Evaluation of 10V Chip Polymer Tantalum Capacitors for Space Applications

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Outline

- Introduction. Problems with CPTCs.
- Experiment.
- Leakage currents (in the paper).
- Degradation of leakage currents during HALT.
- Effect of vacuum.
- Effect of HTS in air.
- Summary and recommendations.

Problems with CPTCs

Known benefits/problems.

- ✓ Failures without ignition. → Is it sufficient to reduce derating to 80% VR?
- ✓ Low ESR → Can it be too low? How to set requirements considering that ESR will change with time/stress?

Known problems.

- ✓ Degradation at high and low humidity. → Operation in vacuum?
- ✓ Degradation at high temperatures. → How to predict the effect of long-term storage/operation?
- ✓ No failures during WGT. → Burning-in conditions?

Additional problems compared to MnO2 capacitors (work in progress).

- ✓ Different polymers and processes are used for LV and HV capacitors and by different manufacturers. → How different is their behavior and how to set adequate requirements?
- ✓ Surge current testing. → Failures might be not determined by blown fuses.
- ✓ Anomalies in transient currents. → Implications for users? Mechanism?
- ✓ Effect of reverse bias. → Is it different compared to MnO2 caps?
- ✓ Effect of soldering stresses. → Internal pop-corning? Can CPTCs be soldered manually?
- ✓ Effect of radiation. → What is the sensitivity of PEDOT/PSS to radiation?

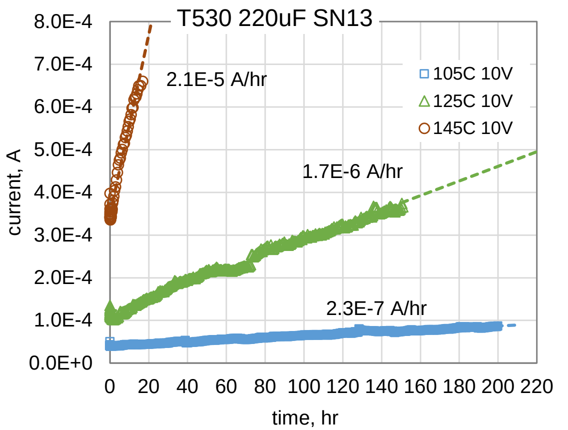
Experiment

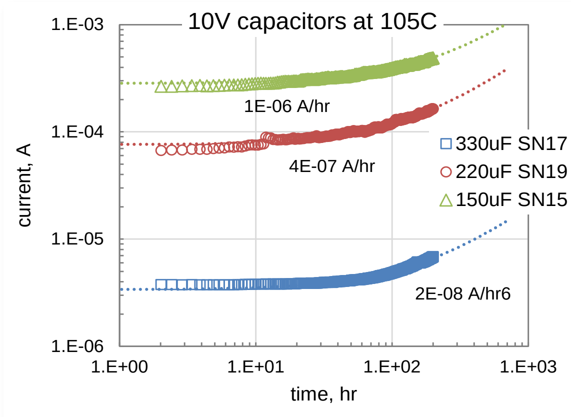
- Monitored HALT at voltages from 8 V to 12 V and temperatures from 85°C to 145°C.
- Vacuum testing: 100 ºC for 2 khr at ~ 1E-7 torr.
- HTS at 100°C, 125°C, 150°C and 175°C with periodic measurements of C, DF, ESR, and *I-t* characteristics (1000s).

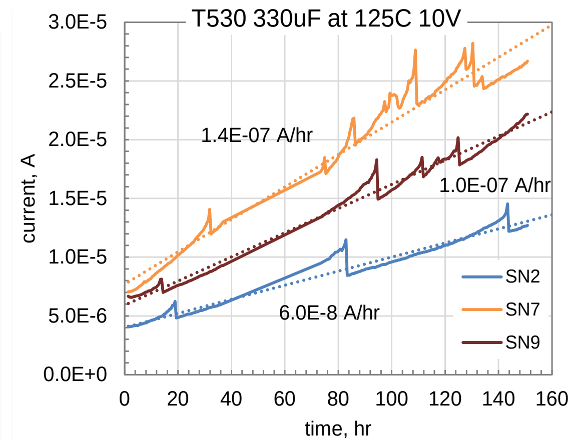
CPTCs used in this study

Part	application	LDC	C, µF	DF_{max}, %	ESR_{max}, mohm	DCL_{max}, µA	Temp. Range
T530X337M010AHE010	general	DC1225	330	8	10	330	-55C to +125C
T530D227M010AHE010	general	DC1316	220	8	10	220	-55C to +125C
T530D157M010AHE006	general	DC1347	150	8	6	150	-55C to +125C
T598D227M010ATE040	auto	(2015)	220	10	40	220	-55C to +125C
T525B336M010ATE080	auto, ind., MIL	(2011)	33	10	80	33	-55C to +125C
T520A106M010ATE080	general	(2011)	10	10	80	10	-55C to +105C
T520B336M010ATE070	general	(2011)	33	10	70	33	-55C to +105C
T525D227M010ATE025	auto, ind., MIL	(2011)	220	10	25	220	-55C to +125C
T520D227M010ATE018	general	(2011)	220	10	18	220	-55C to +105C

