Power Surge Testing for Polymer Tantalum Capacitors

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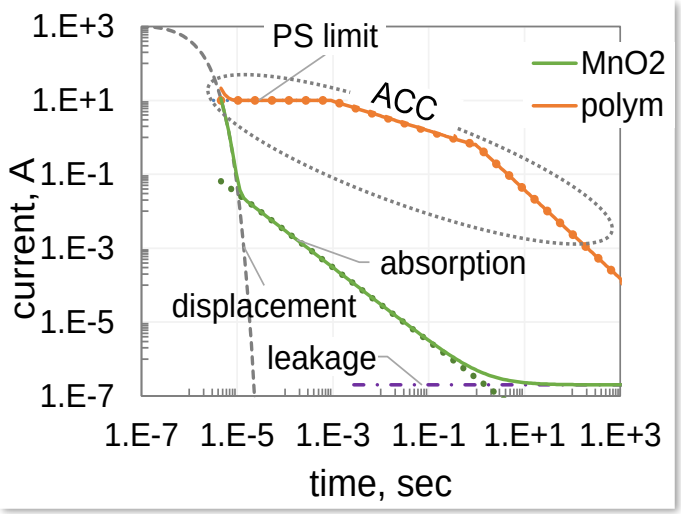
Transient Currents



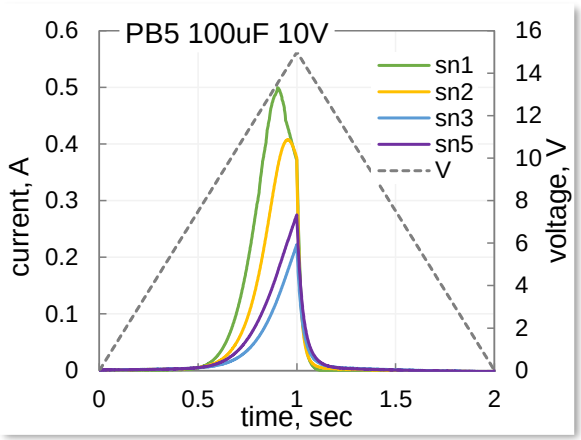
- Displacement and absorption currents are reversible, increase linearly with voltage, and have poor temperature dependence.
- ACC appears as a temporary short at power-on and is specific for dry discharged polymer capacitors only.

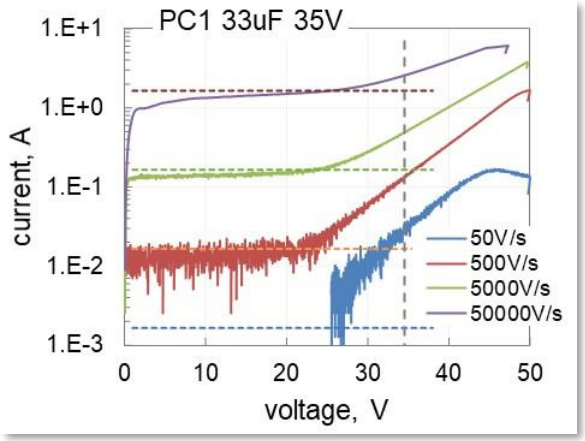
- ACC is likely due to the Schottky emission at the conductive polymer/T2O5 interface. Rising of the barrier with time was explained by the orientation of polymer dipoles or by electron trapping processes.
- The lack ACC control is due to the absence of a standard technique to characterize the effect.

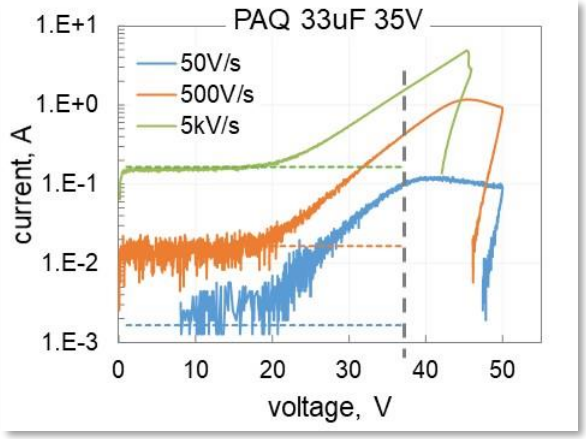
✓ This work suggests a test method (PST), and assesses factors affecting ACC.

