Effect of Environments on Parametric Degradation in Polymer Tantalum Capacitors

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List of Acronyms

AC	alternating current	**MLCC**	multilayer ceramic capacitor
CPTC	chip polymer tantalum capacitor	**˜p**	permeability of plastic
d	thickness of plastic wall	**QA**	quality assurance
D	moisture diffusion coefficient of plastic	**RH**	relative humidity
DC	direct current	**S**	surface area of the slug
DCL	direct current leakage	**S&Q**	screening and qualification
DF	dissipation factor	**TID**	total ionizing dose
ESR	Equivalent series resistance	t_D	diffusion delay
γ	constant that depends on moisture sorption in conductive polymers	τ	Characteristic time of moisture accumulation
HTS	high temperature storage	**VBR**	voltage breakdown

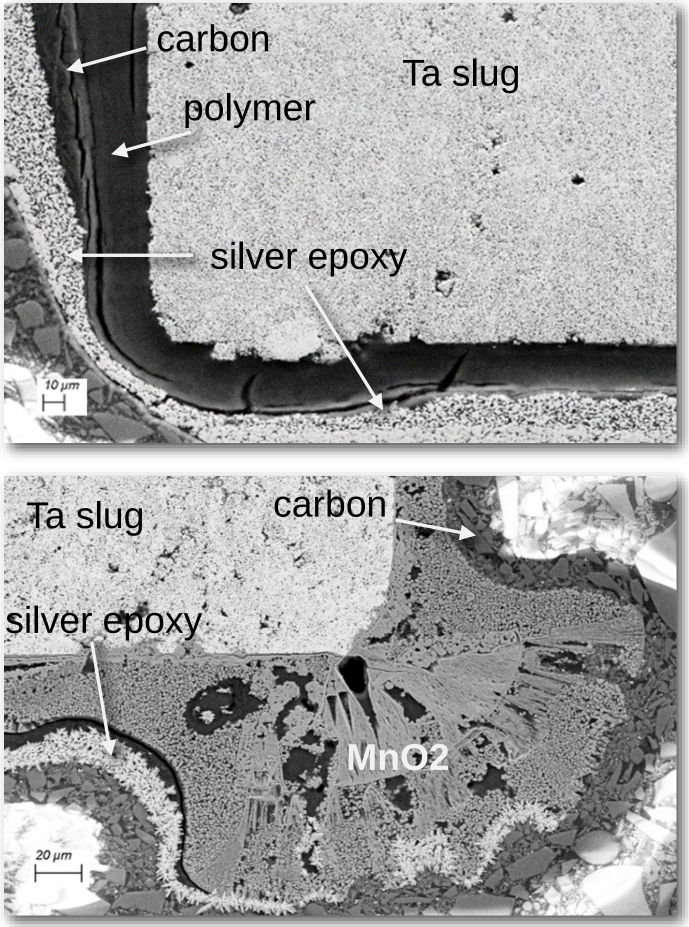
Abstract

Chip polymer tantalum capacitors (CPTCs) are more sensitive to environments compared to conventional, MnO2 cathode capacitors. Contrary to MnO2 capacitors, CPTCs can degrade with time of storage even in dry conditions, that might limit their use for space applications. Performance of CPTCs depends on the amount of moisture in the slug, and varies with time of storage after manufacturing. For this reason, characteristics of the parts and qualification testing should be carried out after preconditioning to stabilize moisture content. This work analyzes kinetics of moisture sorption and desorption in different types of CPTCs from three manufacturers. Variations of capacitance, dissipation factor, ESR, and leakage currents caused by exposure to humid, dry, and radiation environments are discussed. Examples of the effects of long-term exposure to vacuum and humid environments at 85%RH are presented. Temperature dependencies of the characteristic times of moisture diffusion allow for assessments of the bake-out times that are necessary to avoid pop-corning failures after soldering and to precondition parts before qualification testing.

Outline

- Background.
- AC characteristics in dry and humid environments.
- Kinetics of moisture diffusion.
- Variations of AC (C, DF, ESR) and DC (DCL, VBR) characteristics with moisture content.
- Effect of vacuum.
- Effect of radiation.
- Conclusion.

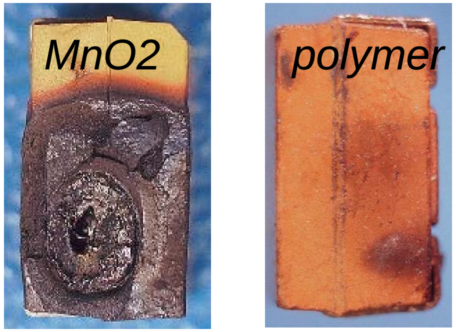
Polymer and MnO2 capacitors



CPTCs have same design as conventional capacitors, but MnO2 is replaced with conductive polymer

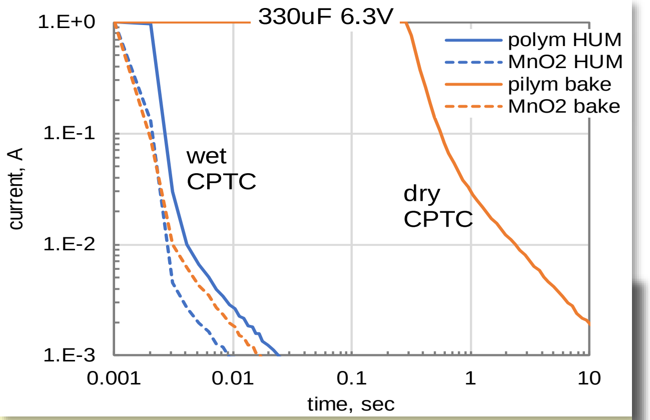
Benefits and Drawbacks of CPTC

Breakdown during SCT



- ☐ Major benefits:
  - Lower ESR (milliohm range).
  - A relatively safe failure mode (no ignition).
  - Possibilities of higher operating voltages (up to 125V).
- ☐ Major drawbacks:
  - Effect of environments: both, excessive and insufficient amount of moisture might be detrimental.
  - Excessive moisture: degradation and pop-corning.
  - Insufficient moisture: anomalous transients.
  - The S&Q system built for MnO2 capacitors, is not sufficient, might be not applicable or effective.