Degradation Rate during HALT







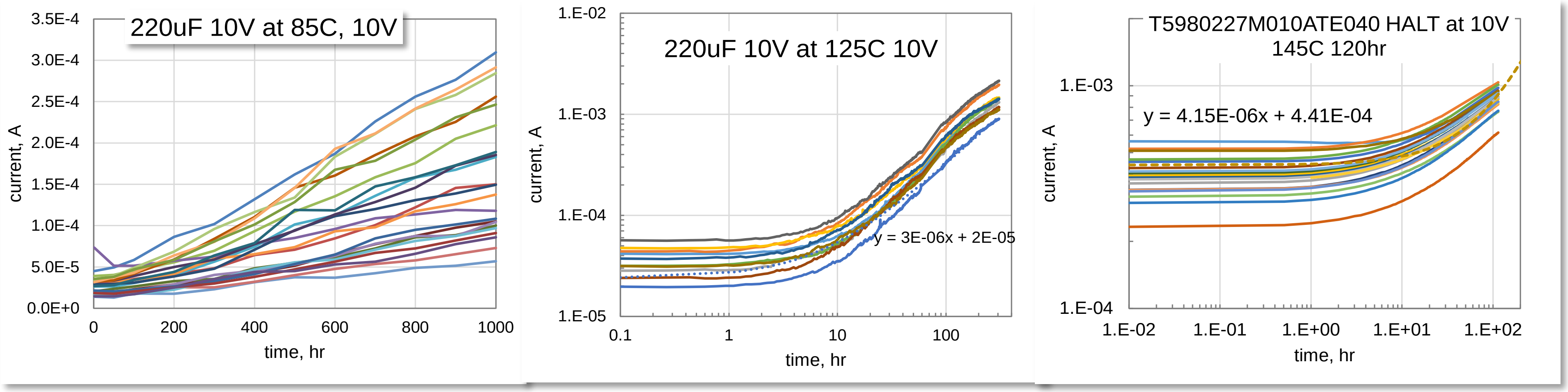
- Current degradation was approximated with linear functions.
- Some parts had spikes on the top of linear degradation.
- Degradation rates were characterized by Weibull distributions (β, η), and voltage and temperature dependencies were approximated with a general log-linear model:

$$\eta(T,V) = a_0 \times \exp\left(\frac{a_1}{T}\right) \times \exp\left(a_2 \times V_{test}\right)$$

- Voltage and temperature acceleration parameters:

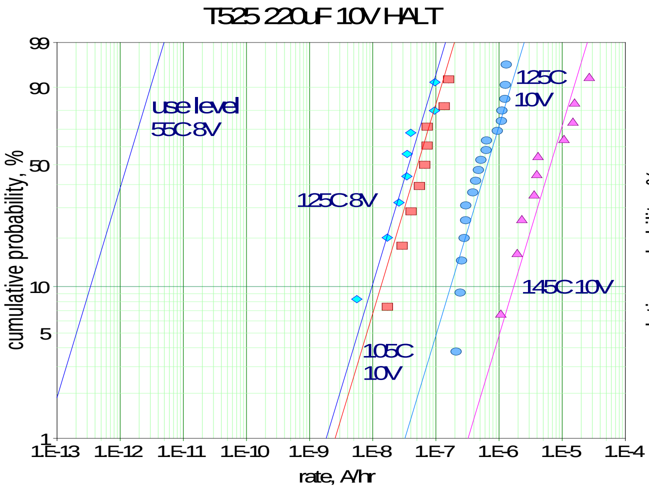
$$B = a_2 \times VR, \;\; E_a = -a_1/k$$

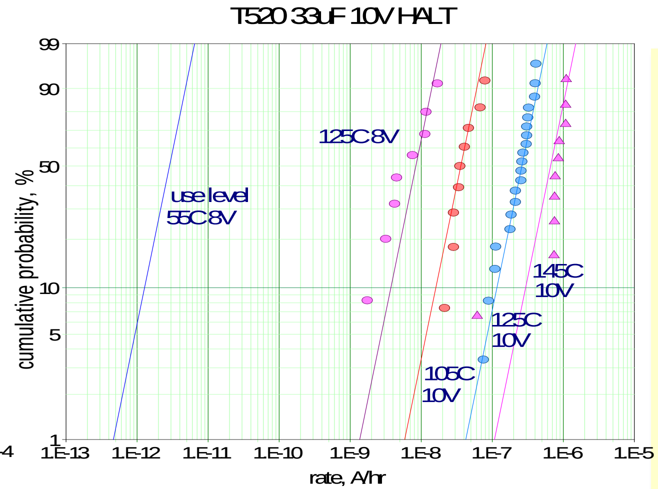
Degradation of Leakage Currents during HALT

