Effects of Moisture on Solid Tantalum Capacitors

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Moisture is the most common cause for the failures in electronic components. These failures are related to moisture induced corrosion, the popcorn effect, delamination, ion migration, tin whisker growth, etc. All these failure mechanisms can take place in solid Tantalum (Ta) capacitors with either inorganic manganese dioxide cathode (Ta/MnO_2 capacitors) or conductive polymer cathode (Polymer Ta capacitors). These mechanisms can cause parametric failures due to the high dc leakage (DCL), equivalent series resistance (ESR), and dissipation factor (DF) as well as catastrophic failures (shorts). As an example Fig. 1 shows popcorn effect at assembly (a), delamination of the carbon and silver external layers at life test (b), migration of silver toward the Ta2O5 dielectric at passive humidity test (c) and tin whisker growth on storage of Polymer hermetic seal (PHS) Ta capacitors with moisture and pure tin solder inside the can (d).

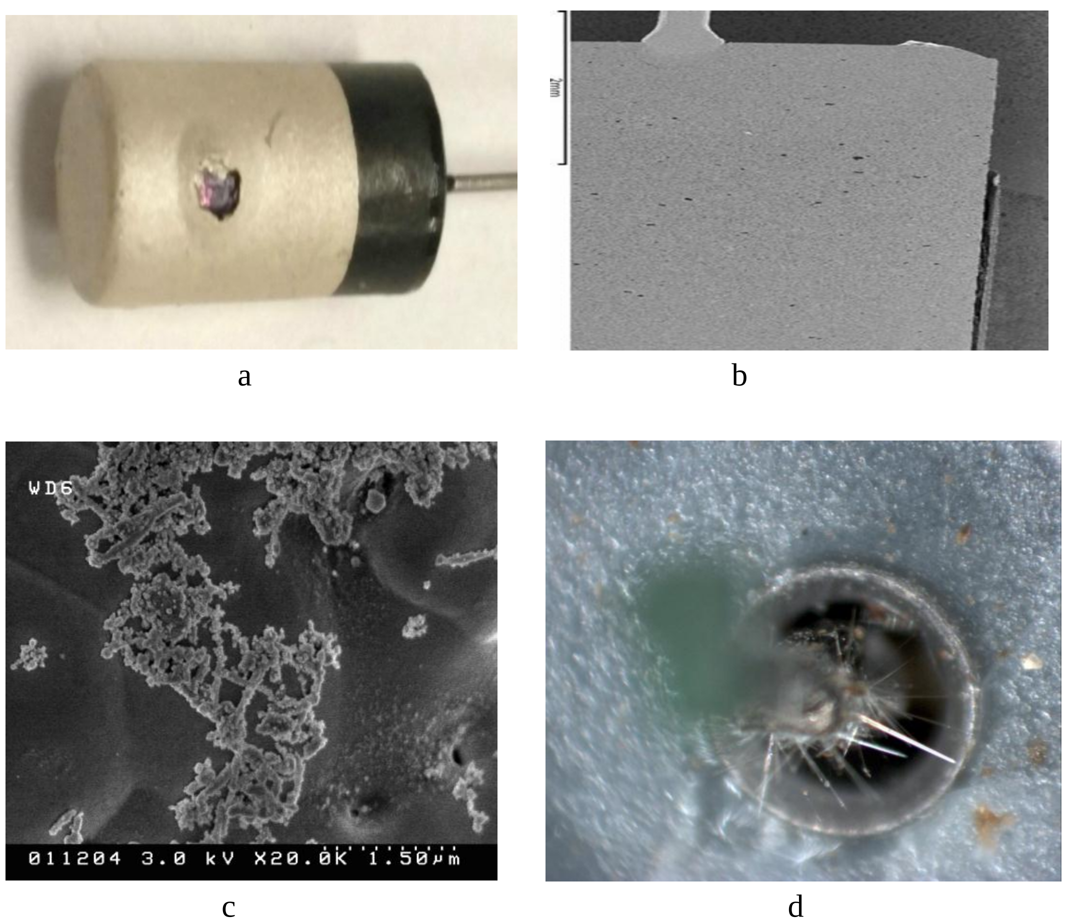
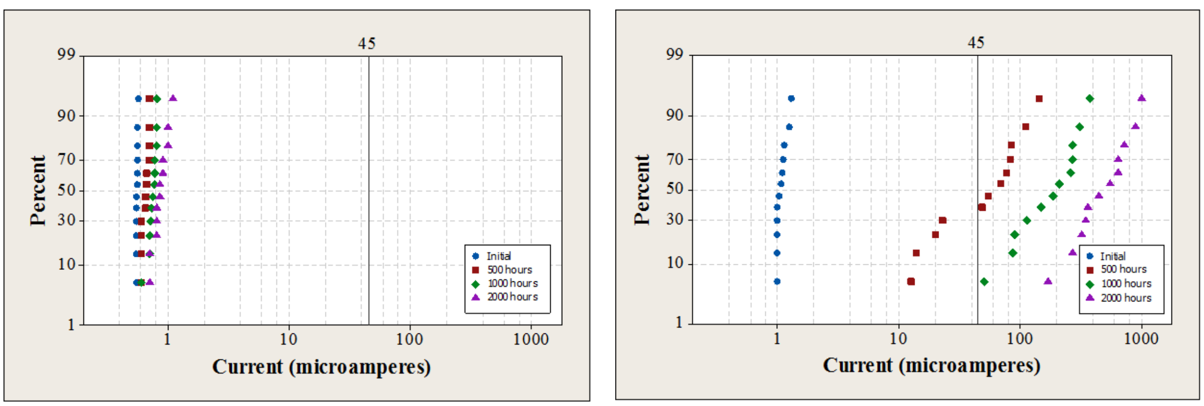