Constant Voltage Ramp (CVR) Method

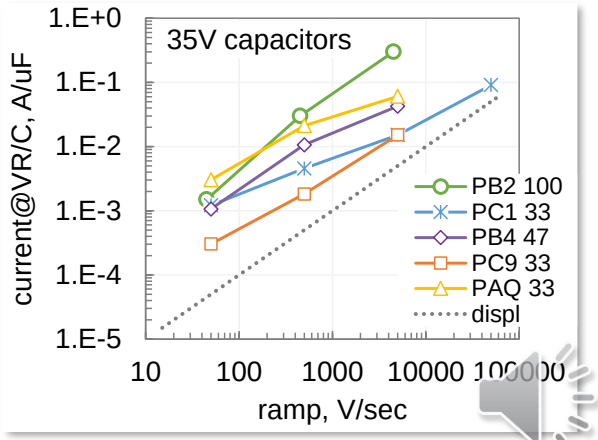
- CVR: increasing V at a constant rate while the currents are monitored.
- CVR was used in several publications at a rate of 120 V/sec.
- Currents depend on capacitance and increase with the ramp rate.
- It is reasonable to characterize ACC by the ratio $I_{ACC}(VR)$ to I_{displ}.







- ACC can be characterized by the ratio $I_{ACC}(VR)$ to I_{displ}.
- However, $I_{ACC}(VR)/I_{displ}$ changes with the rate.

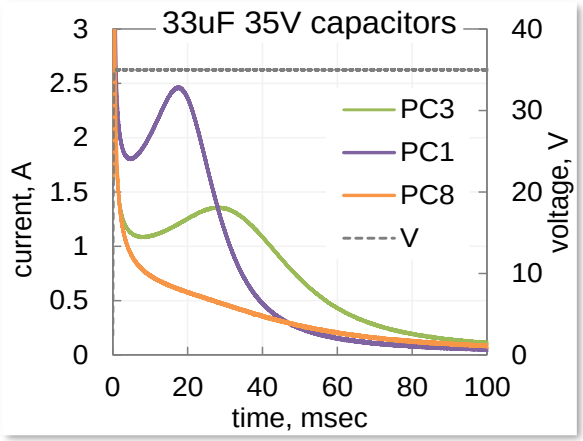


✓ It is difficult to select the same ramp rate for different part types to maximize $I_{ACC}(VR)/I_{displ}$.

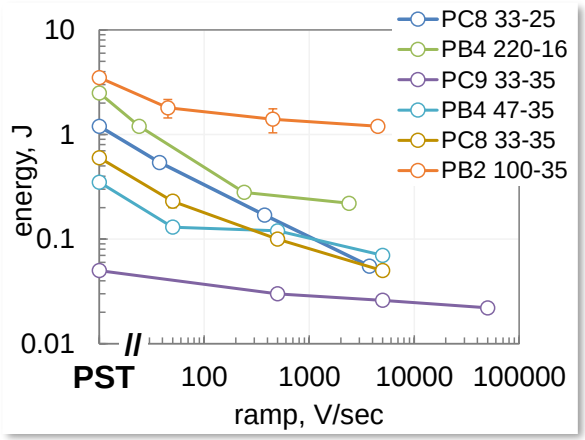
Power Surge Test (PST) Method

- The part is stressed by a voltage pulse (VR) using a power supply capable of stabilizing voltage within 1 msec while the current is recorded with time.
- Contrary to SCT, that creates a stress during less than ~ 1 msec, the level of voltage stress and the power dissipated within the part remains high during the whole period of PST.

PST for 3 types of capacitors



Energy during PST and CVR

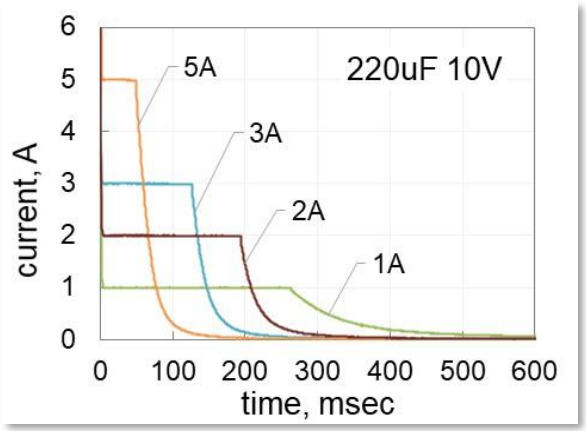


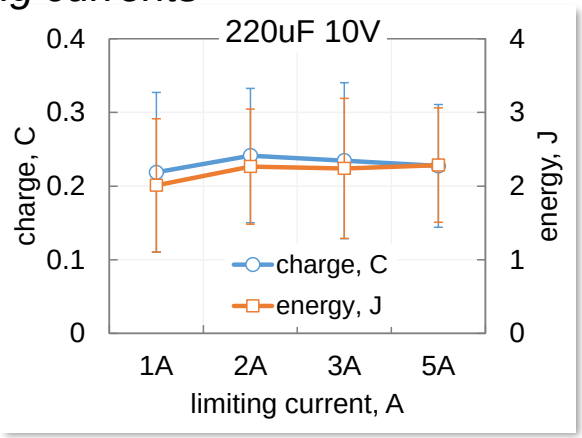
- ✓ Current relaxation might take more than 100msec and is not monotonic.
- ✓ PST results in a higher energy dissipation compared to CVR test.