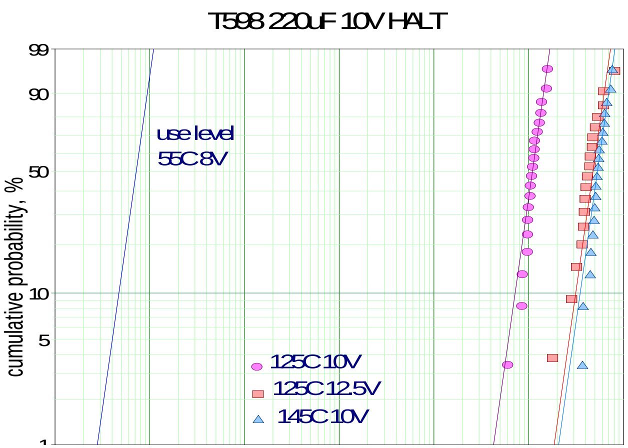


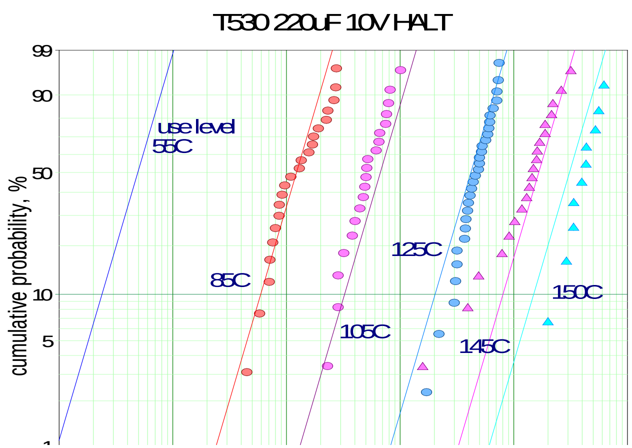
- ✓ Linear approximation is valid for more than 1000 hr at 85 ºC and up to ~200 hrs at 145 ºC.
- ✓ There is a trend of DCL saturation at the end of HALT.
- ✓ Degradation is partially reversible and DCL can be reduced by annealing at T≥ 150 ºC for more than 100 hours.
- ✓ A similar behavior was also observed for MnO2 capacitors.

HALT Results (T525/T530)









- ✓ The model describes adequately experimental data and can be used to predict degradation at use conditions.
- ✓ Time to failure was calculated as

$$TTF = \frac{\Delta I_{cr}}{\alpha}$$

where $\Delta I_{cr} = DCL_{max}$

Acceleration Factors and TTF_1%

part type	C, µF	B	E_a, eV	TTF at 55 ºC 10V, year	TTF at 55 ºC 8V, year
T520	220	12.9	1.28	4.8	64.4
T525	220	14.3	1.65	289	5125
T520	33	17.2	1.28	18.8	579.6
T525	33	14.6	1.2	4.1	75.3
T520	10	17.8	1.27	22.8	815.4
T530	330	N/A	1.5	290	5796*
T530	220	N/A	1.09	2.3	45.7*
T530	150	N/A	1.06	0.5	10.4*
T598	220	13	1.13	17.9	228.3

*Estimations in assumption $B = 15$

Temperature AF

$$AT_T = \exp\left[-\frac{E_a}{k}\times\left(\frac{1}{T_1}-\frac{1}{T_2}\right)\right]$$

Voltage AF

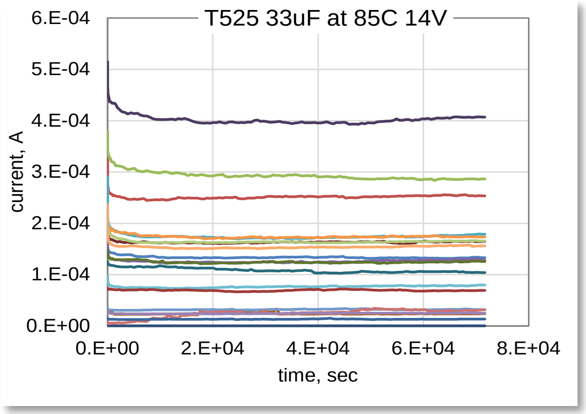
$$AF_V = \exp\left[B\times\left(\frac{V_{test}}{VR}-1\right)\right]$$

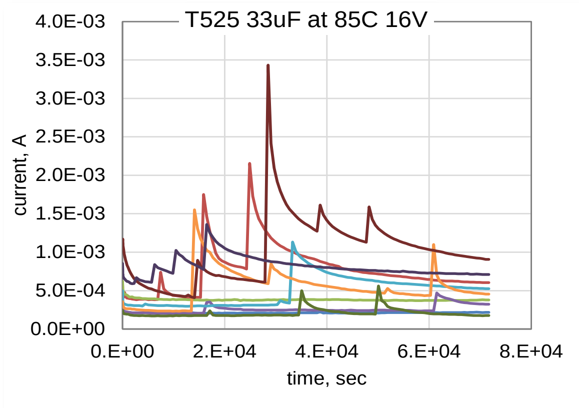
TTF is a conservative estimation for life at use conditions.

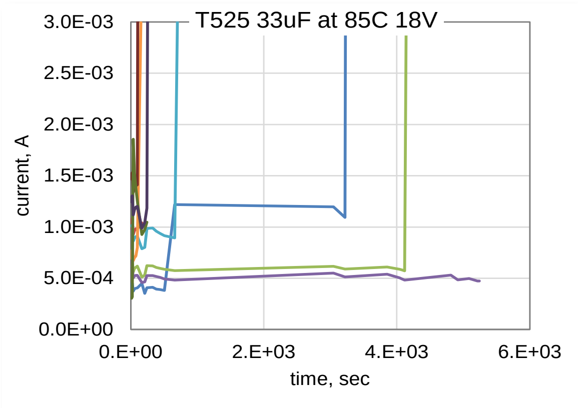
- ✓ Voltage acceleration constants *B* varies from 12.9 to 17.8.
- ✓ E_a average is 1.27 eV ± 0.19 eV.
- ✓ At 8 V and 55 ºC *TTF_1%* > 10 years; however it reduces with T.

Mechanisms of Spiking and Degradation

Step Stress Testing at 85 ºC: 20 hr at 12V to 20V in 2V increments.