Fig. 1. Moisture related failure sights in solid Ta capacitors: popcorn effect (a), delamination (b), silver migration (c) and tin whiskers (d).

To minimize these effects of moisture, KEMET uses special materials in external coatings of non-hermetic surface mount Ta capacitors such as the T591/T598 humidity resistant automotive grade Polymer Ta capacitors. These include hydrophobic coatings and a special epoxy encapsulation. KEMET also uses special alloys as solders in T550/T551 PHS Ta capacitors.

The presence of moisture also has a strong effect on asymmetric conduction in solid Ta capacitors.[1-8] This paper summarizes effects of moisture on DCL magnitude and stability at normal (plus on Ta) and reverse (minus on Ta) polarities investigated in hermetic and non-hermetic Ta capacitors with either pre-polymerized slurry PEDOT/PSS or MnO_2 cathodes. Significant amount of the experimental data and modeling on Polymer Ta capacitors was obtained in collaboration between the KEMET Electronics and Clemson University.[9-12]

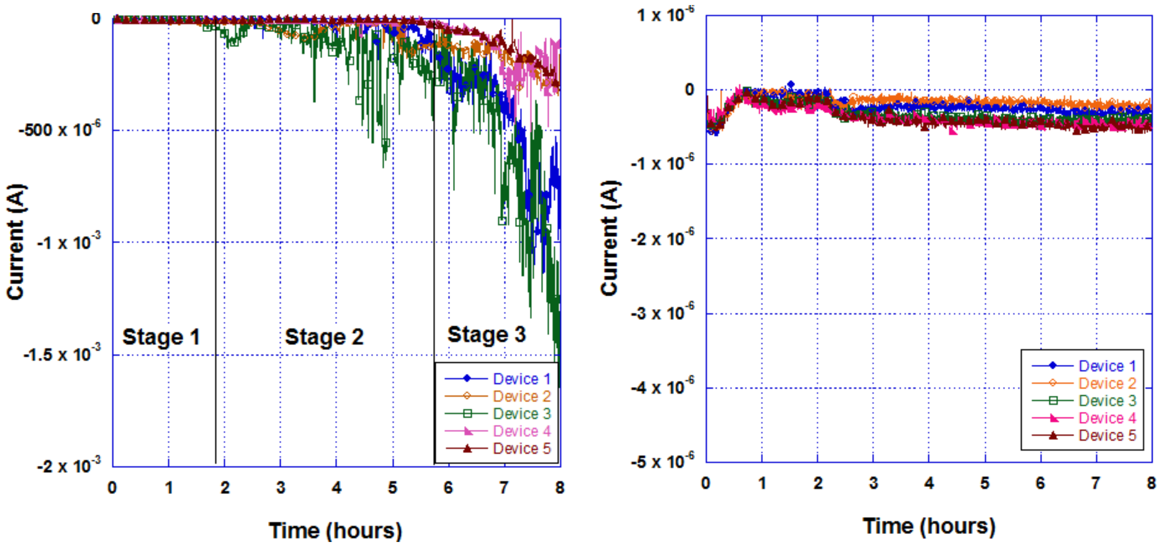
Fig. 2 shows DCL distribution during Life test of B-case 75 µF-75V humidified (a) and dry (b) PHS Ta capacitors at 75 V normal polarity and 85˚C.[11]



a b

Fig. 2. DCL distribution during Life test at normal polarity of humidified (a) and dry (b) PHS Ta capacitors

As one can see in Fig. 2, DCL was stable in humidified capacitors, while it was increasing during Life test in dry capacitors. The opposite effect of moisture on reverse voltage test of these capacitors was observed at – 1 V and 70˚C with unstable DCL in humidified PHS Ta capacitors and stable DCL in dry PHS Ta capacitors (Fig. 3).



