Reliability Issues with PME and BME Ceramic Capacitors

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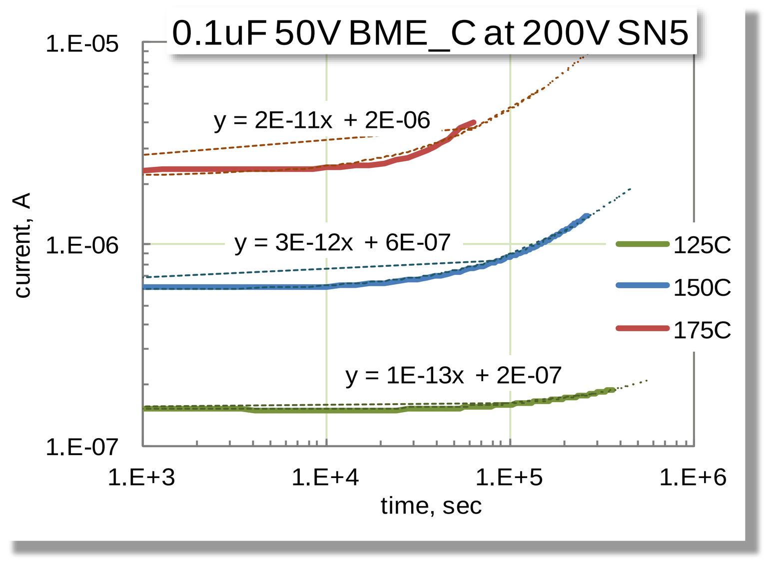
INTRODUCTION

Two major reliability problems with low-voltage, class II dielectric MLCCs: (i) degradation of IR associated with migration of oxygen vacancies (V_O^{++}), and (ii) failures related to cracking caused either by soldering or by post-soldering stresses. The first one prevails for commercial base metal electrode (BME) capacitors, whereas the latter to precious metal electrode (PME) capacitors that until recently were the only types of capacitors used for hi-rel and in particular space applications. This work gives a review of degradation processes specific to PME and BME multilayer ceramic capacitors.

RELIABILITY ACCELERATION FACTORS

Distributions of degradation rates at different V and T were approximated with Weibull functions, and results of HALT were analyzed using a general Weibull Log-Linear model:

$$L = A \times \exp\left(\frac{E_a}{kT}\right) \times V^n$$



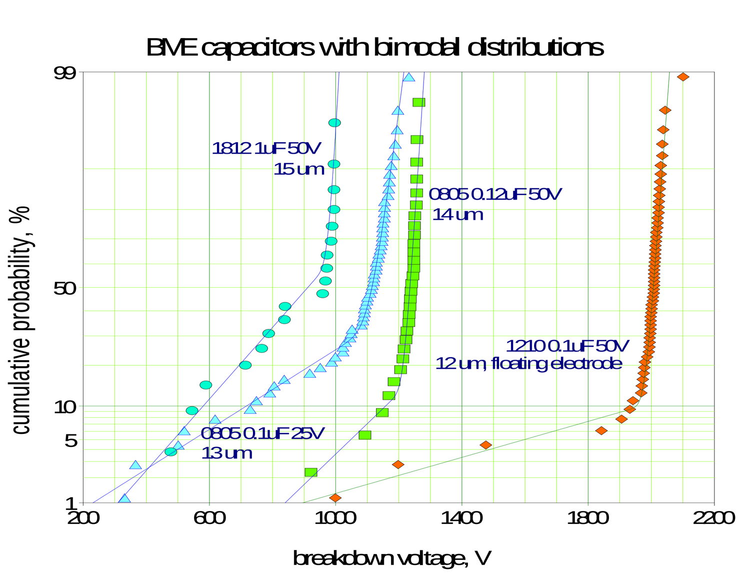
An example of degradation of leakage currents in BME MLCCs at different T.