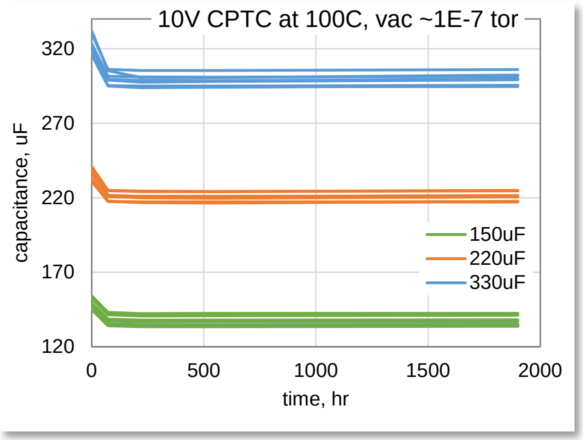


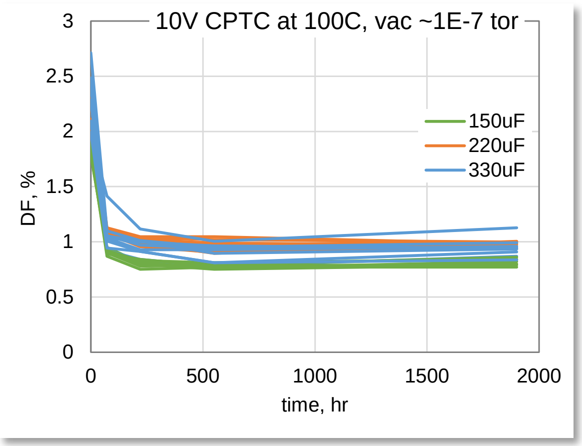


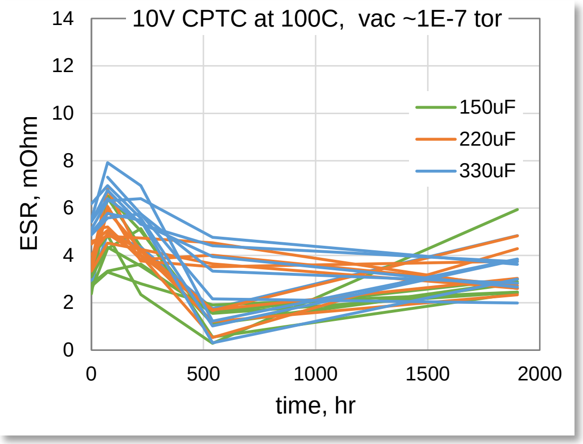
- ✓ Catastrophic failures can be observed at voltages close to VBR.
- ✓ Spiking is a manifestation of local scintillation breakdowns creating damage to the dielectric that is not fully self-healed.
- ✓ Degradation is likely due to migration of oxygen vacancies, so E_a is a sum of activation energy of leakage currents (U) and migration of V_o^{++} (E_v). At U ~ 0.16 eV E_v *is* ~1.1 eV.
- ✓ Contrary to CPCTs, catastrophic failures as revealed by blown fuses, are the major concern for MnO2 capacitors.
- ✓ Spiking is a concern for CPTCs and should be addressed by S&Q.

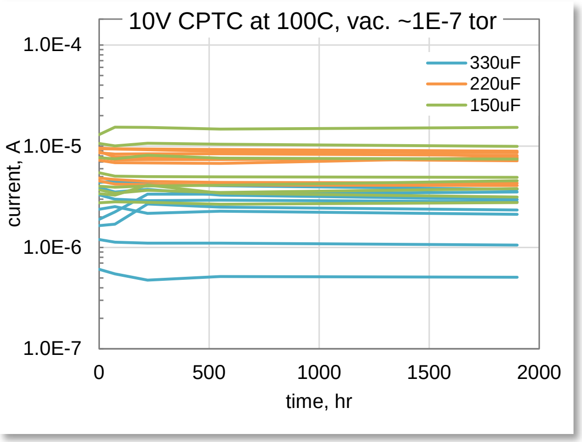
Effect of Vacuum

Storage at 100 ºC for 1900 hours in a vacuum at ~ 1E-7 torr.