Example of anomalous transients



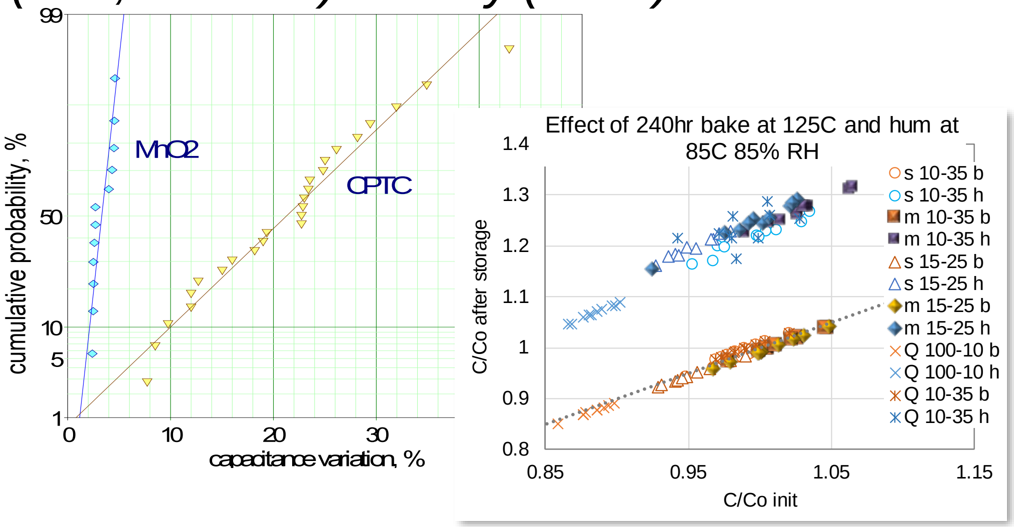
- ✓ Assessments of kinetics of moisture sorption and desorption are necessary to select preconditioning for soldering and qualification testing.
- ✓ Radiation might have a stronger effect on polymer than on MnO2.

Deviations of AC Characteristics

- ❑ Different types of capacitors rated from 6.3 V to 100 V and from 10 μF to 330 μF from 3 vendors. Most parts had case size D.
- ❑ Variations of *C*, *DF*, and *ESR* between humid (85% RH) and dry conditions were measured for 25 types of CPTCs and 12 types of MnO2 capacitors

Effect of 200hr storage in humidity (85C, 85% RH) and dry (125C) chambers

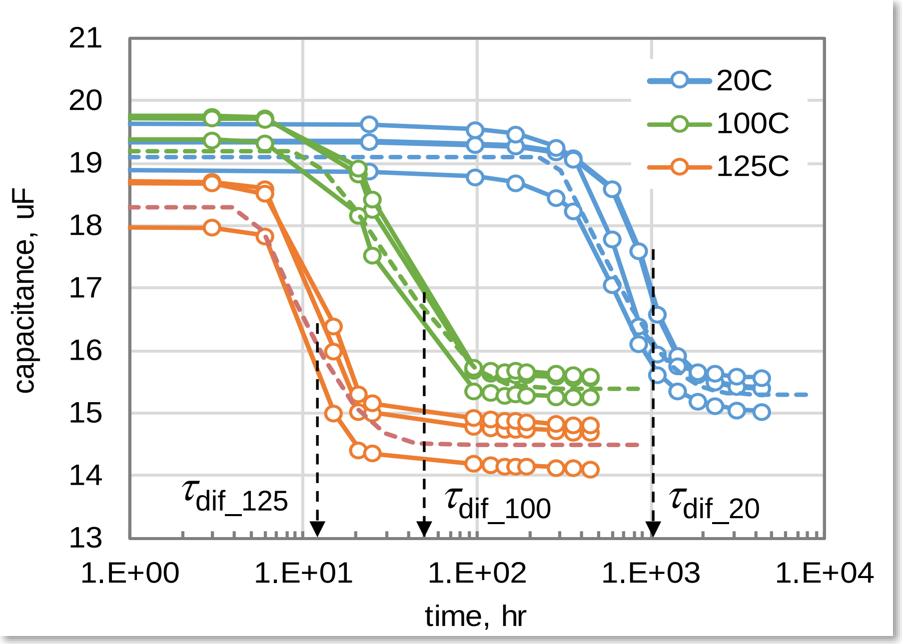
		$\Delta C/C_o$, %	$\Delta DF/DF_{init}$, %	$\Delta ESR/ESR_{init}$, %
CPTC	Avr.	26.6	18.7	-4.5
	STD	8.0	38.9	63.6
MnO_2	Avr.	2.5	13.6	44.3
	STD	1.1	27.7	72.4