PST Metrics

- ACC can be characterized by the current after 10 msec, I_{10}, transfer charge (Q), or dissipated energy (E).
- Q and E are calculated by digital integration till $I(t)$ = 10mA.

PST at different limiting currents





$$Q = \Sigma(I_i \times \Delta t)$$

$$E = \Sigma(I_i \times V_i \times \Delta t)$$

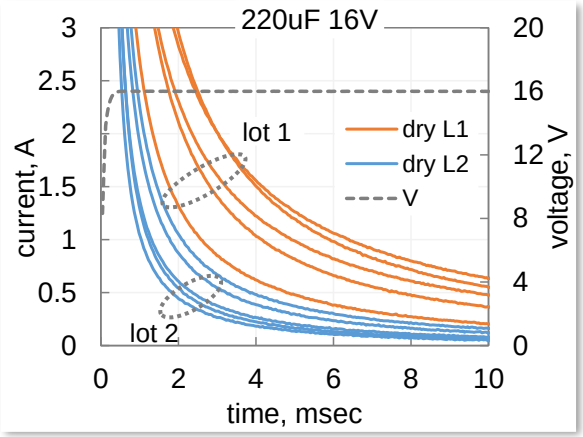
$$E \approx Q \times V\,R$$

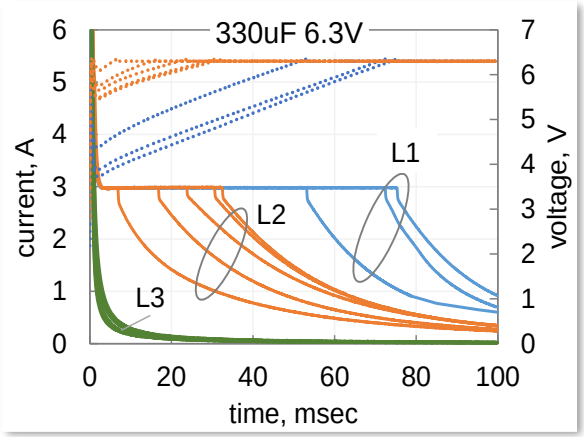
- ✓ Q and E do not depend on the shape of current relaxation.
- ✓ Measurements of I_{10} is simple and is useful for parts with smooth relaxation when currents are not limited by PS.
- ✓ The level of ACC can be characterized as high at $I_{10} \geq 1$ A or $E \geq 1$ J, low at $I_{10} < 0.1$ A or $E < 0.1$ J, and as medium in other cases.