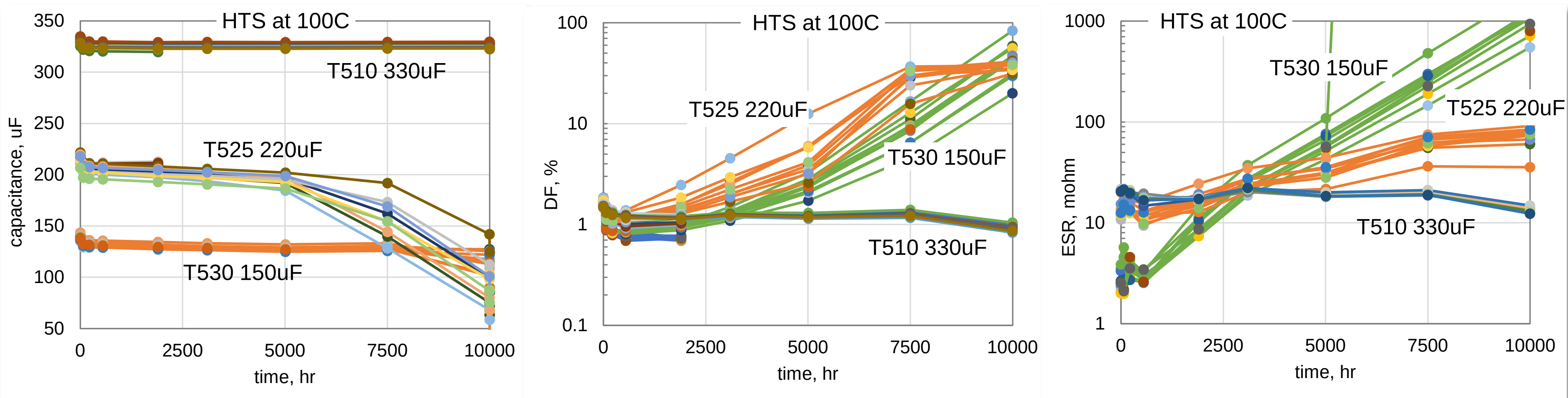






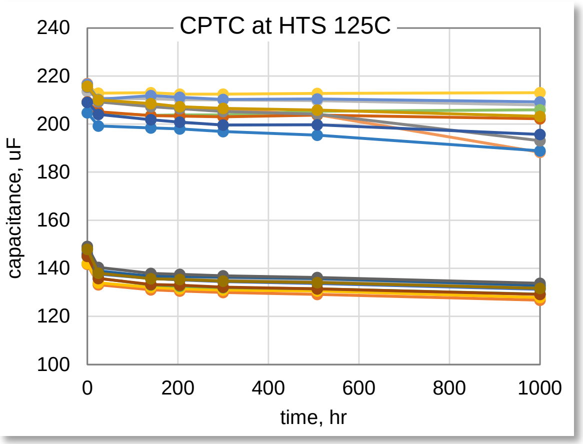
- ✓ Storing capacitors in deep vacuum at 100ºC did not change AC and DC characteristics substantially.
- ✓CPTCs do not degrade in vacuum and might be used in space applications.

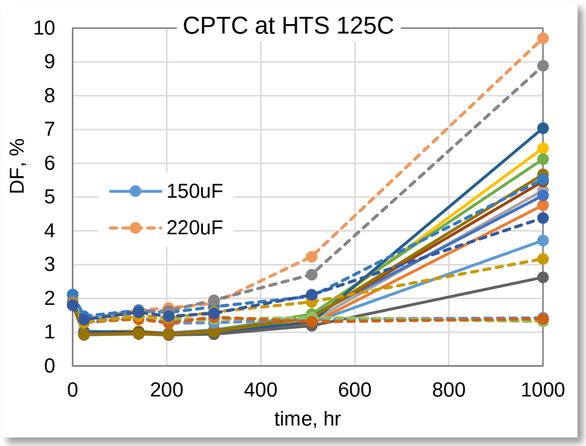
HTS in Air at 100 ºC for 10,000 hr

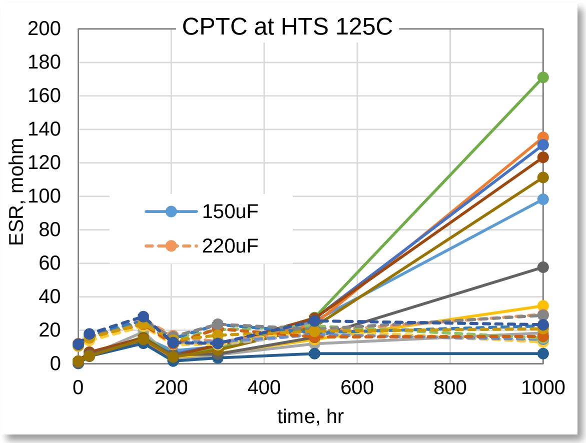


- Substantial degradation of DF and ESR in CPTC at 100 ºC in air can be observed after ~2000 hr.
- Storage life at 125 ºC for 1000 hr might not guarantee long term stability at lower temperatures.
- No degradation in MnO_2 capacitors.