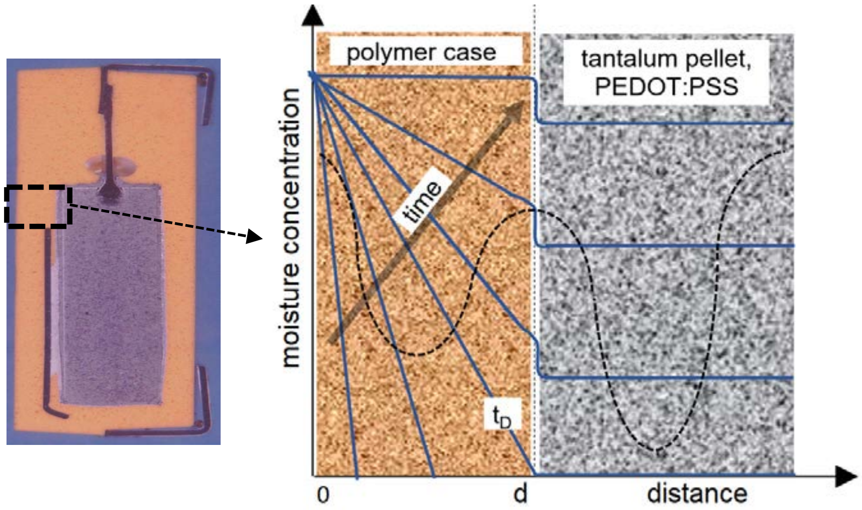
- ✓ Capacitance variations with moisture can exceed 40% for CPTCs.
- ✓ No significant changes in DF and ESR for both polymer and MnO2.
- ✓ Capacitance variations are reproducible from sample to sample.

Tantalum Slugs as Humidity Sensors

Pre-humidified 15 μF 25 V CPTCs during drying at 20 ºC, 100 ºC, and 125 ºC



Modeling of moisture diffusion



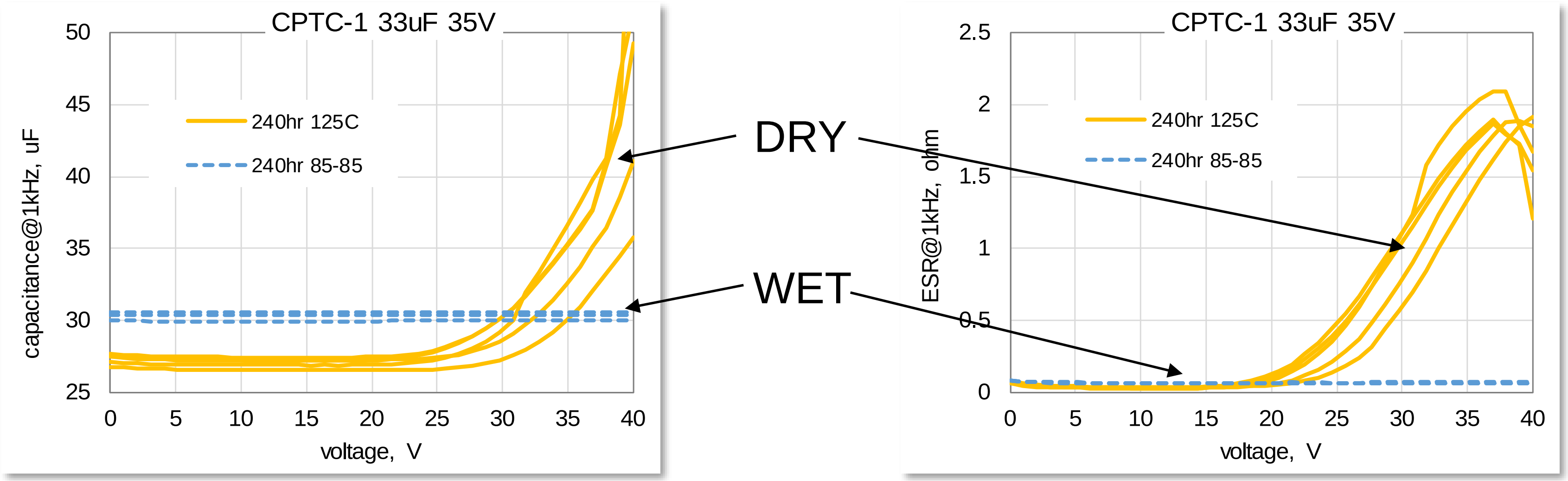
$$C(t) = C_{min} + \Delta C_{max} \times exp\left(-\frac{(t - t_D)}{\tau}\right)$$

$$t_D = \frac{d^2}{6 \times D} \qquad \tau = \frac{d}{\gamma \times \tilde{p} \times S} \qquad t_{bake} \approx \tau_{dif} = t_D + \tau$$

- ✓ Kinetics of moisture diffusion can be characterized by two parameters, t_D and τ that decrease exponentially with temperature.
- ✓ Bake time = $t_D + \tau$ for soldering and 3×($t_D + \tau$) for QA testing.

Effect of Moisture on Voltage Dependence of AC Characteristics

Independence of AC characteristics of voltage is a specific feature of MnO2 tantalum capacitors. This might be not true for CPTCs.



- ✓ AC characteristics of wet CPTCs do not depend on bias.
- ✓ At low frequencies C, ESR, and DF are increasing with voltage in dry CPTCs.
- ✓ The effect is a manifestation of anomalous transient phenomenon.