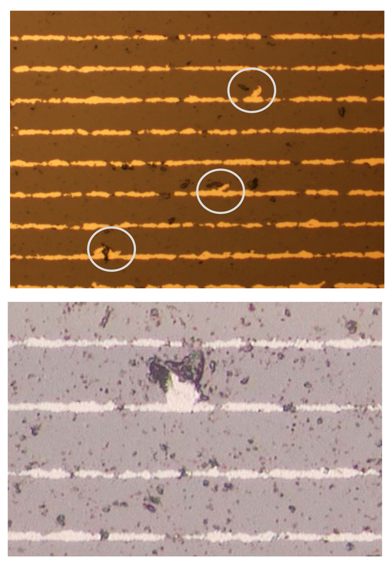
	Results for BME	Typical values for PME
n	3.9 – 5.5	3
E_a, eV	1.8 – 2.4*	0.9 -1.1

*E_a is a sum of activation energy of leakage currents, E_{a_leak}, and migration of V_O^{++}, E_{a_migr}. Considering that E_{a_leak} is ~ 0.8 eV, E_{a_migr} is in the range from 1 to 1.6 eV, which is close to values reported for V_O^{++}.

The probability of failures of BME capacitors at operating conditions is negligibly small in most cases. The major reason of failures is the presence of defects in the parts.

REVEALING DEFECTS



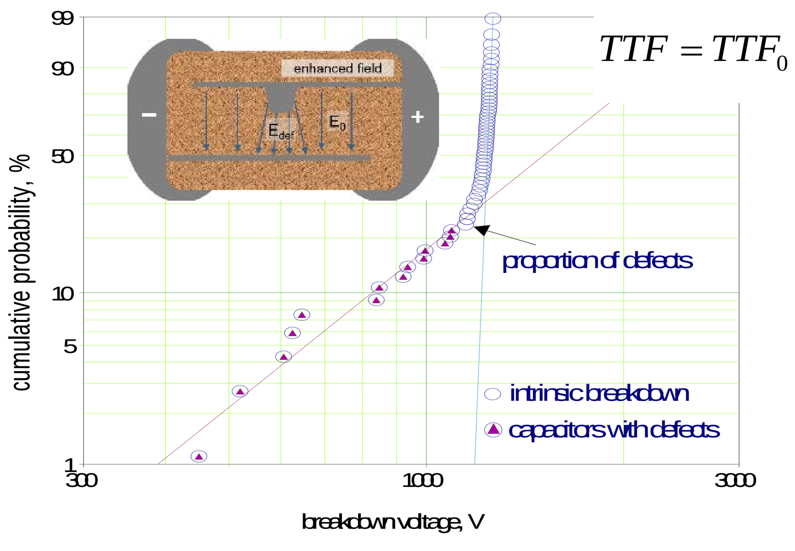


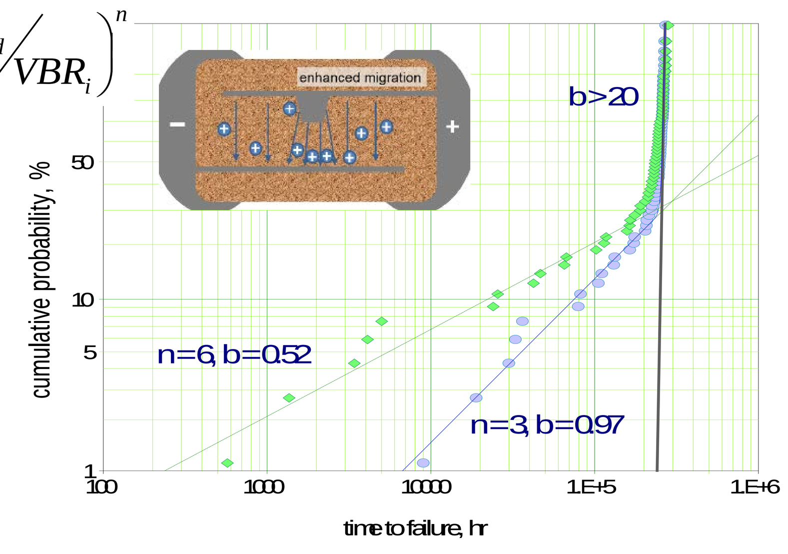
Defects can be revealed by analysis of distributions of breakdown voltages: the intercept indicates the proportion of defective parts, and the spread of low-voltage tail – their significance.