HTS at 125 ºC

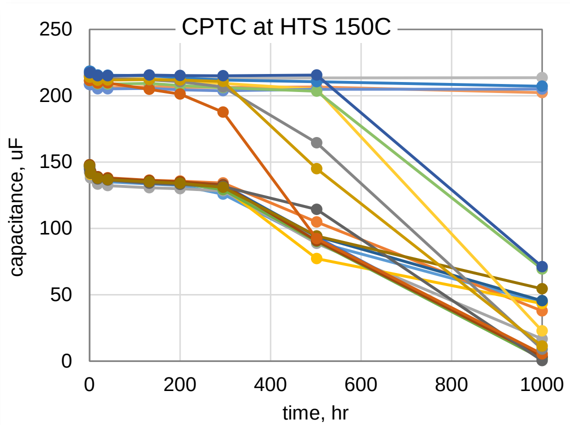


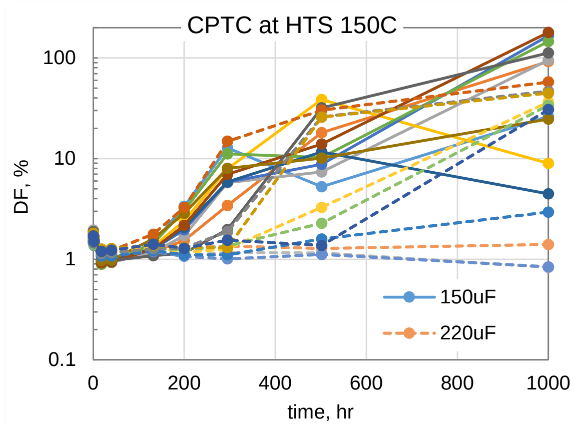


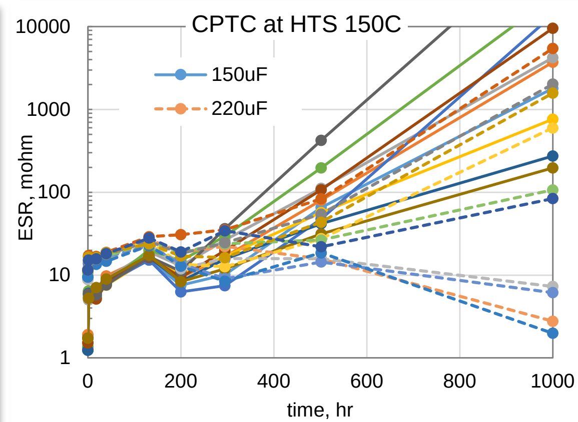


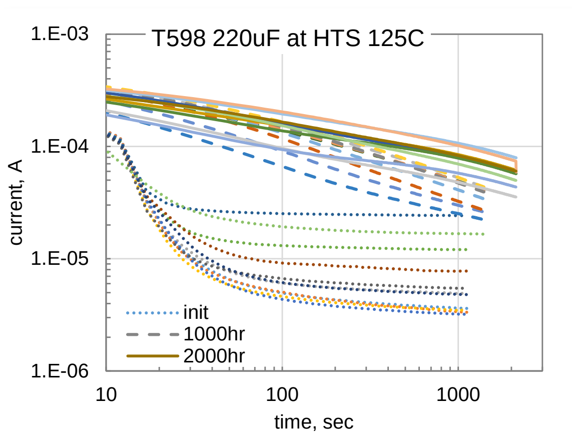
- ✓ Degradation of DF and ESR in T530/T525 starts after ~500 hrs, whereas no degradation was observed for “auto” parts (T598) tested for 2000 hrs.
- ✓ The level of degradation is lot-related.
- ✓ Mechanisms of degradation of DF and ESR might be different.
- ✓ No degradation in MnO_2 capacitors.

HTS at 150 °C





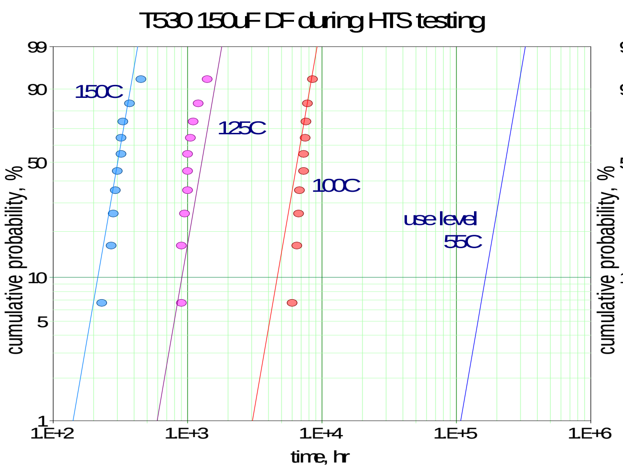


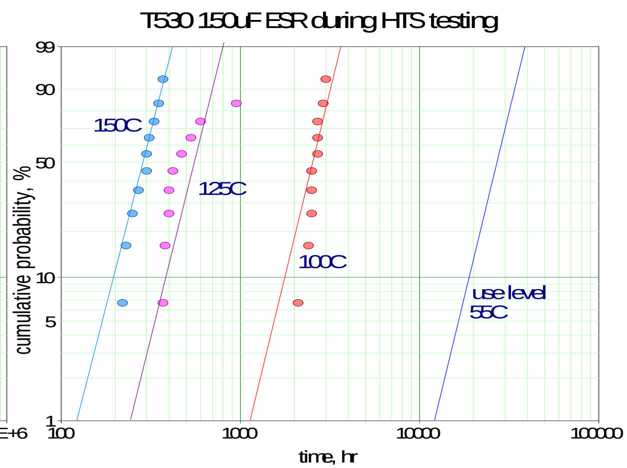


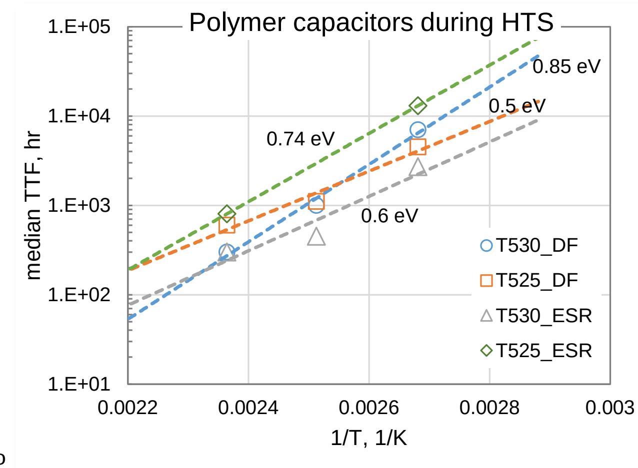
- ✓ Substantial degradation in all AC characteristics for general purpose CPTCs.
- ✓ No degradation of C, DF and ESR in MnO_2 and T598, auto grade capacitors;
- ✓ A substantial increase in relaxation currents for T598 capacitors.

Degradation Model for HTS

- TTF_DF: *DF(TTF) = 3×DF*$_{limit}$; TTF_ESR: *ESR(TTF) = 3×ESR*$_{limit}$
- E_a for HTS was calculated based on medians of TTF distributions.