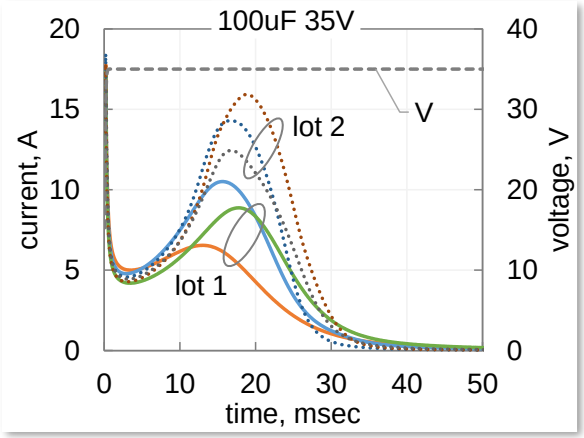
Reproducibility of PST Results

- PST pulses: 200msec at VR followed by 200msec at 0V

Lot-to-lot and sample-to-sample variations

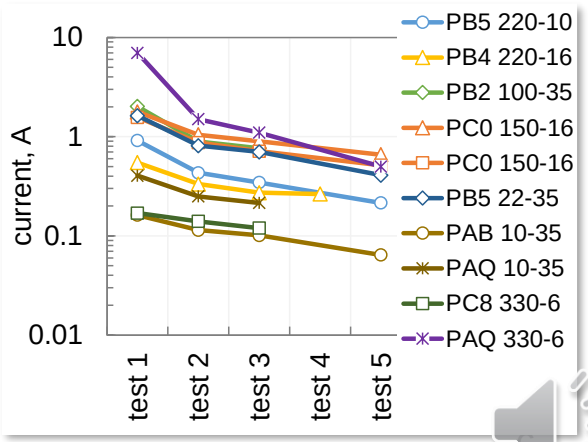






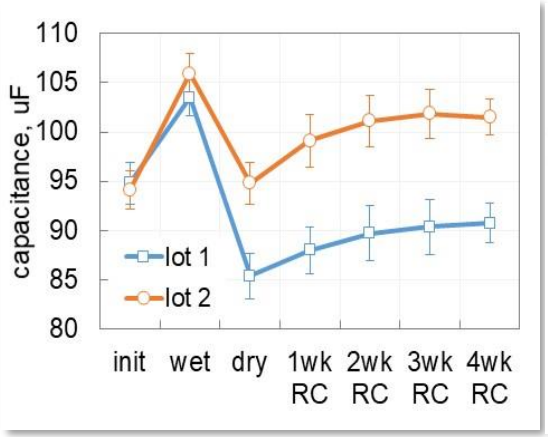
- ✓ Different lots might have substantially different level of ACC.
- ✓ For the same lot, sample-to-sample variations of I_{10} are ~20% and ~10% for E.
- ✓ Repeat measurements reduce ACC currents substantially, up to 5 times.

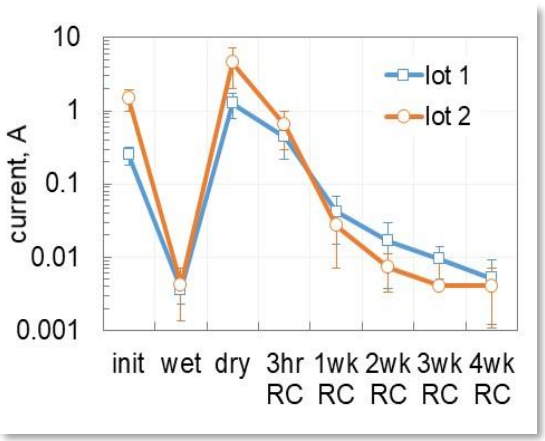
Repeat testing

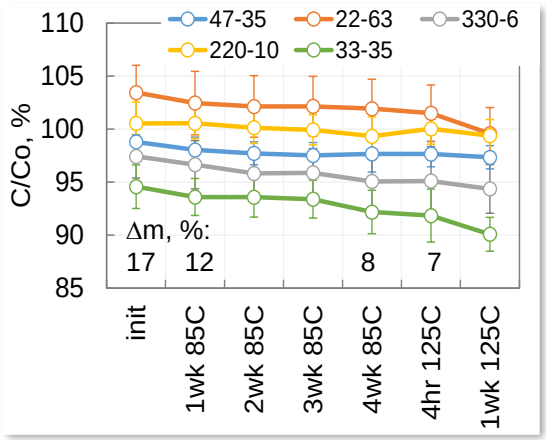


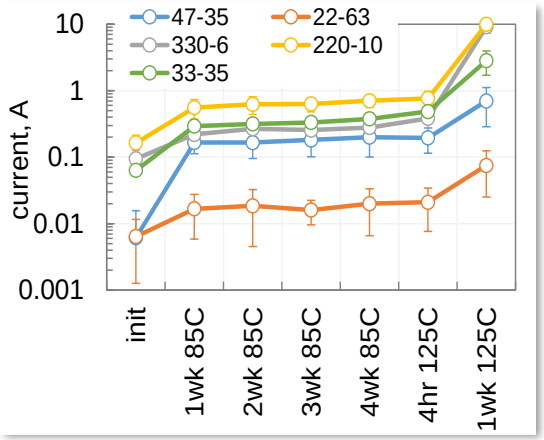
Effect of Preconditioning

- Capacitance and I_{10} were measured after different preconditioning to assess the effect of moisture on ACC. $\Delta m = 100\frac{C-C_{dry}}{C_{wet}-C_{dry}}$, %
- Dry conditions: 16-24hr 125C. Wet conditions: 168hr 85C 85% RH.









✓ACC is practically absent for wet parts, but for dry parts I_{10} is in amps range.

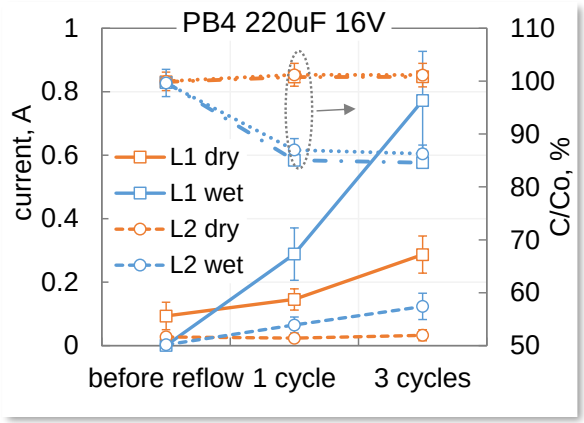
✓Storing at RC reduced I_{10} to the level of wet capacitors.