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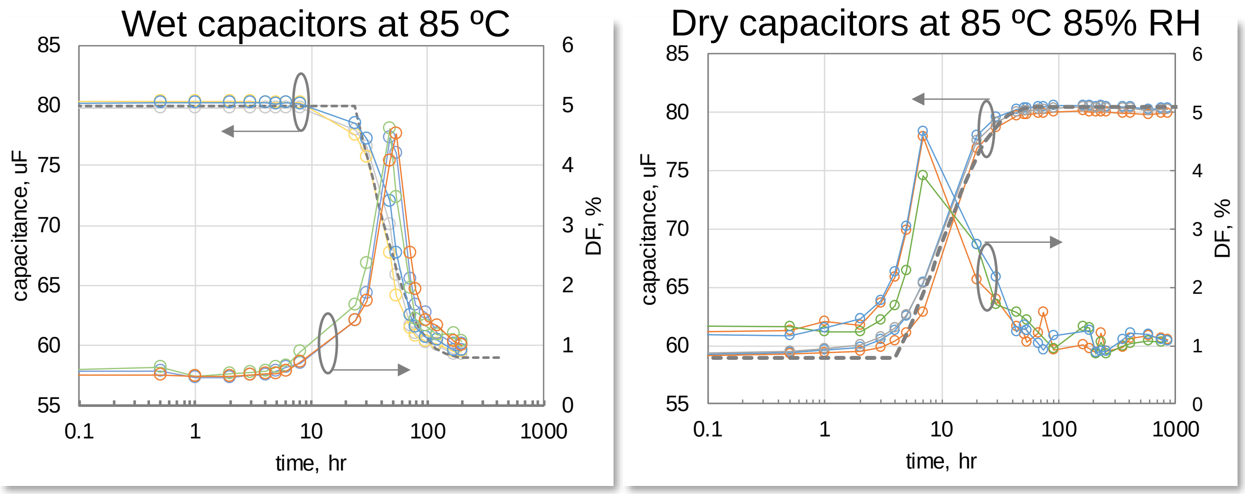
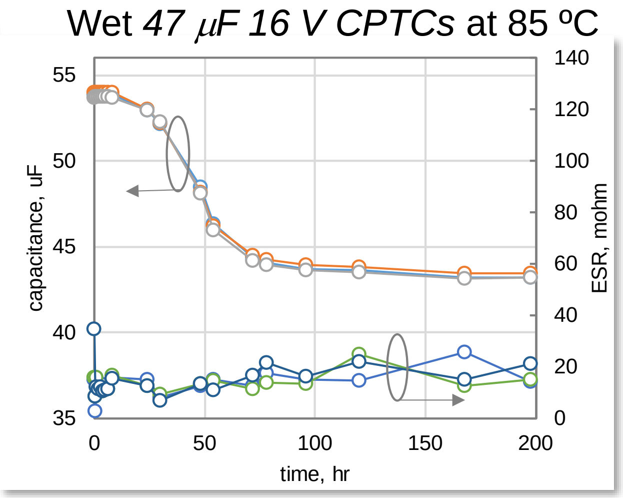
Variations of DF and ESR with Moisture Content

Variations of C and DF during drying and soaking with moisture in 68 μF 16 V CPTCs.



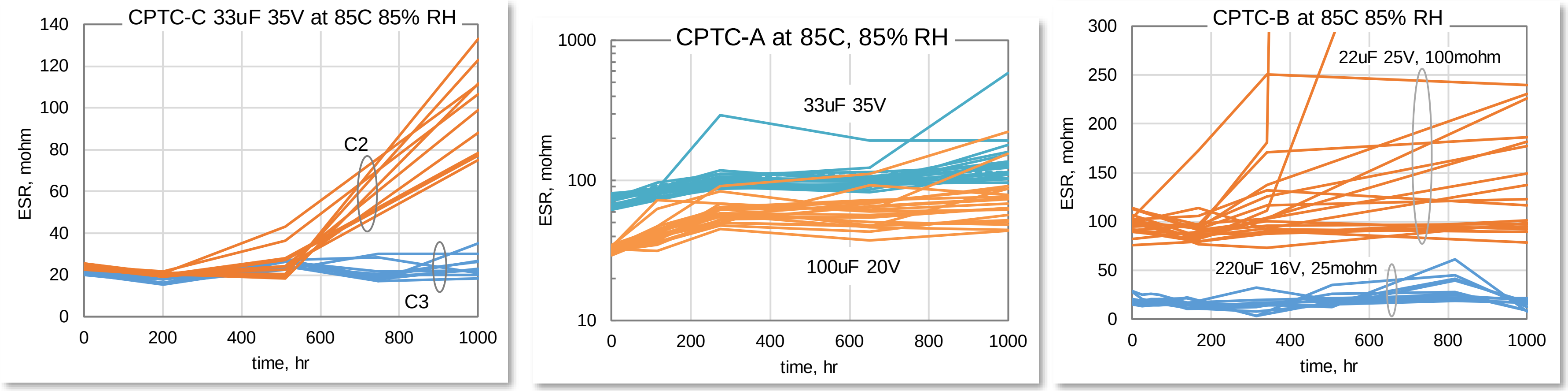
Variations of C and ESR at 85 ºC during drying.



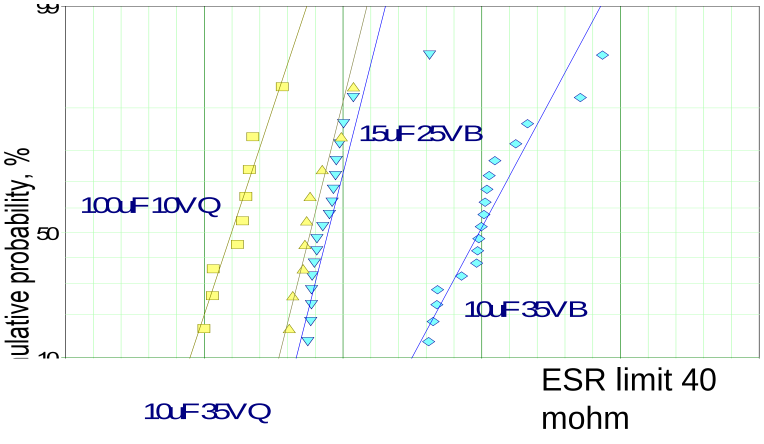
- ✓ Contrary to ESR, variations of DF with time of moisture sorption or desorption go through maximum.
- ✓ In some cases, the level of DF_{max} exceeds 10%.
- ✓ Times to DF_{max} correspond to τ_{dif}.