	T530 _DF	T525 _DF	T530 _ESR	T525 _ESR	T598 _ESR
E_a, eV	0.85	0.5	0.6	0.74	0.7*
TTF_m at 85 ºC, y.	2.21	0.88	0.57	3.92	>6*
T_{max} for 10 y. oper.	70ºC	38ºC	43ºC	71ºC	

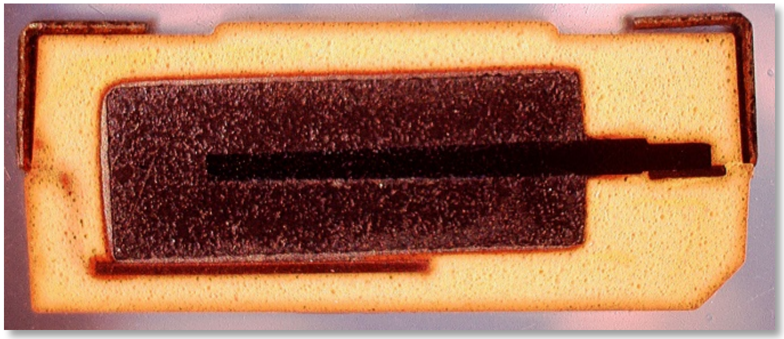
*expected values at 0.7 eV

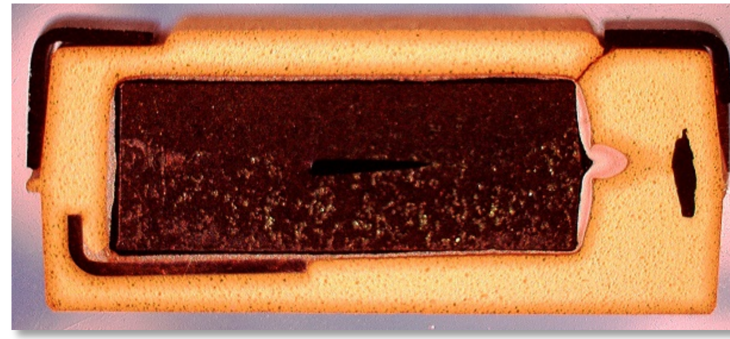
✓ E_a is in the range from 0.5 to 0.85 eV.

✓ Considering effect of vacuum, properly qualified SPCTs can be used for space.