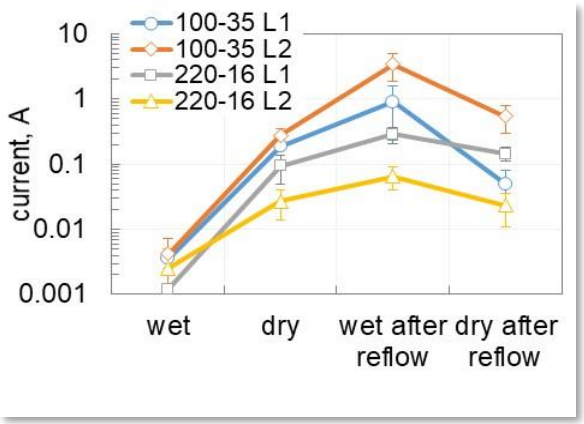
✓ACCs are much more sensitive to moisture compared to capacitance.

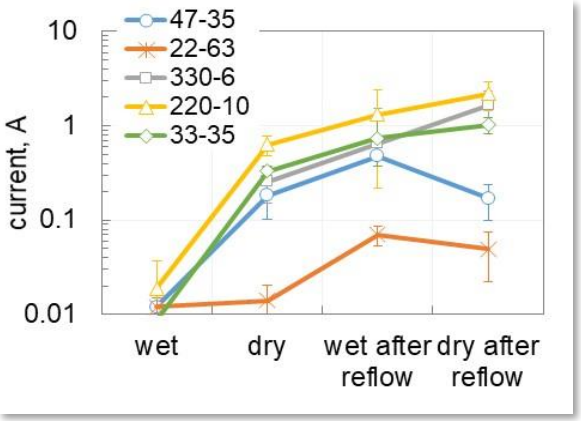
✓Even a small amount of moisture, <10% of RC, can reduce ACC substantially.

Effect of Reflow Soldering

- Reflow soldering at 235 °C reduces moisture content by 50% to 75%, so increasing of ACC was expected.