Effect of 1000hr at 85C 85%RH on ESR

Examples of ESR variations during long-term storage at 85C 85%RH



Four types of CPTC-A after 1000hr at 85C 85%RH

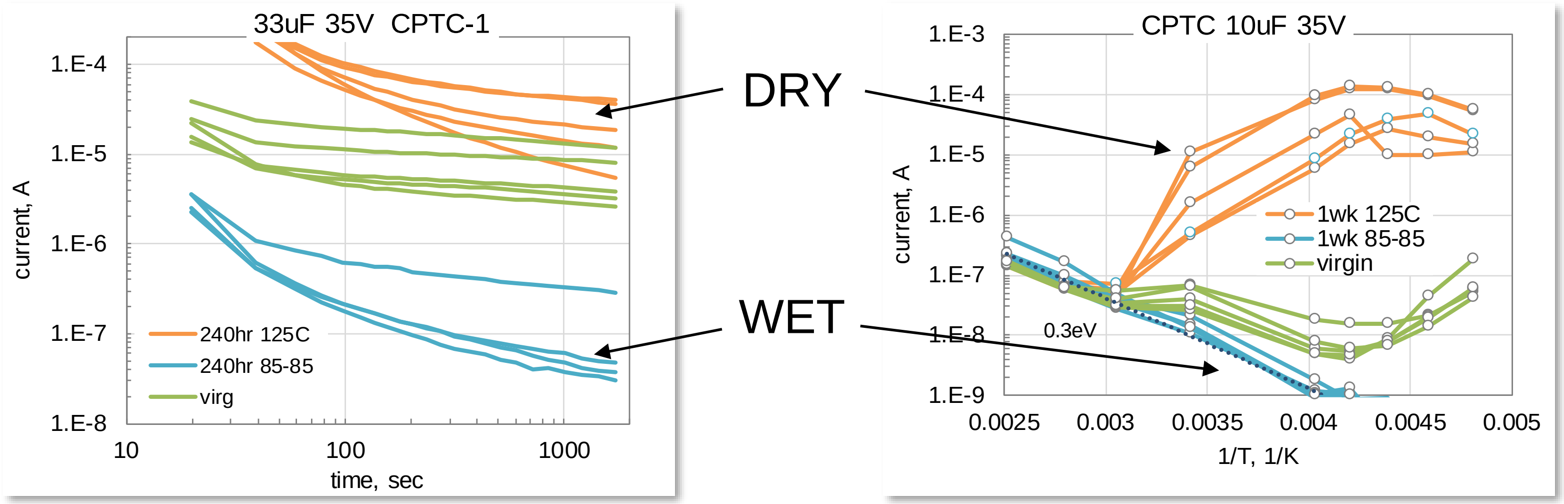


- ✓ There is a trend of increasing ESR by 1000 hr.
- ✓ In most cases ESR remains below 3X the initial limit, but some lots fail humidity storage testing.

Effect of Moisture on DCL

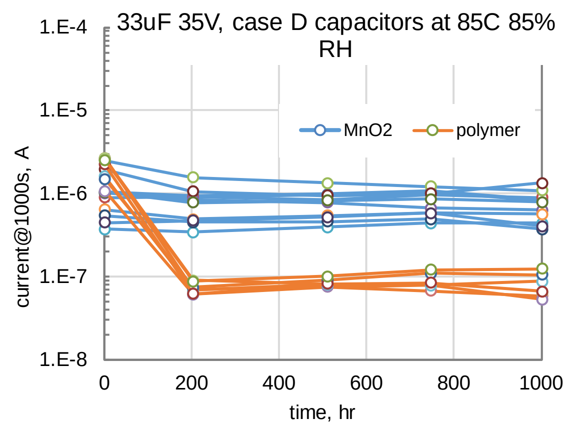
Relaxation of leakage currents after voltage application

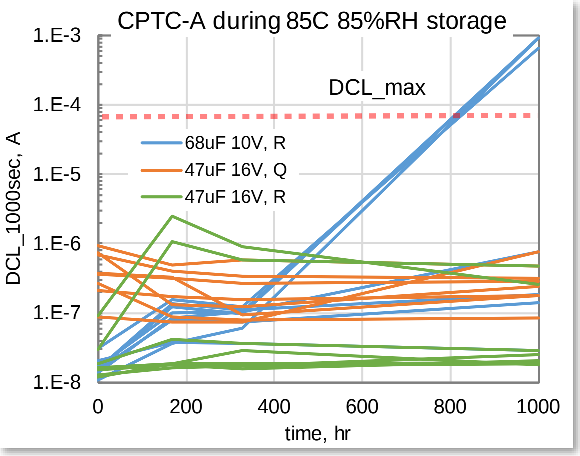
Temperature dependence of leakage currents

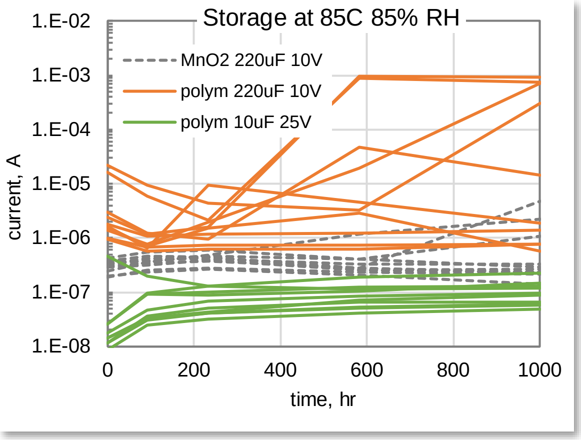


- ✓ DCL can increase after CPTCs' drying up to 10^3 times.
- ✓ Contrary to wet, DCL in dry polymer capacitors does not follow Arrhenius law.
- ✓ Contrary to MnO2 capacitors, leakage currents at low temperatures in dry CPTCs might increase up to 10^6 times.