FAILURES IN CAPACITORS WITH DEFECTS

Times to failure can be calculated based on VBR: the same degradation processes that cause wear-out failures in capacitors without defects, can result in IM failures of the parts if defects are present.

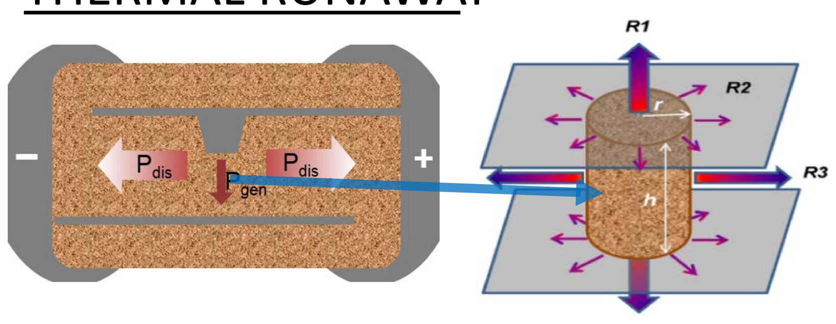
$$TTF = TTF_0 \times \left(\frac{VBR_d}{VBR_i} \right)^n$$





If voltage acceleration constant, n, is known distributions of times-to-failure can be calculated based on distributions of breakdown voltages.

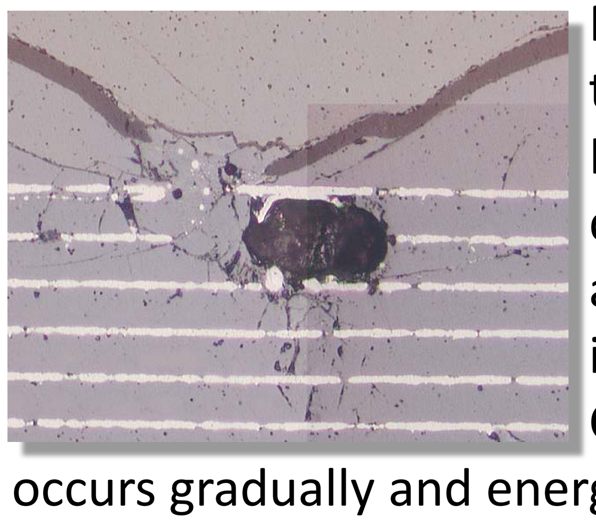
THERMAL RUNAWAY



$$C \times \frac{dT}{dt} = \pi \times r^2 \times J_d(T, E) \times V - \frac{T - T_0}{R_\theta}$$

$$R_\vartheta = (1/R1 + 1/R2 + 1/R3)^{-1}$$

Modeling showed that in the range of typical HALT conditions (T from 125C to 200C and voltages up to 10×VR), voltage increases the probability of catastrophic failures to a greater degree compared to temperature. Small size defects that would never cause failures at normal operating conditions can result in short circuit failures during testing at increased voltages, thus resulting in wrong acceleration factors and false reliability predictions.

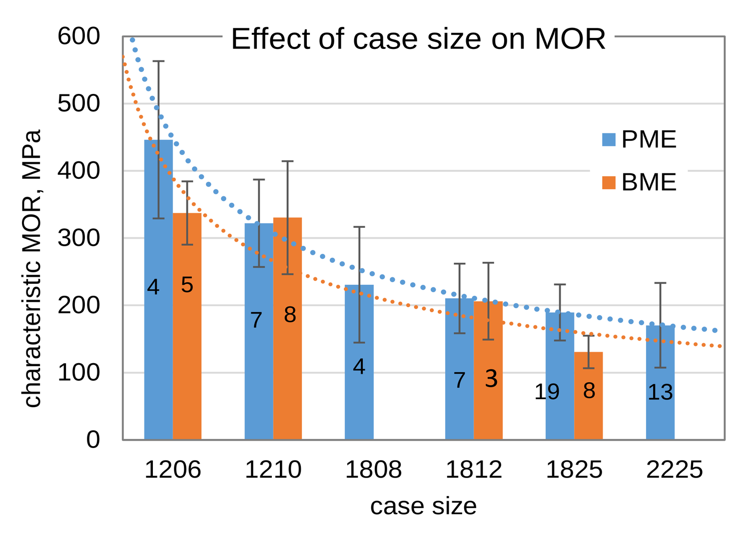


Failures in PME capacitors are likely due to the time dependent dielectric breakdown (TDDB). Instant release of energy in the defective area during breakdown causes adiabatic overheating and local melting resulting in short circuit failures in PME MLCCs.