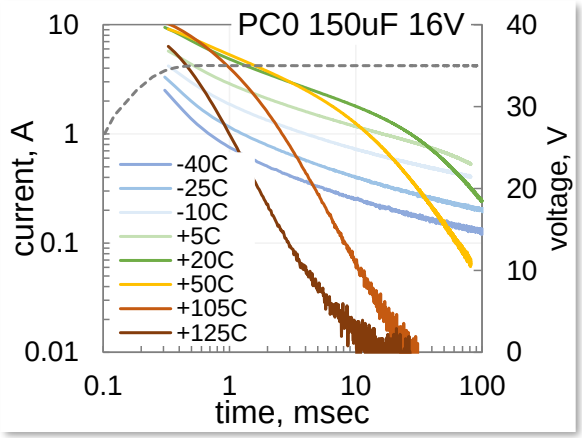


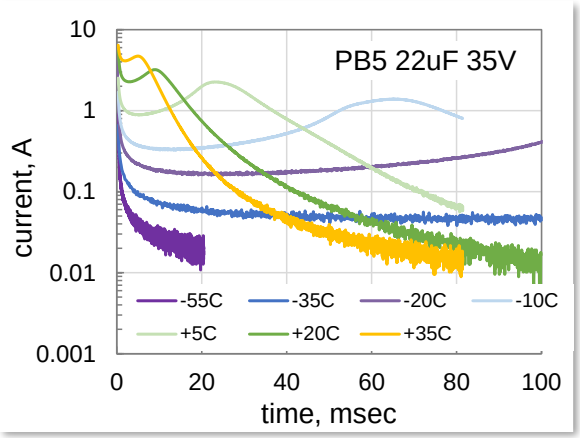


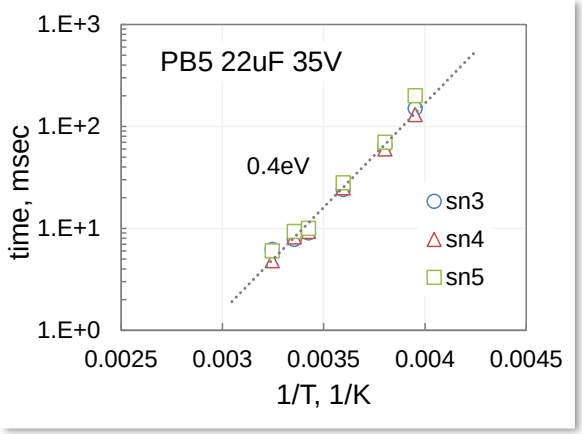
- ✓ Increasing number of reflow cycles increases the level of ACC.
- ✓ ACC increases even for initially dry capacitors.
- ✓ In some cases, reflow soldering increases ACC in initially wet parts to a much greater degree compared to initially dry parts.
- ✓ Exposure to HT results in structural changes in PEDOT:PSS that depend on the moisture content and can cause variations in the barrier height at the polymer/Ta2O5 interface.

Effect of Temperature

- Typically, relaxation of currents occurs smoothly with the rate increasing with temperature.
- In some cases, *I-t* curves have a hump at a time that exponentially increases with temperature and might exceed 100 msec.



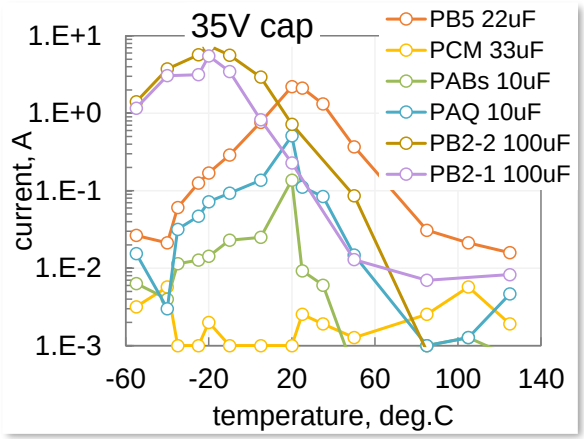


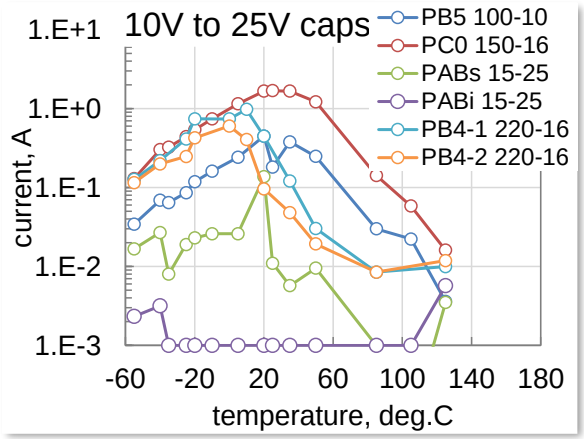


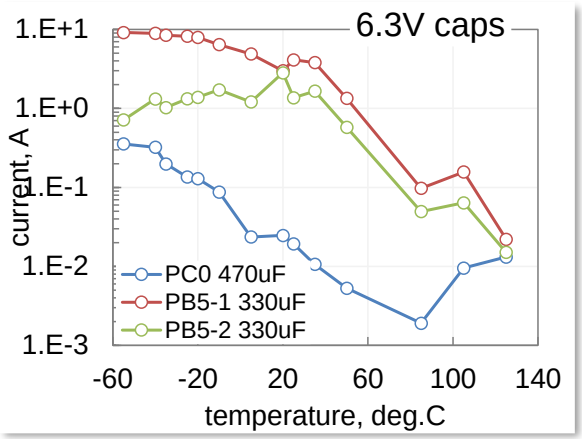
- ✓ The humps can be explained by the space charge limited transient currents theory; however, the time to maximum should be inversely proportional to voltage, which contradicts experimental data, and assessments for carriers' mobility are not consistent with literature.
- ✓ More analysis is necessary to explain the mechanism of ACC.

Effect of Temperature, Cont'd

- Based on previous studies, the level of ACC is greater for HV capacitors, decreases at HT and increases at LT.
- In most cases, $I_{10}(T)$ curves had maximum that depending on the part type varied between -55 °C and +30 °C.
- Maximum current varies from 10 A to a few milliamperes.





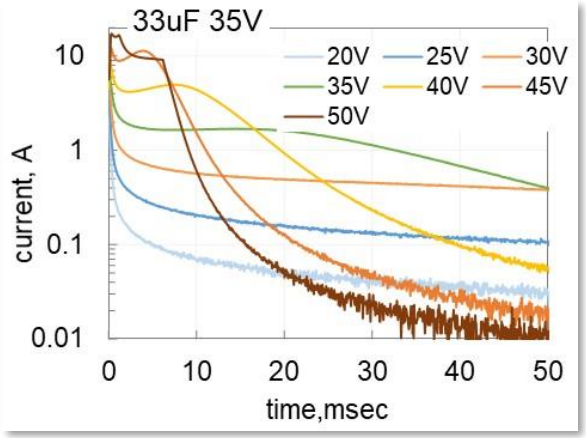


- ✓ No correlation between the rating and the values of T_{max} or I_{max}.
- ✓ Some 6.3 V capacitors had I_{max} ~ 10 A, which is greater than the maximum level observed in HV parts.