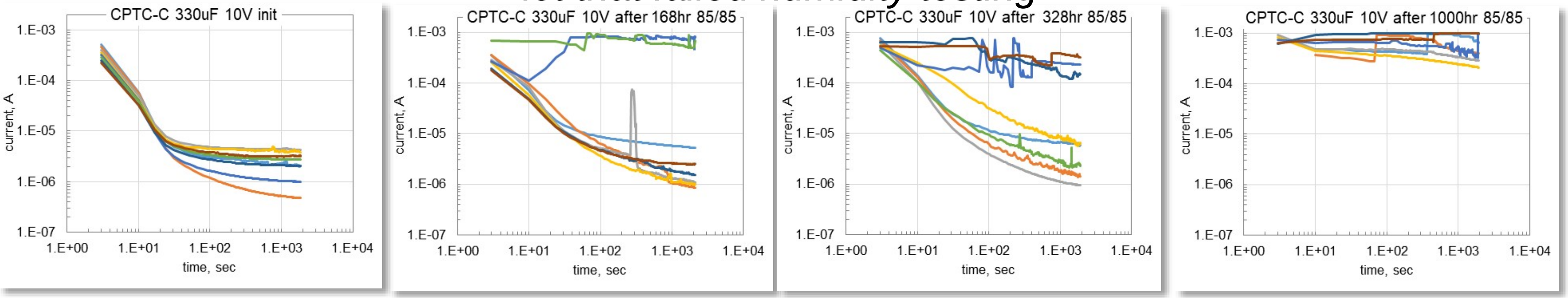
Effect of 1000hr at 85C 85% RH on DCL







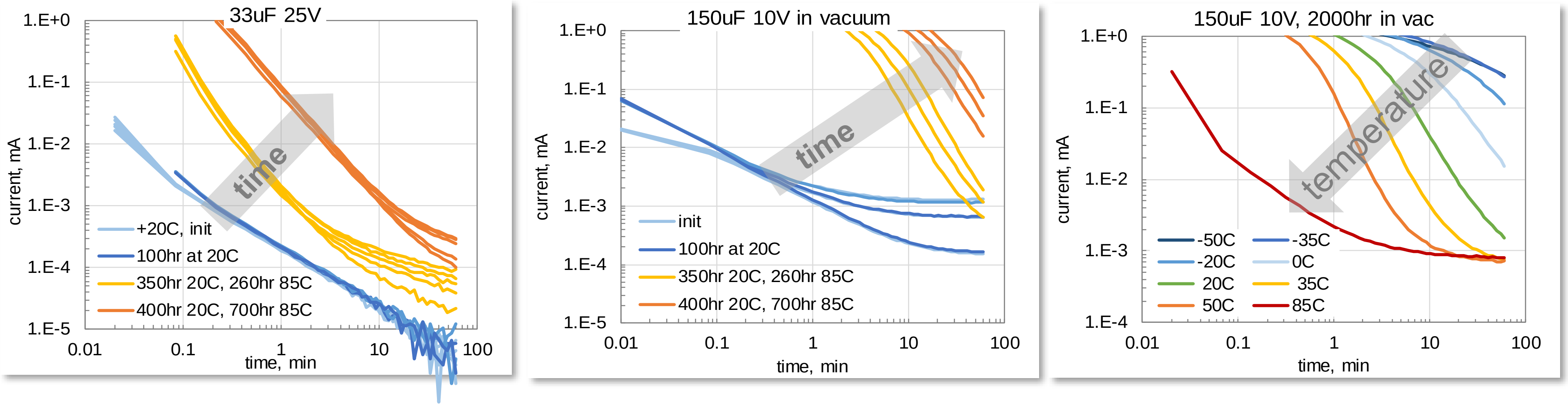
Relaxation of leakage currents after different times of storage at 85C 85% RH in a lot that failed humidity testing

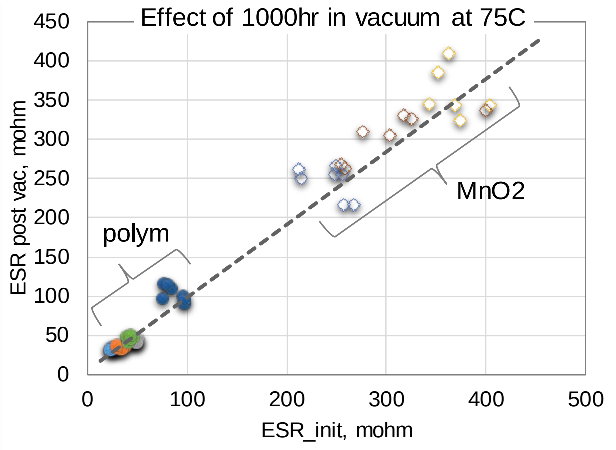


- ✓ Some types of CPTCs can withstand storage at 85 ºC 85% RH for 1000 hours without DCL degradation.

