
- HTS was carried out at 100C, 125C, and 150C.







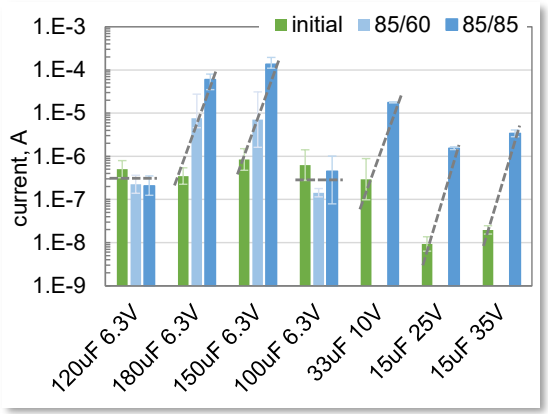


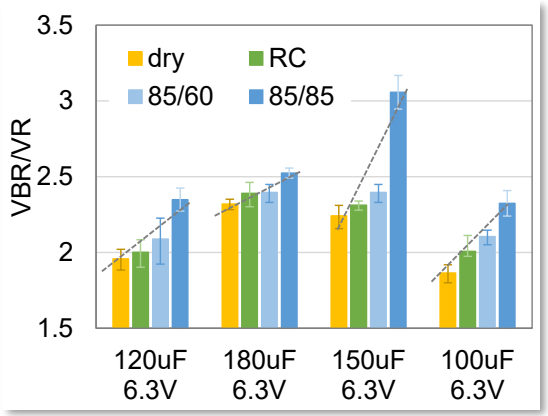


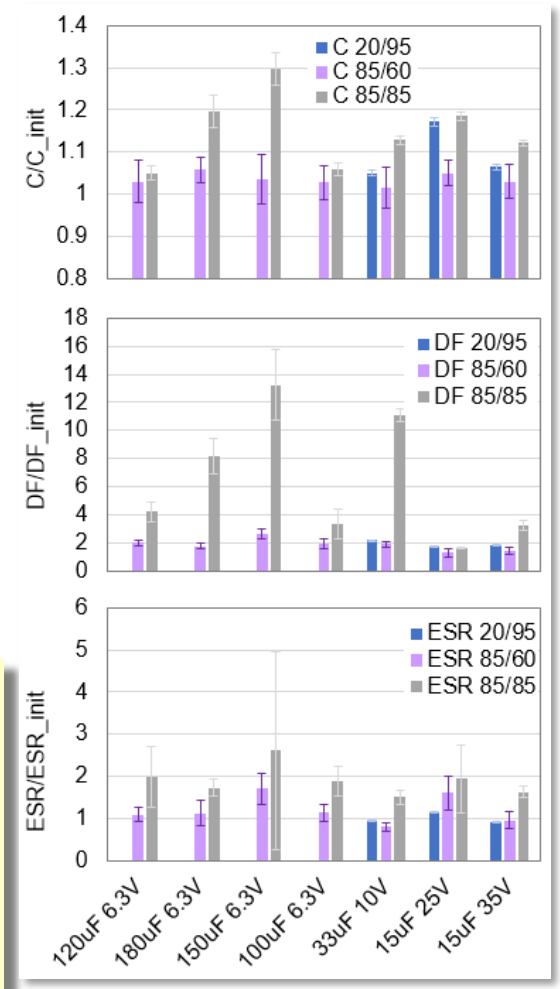
- ✓ Behavior of the parts during HTS is similar to PTCs.
- ✓ Significant increase of DCL at T > 100C.
- ✓ Three cycles of reflow soldering (T_{max}= 235C) did not degrade DCL and VBR.
- ✓ A tendency of reducing VBR after HTS.
- ✓ No ACC after HTS.
- ✓ E_a of degradation processes 0.73 ±0.1 eV.
- ✓ Extrapolations to 65C indicate TTF from 6 to 48years.

APC: Effect of Humidity

- Conditions during storage in humid environments:
  (1) 20C, 95% RH for 1500hr,
  (2) 85C, 85% RH for 850hr,
  (3) 85C, 60% RH for 500hr.