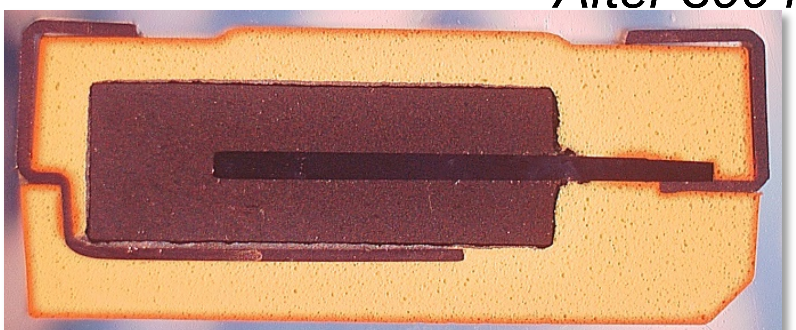
Mechanism of HTS Degradation

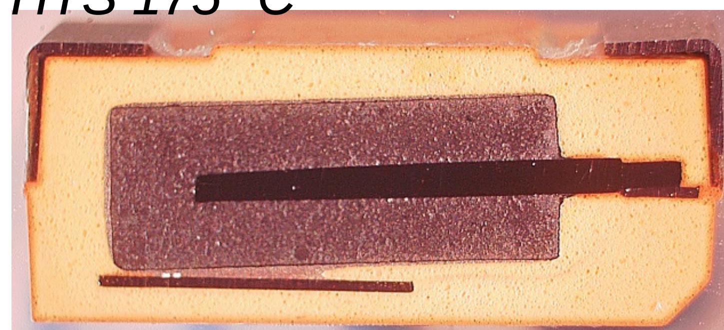
After 1000 hr HTS 150 °C





After 300 hr HTS 175 °C

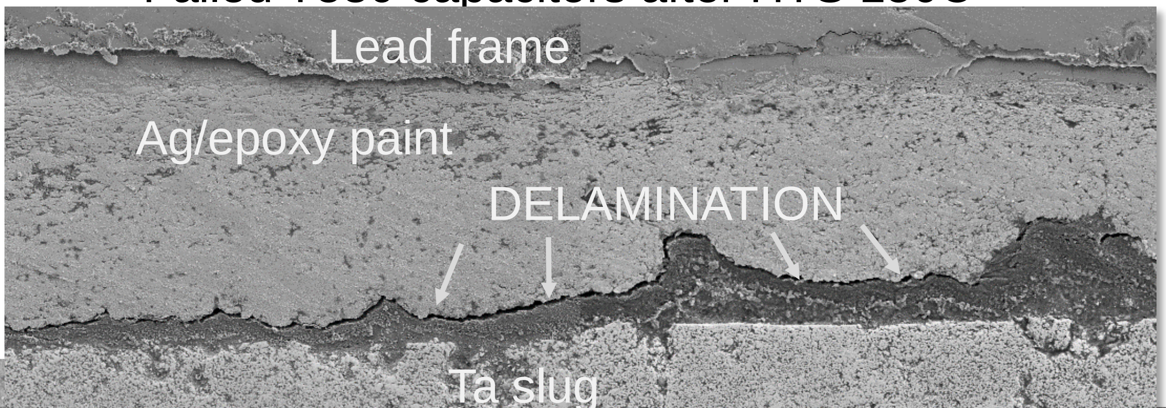


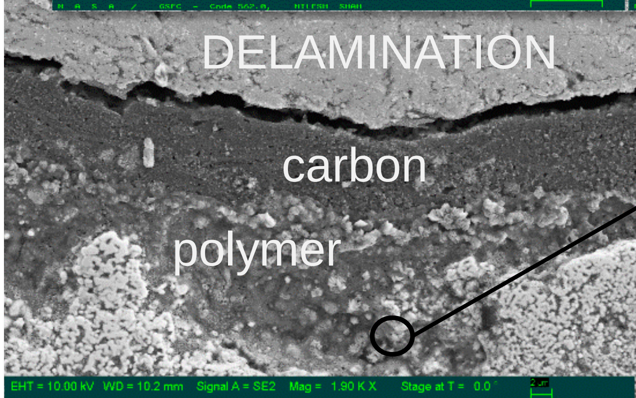


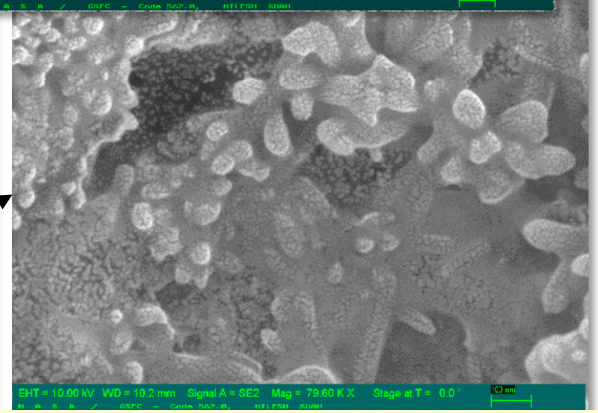
- ✓Discoloration of MC indicates a pass for O_2 causing decomposition.
- ✓Oxygen penetrates along the lead frame/MC interface and cracks.
- ✓Contrary to HTS 150 °C, there is no decomposition in MC around the slug after 300 hr of HTS 175 °C.

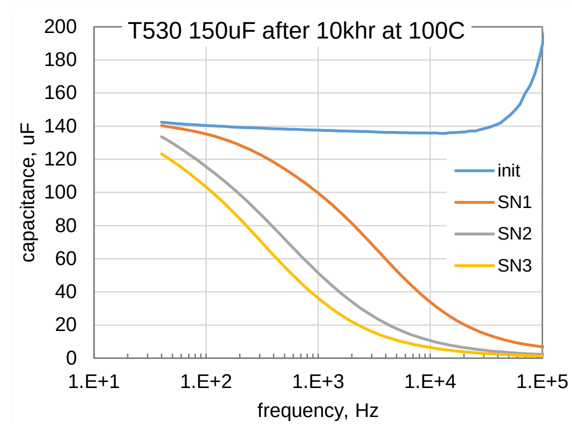
Mechanism of HTS Degradation, Cont'd

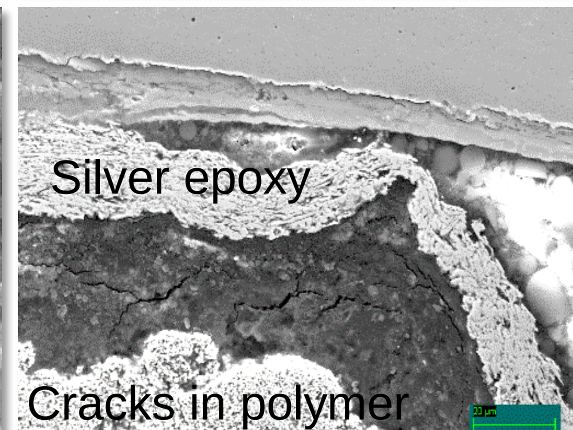
Failed T530 capacitors after HTS 150C











Degradation of ESR and capacitance:

- ✓ Increasing resistance of the polymer;
- ✓ Cracking in the polymer due to thermal decomposition and volume reduction;
- ✓ Delamination between carbon and silver epoxy layers.

Summary

- Degradation of leakage currents and failures.
  - The rate of DCL degradation increases with *T* and *V* exponentially, E_a ~1.2± 0.1 eV for T525/T530 and 1.65 eV for T598 capacitors; 13 < *B* < 18.
  - Parametric failures are due migration of oxygen vacancies in Ta2O5 dielectric and catastrophic failures are due to TDDB.
  - Some CPTCs had erratically changing currents. Spiking is lot-dependent phenomenon and is likely due to insufficient self-healing.
- Effect of vacuum.
  - No degradation of AC characteristics and DCL was observed in vacuum.
  - Degradation of CPTCs is mostly due to the thermo-oxidative processes in conductive polymers, so a better stability of AC characteristics and increased operating and storage temperatures are expected in space.
  - However, self-healing capabilities in vacuum might be reduced compared to the operation in air. This requires more thorough screening and qualification procedures to eliminate parts and lots with excessive spiking.
- Recommendations:
  - To reduce instability and noise, capacitors should be screened by monitored burning-in at 105 ºC, 1.1VR for 40 hours.
  - Monitored life testing at 105 ºC, VR for 2000 hours.

Summary, Cont'd

- High temperature storage.
  - Contrary to MnO_2, DF and ESR in CPTCs might degrade in air substantially even at 100 ºC after a few thousand hours.
  - Different lots have different susceptibility to degradation.
  - No degradation of AC characteristics was observed in automotive grade capacitors during 2000 hours at 125 ºC. However, relaxation leakage currents increased substantially.
  - Activation energy of parametric AC failures is between 0.5 and 0.85 eV, so some parts might fail in less than a year at 85 ºC.
  - ESR failures are caused by cracking, formation of delaminations, and oxidative degradation of polymers that reduces its conductivity.
  - Oxygen penetrates to the slug along the interfaces between MC and LF and through the cracks in the package.
- Recommendations:
  - Each lot should pass HTS testing at 125 ºC for 1000 hrs and parts should be qualified by HTS at 100 ºC for 10,000 hours.