Contrary to PME, degradation in BME capacitors occurs gradually and energy generated at the defect can be balanced by heat dissipation thus preventing melting of metals and ceramics.

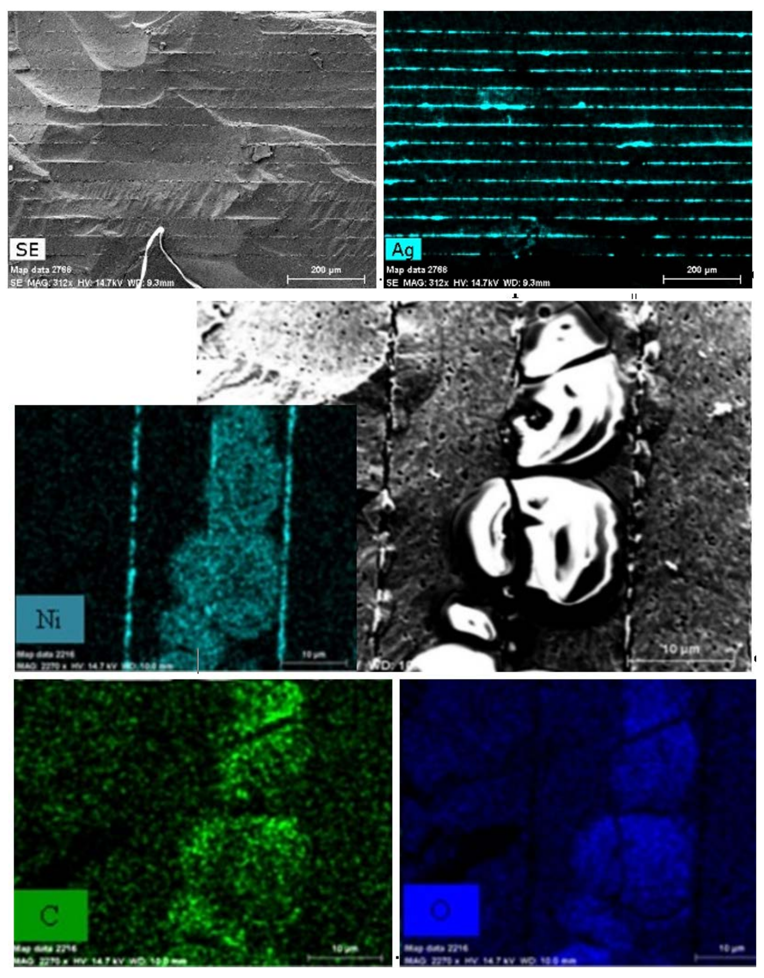
MECHANICAL CHARACTERISTICS

A fracture occurs when the sum of external and internal mechanical stresses exceeds the tensile strength of the part. To reduce the probability of cracking, the level of stress should be reduced, and the strength of the parts increased by selecting the most mechanically robust capacitors.



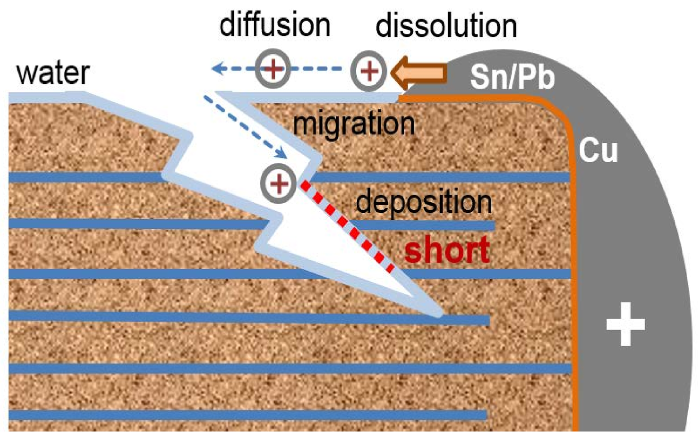
Comparison of MOR values for BME and PME capacitors showed no substantial difference. There is a trend of decreasing strength with increasing size of the parts for both PME and BME capacitors. For this reason, the smaller case size capacitors are less prone to assembly related cracking. Considering that the same value BME capacitors have smaller size, replacement of PME with BME capacitors is beneficial for cracking reduction.