Effect of Vacuum

Relaxation of leakage currents during 1 hour after voltage application for different CPTCs in the process of storage in vacuum (~3 μtor)

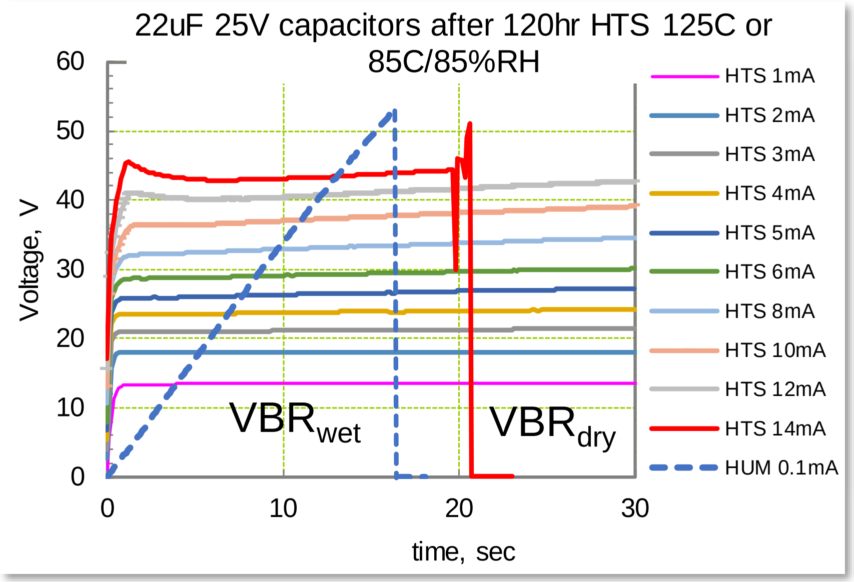




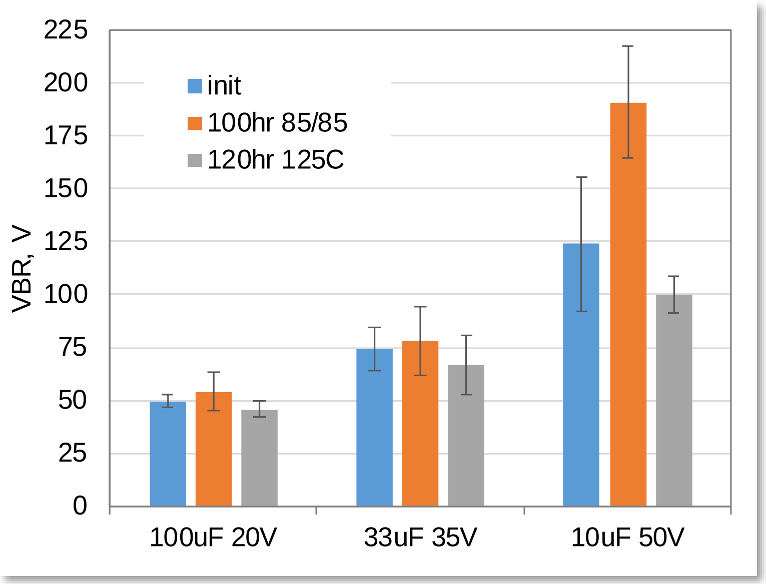
- ✓ Anomalous transients appear with time in vacuum.
- ✓ Leakage currents are decreasing with temperature.
- ✓ There is no significant effect of vacuum storage on ESR.

Effect of Moisture on Breakdown

VBR was determined using constant current stress testing (CCS)



Average values of VBR for different CPTCs after environmental stresses

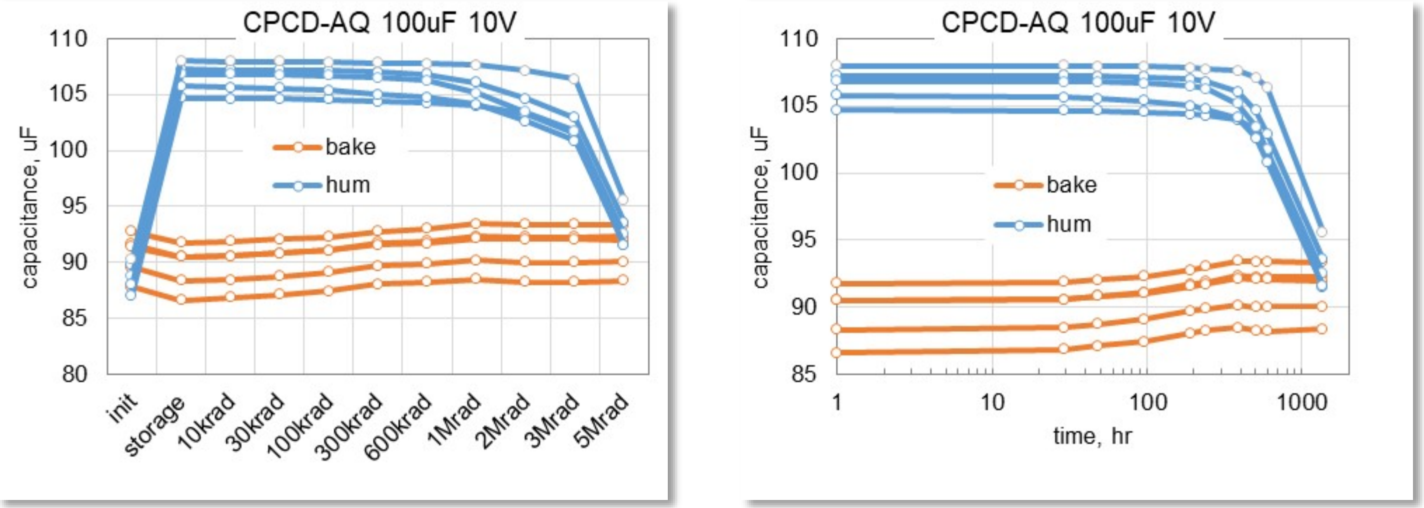


- ✓ Saturation of voltage during CCS test in dry CPTCs is yet another manifestation of anomalous transients.
- ✓ Moisture appears to increase VBR in CPTCs (~ 20%).
- ✓ Different mechanisms of breakdown: electric in the presence of moisture and thermal in dry CPTCs.