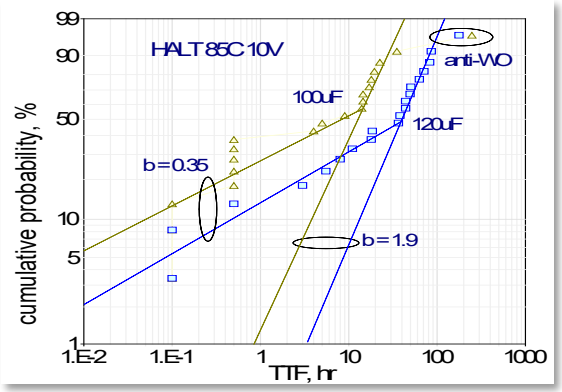


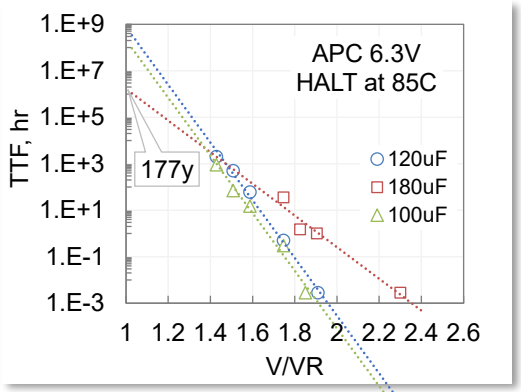


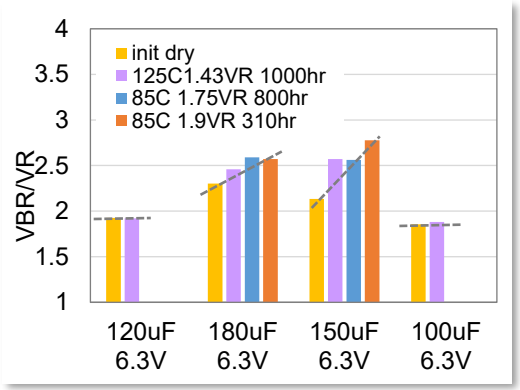
- ✓ Moisture degraded DCL in 5 out of 7 types and increased VBR in all types of APCs.
- ✓ Three out of 7 lots had parametric failures after 85/85 storage, but all lots passed 85/60 test.
- ✓ Variations of ESR are <3X for all types except gr.3.

APC: Highly Accelerated Life Test

- Leakage currents were monitored during HALT at different T and V.
- TBDD: $TTF = t_o \times exp\left[\frac{\Delta H}{kT} \times \left(1 - \frac{V}{V_{BR}}\right)\right]$ $AF_V = exp\left[B \times \left(\frac{V}{VR} - 1\right)\right]$







- ✓ Similar to TPCs, APCs have IM and WO failures.
- ✓ Anti-WO failures are due to increasing VBR during HALT.
- ✓ TTF(V) can be described using thermochemical TDDB model.
- ✓ Voltage acceleration constant *B* is substantially greater than for TPCs.
- ✓ Estimated TTF values at 85C and VR exceed 170 years.
- ✓ 150uF 6.3V capacitors had no current spiking and failures at all HALT conditions.

Preliminary Conclusions

- LIBC:
  - Monitored BI is useful to reduce parametric failures.
  - With proper screening and qualification (TBD) feed-through capacitors can be used for space applications.
- MPFC:
  - A special care should be taken to prevent moisture sorption during manufacturing, assembly, and terrestrial T&I periods.
  - In dry conditions, reliability of NanoLam caps exceeds reliability of commercial PP caps manufactured using traditional technology.
  - CS4 caps might need improvements in design to assure a better moisture resistance and stability after reflow soldering.
- APCs:
  - Reliability of different types of capacitors differ substantially.
  - Stability at high temperatures is similar to PTCs.
  - Moisture resistance might be sufficient for space applications.
  - The presence of IM failures indicates the need for BI screening.