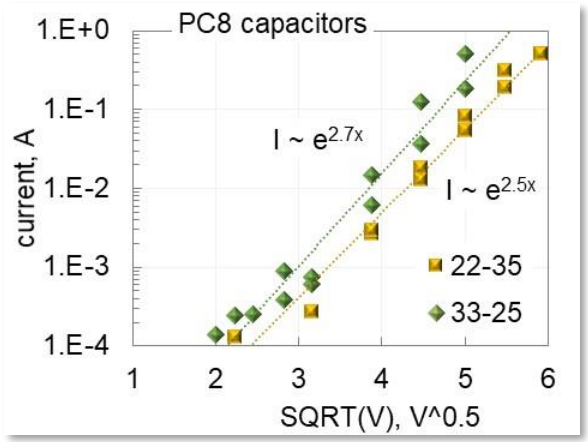
Effect of Voltage

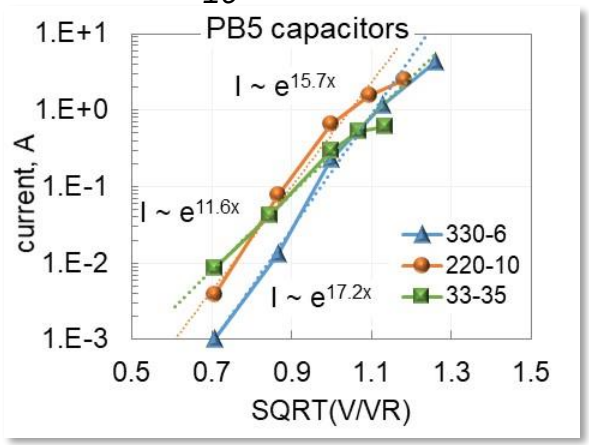
- Based on previous studies, decreasing of voltage reduces ACC substantially.

An example of I-t_V curves



Voltage dependencies of I_{10}



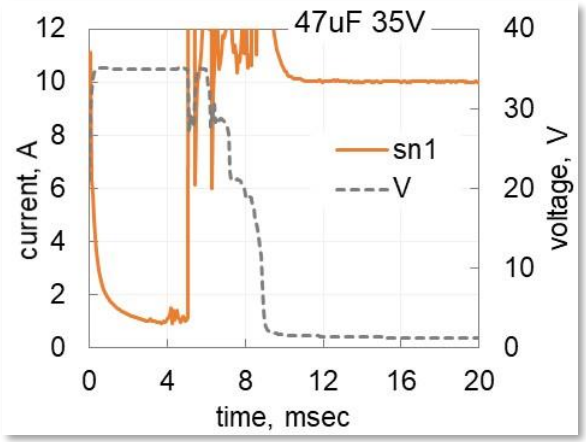


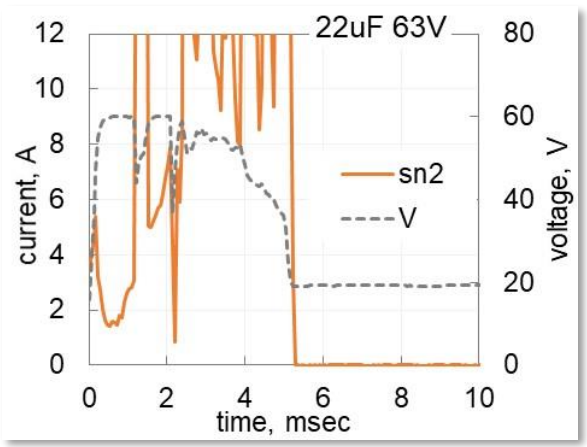
- ✓ At I_{10} < 1 A, the currents increase exponentially with $V^{0.5}$ indicating Schottky conduction mechanism.
- ✓ In most cases, derating to 0.5VR practically eliminates ACC.