CAPACITORS WITH CRACKS IN HUMID ENVIRONMENTS



In humid environments the probability of failures for PME capacitors with cracks is greater than for BME capacitors.

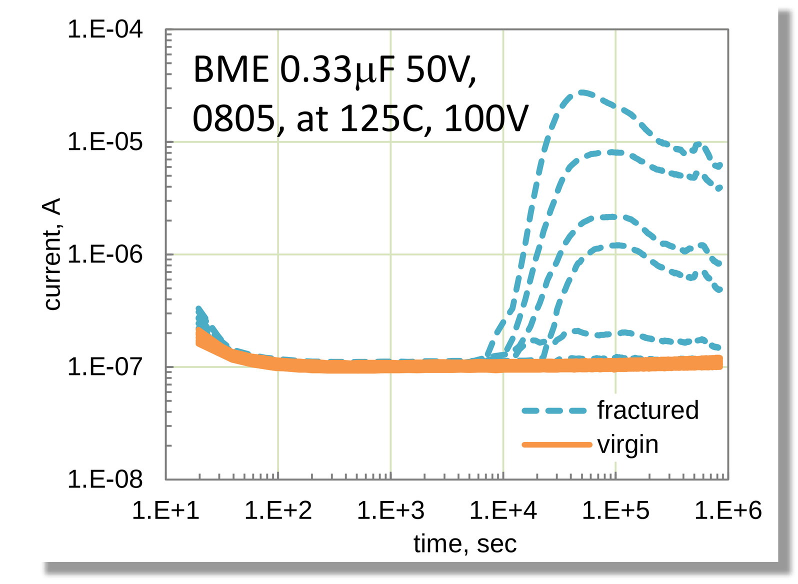
Failed BME capacitors had much greater IR than PME capacitors. The difference in resistance to humidity testing is due to the specifics of electro-chemical behavior of Ni and Ag/Pd electrodes and properties of formed products (conductive Ag-based deposits for PME and isolative Ni/C/O compositions for BME capacitors).

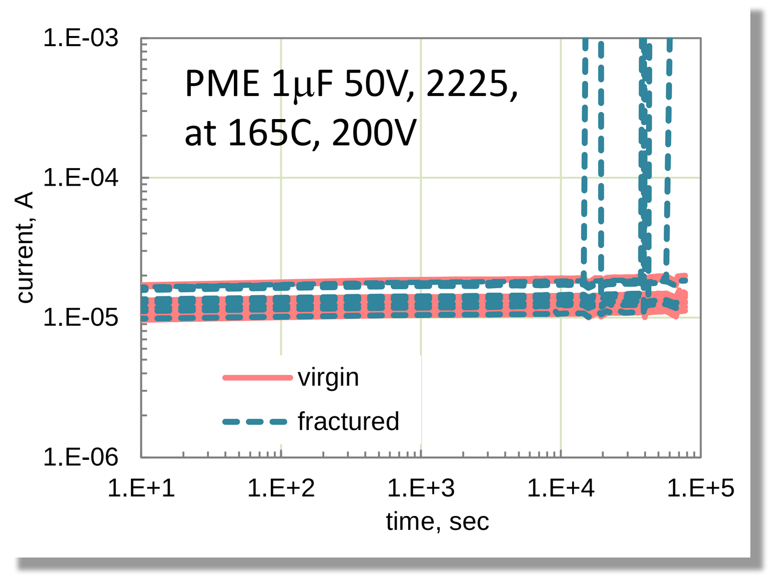


Although the products of Ni migration have high resistivity, anodic dissolution of Sn, Pb or Cu from terminations might provide materials to form conductive deposits or dendrites in cracks located close to terminations.