Radiation Effect

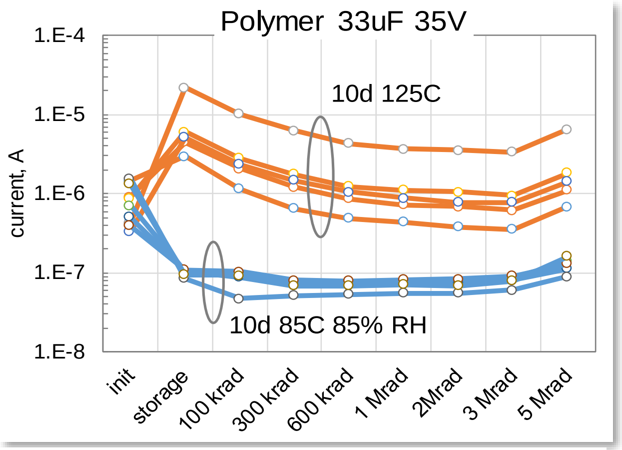
- 13 types of polymer and 5 types of MnO2 capacitors have been tested with time of exposure to Co-60 at the rate of 40 rad per sec.
- 5 pcs from each group have been preconditioned by baking at 125 ºC for 10 days and 5 pcs saturated with moisture (10 days at 85 ºC/65% RH).
- C, DF, ESR, and DCL, have been measured initially, after preconditioning, and then periodically up to 5 Mrad TID.

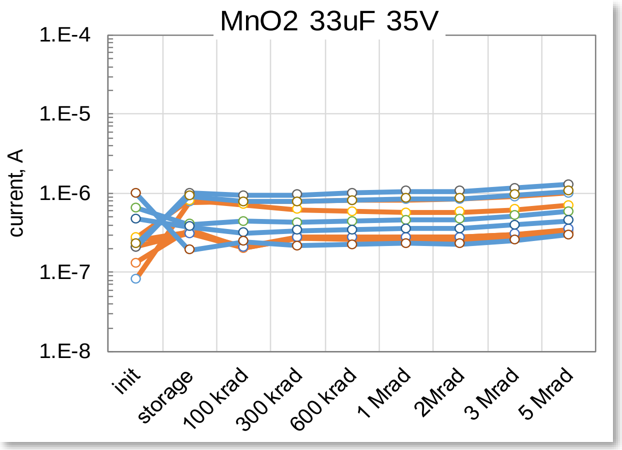
Same data plotted vs TID and time at room conditions

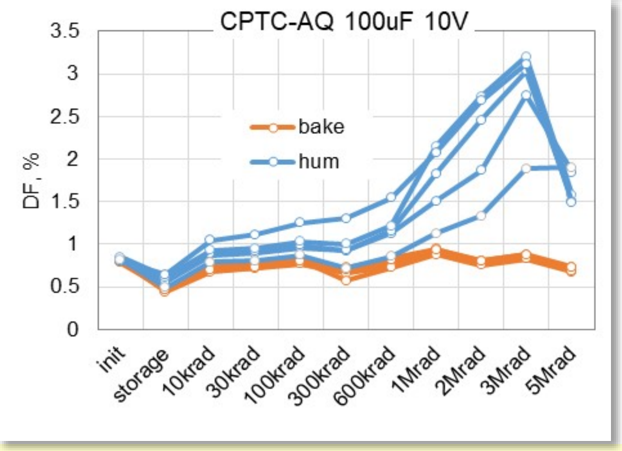


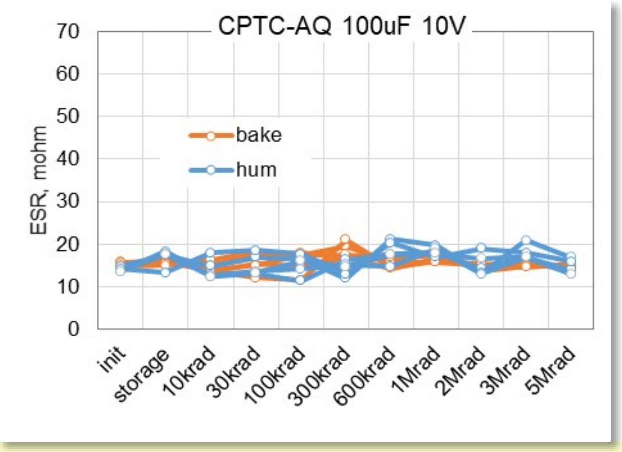
✓ Different behavior of dry and wet CPTCs is due to variations of moisture content in the slug with time of testing.

Examples of Results of Radiation Testing for Different Part Types









✓ No effect of radiation on characteristics of polymer and MnO2 tantalum capacitors up to 5 Mrad (Si) was observed.

Conclusions

- At 85% RH capacitance increases by 27 ± 8% of the value in dry conditions for polymer and by 2.5 ± 1.1% for MnO2 capacitors.
- Tantalum slugs can be used as humidity sensors and variations of capacitance with time can be modeled to characterize kinetics of moisture diffusion using two parameters, t_D and τ.
- DF reaches maximum at the characteristic time of moisture diffusion and then decreases to the values close to initial.
- Most lots of CPTCs can withstand 1000 hours storage at 85 ºC, 85% RH without significant degradation of ESR ($>3\times ESR_{init\ limit}$).
- Moisture stabilizes C and DF under bias, reduces (~10^3X) leakage currents and increases (~20%) breakdown voltages in CPTCs.
- Storage in vacuum might increase DCL substantially (orders of magnitude), especially at low temperatures.
- Radiation up to 5Mrad (Si) does not affect characteristics of MnO2 and polymer tantalum capacitors.