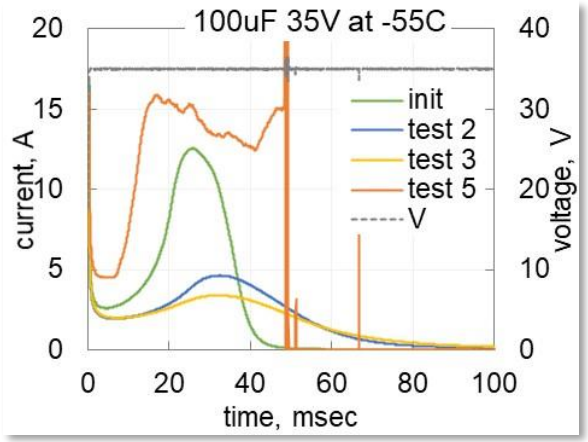
Failures During PST

- No failures caused by ACC were reported during CVR testing.
- PST results in higher dissipated energy and can cause failures.

Examples of failure events





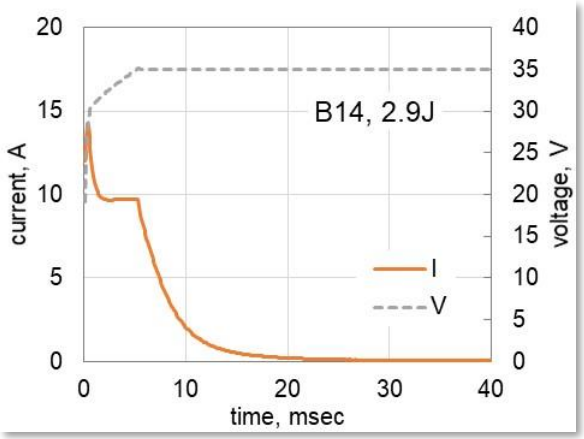


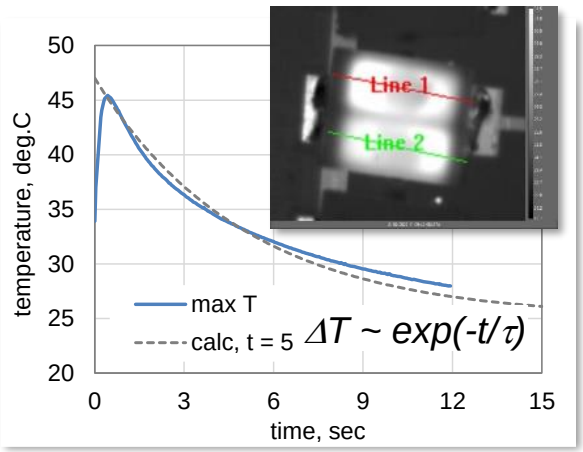
- ✓ The propensity to failure is lot-related and increases after reflow soldering.
- ✓ There is a need to use PST as a screening procedure.

Thermal Effect During PST

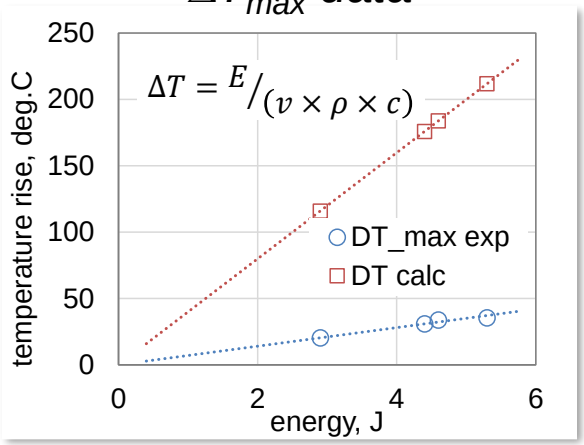
- Temperature of the parts soldered onto PWBs was monitored during PST using an IR camera.
- $\Delta T_{max}(t)$ was approximated with an exponential function at $\tau = R_\theta \times C_\theta$.
- For power pulses <100 msec, the heating is adiabatic, and *E* goes for increasing temperature of the slug.
- The actual temperature of the slug, $T_{exp} << T_{act} < T_{calc}$.

An example of PST and temperature relaxations





Calculated and experimental ΔT_{max} data



✓ ACC can create substantial thermo-mechanical stresses in the slug.

Summary

1. The absence of a standardized test and a lack of manufacturing control results in a large lot-to-lot variation of ACC in polymer tantalum capacitors.
2. The level of ACC is divergent, varied due to moisture absorption, structural variations in PEDOT:PSS, and charges accumulated during repeat measurements.
3. PST results in a higher energy dissipation compared to CVR, might cause a thermal shock and failures of capacitors.
4. The significance of ACC depends on application conditions and may be negligible at voltages below 0.5VR and relatively high temperatures (above ~65 °C). Lots with high ACC levels require additional tests and analysis.
5. PST is recommended as a screening and LAT (see “Guidelines for screening, LAT, and derating for PTCs”, GSFC, 2022).