CAPACITORS WITH CRACKS IN DRY ENVIRONMENTS

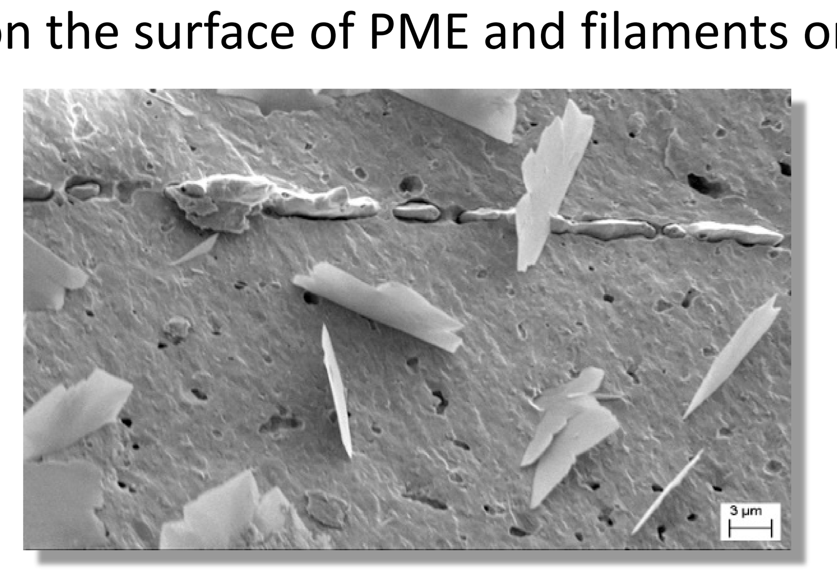
BME with cracks: currents are increasing after a certain induction period, gradually raise up 100X -1000X, and then are stabilizing and even decreasing with time of testing. PMEs: currents are sharply increasing indicating a short circuit failure. Behavior of BME MLCCs can be explained assuming accelerated transport of oxygen vacancies along the cracks.



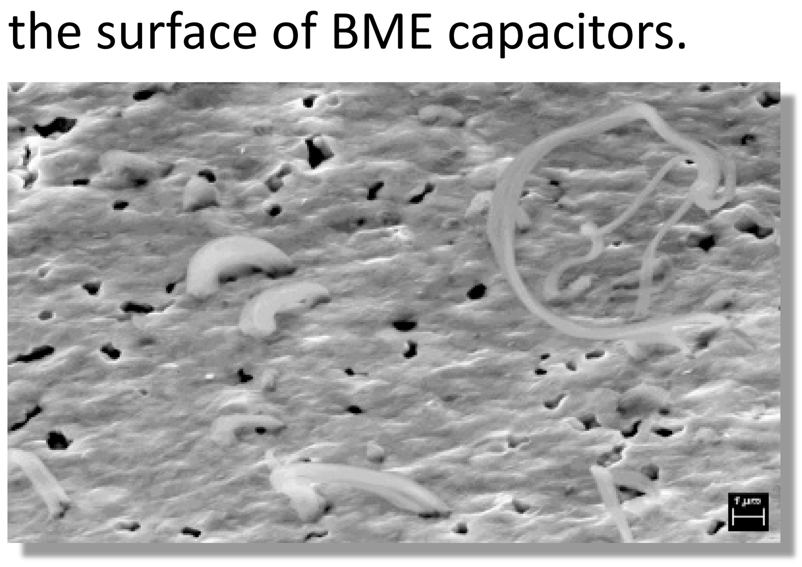


STRUCTURAL ANOMALIES IN MLCCs

Two types of anomalous structures were observed during SEM examinations of fractured capacitors after exposure to humid environments: thin platelets on the surface of PME and filaments on the surface of BME capacitors.



Pb, C, and O in the composition of the platelets on PME MLCCs suggests formation of hydrocerussite-like, Pb3(OH)2(CO3)2 structures.



Carbon filaments on the surface of BME capacitors

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