a b

Fig. 3. DCL distribution during Life test at reverse polarity of humidified (a) and dry (b) PHS Ta capacitors

To provide DCL stability and reliability at normal polarity and some reverse voltage capability, a controlled amount of humidity is added to T550/T551 PHS Ta capacitors.[13]

Ta capacitors with the manganese dioxide cathode (Ta/MnO_2 capacitors) also demonstrate sensitivity to the deficit of moisture, especially, when intense drying is performed at high temperature in air or in vacuum. As an example Fig. 4 shows the breakdown voltage (BDV) distribution in D-case surface mount Ta/MnO_2 capacitors 15 µF - 35 V in ambient conditions and after drying at 175^oC for 24 hours and cooling down to room temperature in dry air.

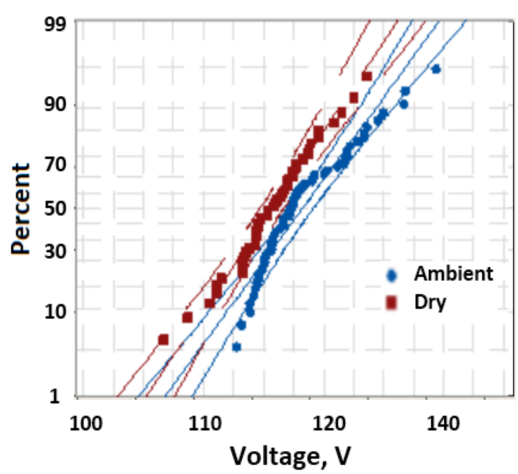


Fig. 4. BDV distribution in surface mount Ta/MnO_2 capacitors 15 µF - 35 V tested at room temperature in ambient conditions and after intense drying.

According to Fig. 4a there is small decrease in BDV of the population of the capacitors as a result of the intense drying and also a “tail” of several low BDV readings indicating potentially unreliable parts which can be screened by SBDS. The surge step stress test (SSST)[7] performed on a representative sample of a production batch also helps display problems with the manufacturing process, especially in external layers of the capacitors, and limit number of the surge and power-on failures.

It is obvious that presence of moisture has a profound effect on asymmetric conduction and stability of solid Ta capacitors depending on the polarity. In Polymer Ta capacitors with pre-polymerized PEDOT/PSS cathode at normal polarity moisture acts as a plasticizer increasing polymer chain mobility while decreasing relaxation time of the dipoles near the Ta_2O_5/Polymer interface.[9-11] These effects help decrease the DCL magnitude and improve the DCL stability due to maintaining a sufficient barrier at the Ta_2O_5/p-type PEDOT/PSS interface. Moisture as a plasticizer also eliminates anomalous transient currents at normal polarity in low voltage Polymer Ta capacitors with PEDOT/PSS cathode.[12] In Ta/MnO_2 capacitors at normal polarity moisture acts as a catalyst intensifying the redox reactions in manganese oxides in vicinity of the structural defects in the Ta_2O_5 dielectric such as micro-pores and crystalline inclusions.[14] This effect helps improve self-healing properties and reliability of the Ta/MnO_2 capacitors due to blocking current flow through the defect sights in the dielectric by high resistance lower manganese oxides and preventing further damage to the dielectric by rising temperature.[15] At reverse polarity DCL stability degraded over time in humid Polymer and Ta/MnO_2 capacitors. This can be attributed to H^+ ions diffusion toward the Ta/Ta_2O_5 interface increasing current injection into the dielectric and eventually resulting in local overheating and unrepairable damage of the dielectric.

The effects of moisture on solid Tantalum capacitors at both normal and reverse polarities diminish with reducing size and density of the structural defects in the dielectric. Typically this can be achieved by usage of the smaller size tantalum anodes with coarser tantalum powders sintered in vacuum at higher temperatures; reducing thickness of the Ta_2O_5 dielectric in lower voltage capacitors, which makes it more thermodynamically stable[16]; and the use of lower temperature manufacturing as in Polymer Ta capacitors in comparison to Ta/MnO_2 capacitors where deposition of the cathode requires numerous high temperature firings of manganese nitrate. In addition to that good coverage of the Ta_2O_5 dielectric with polymer or MnO_2 cathode allows to keep moisture at the Ta_2O_5/cathode interface and stabilize DCL in dry air or vacuum. A combination of flawless technology (F-Tech), providing the lowest defect density in the dielectric[9], with the good coverage of the dielectric with PEDOT/PSS[17] or MnO_2 cathode, and simulated breakdown screening (SBDS) to weed-off weak parts[18,19], allows manufacturing of surface mount Ta capacitors with minimal effects of moisture and high DCL stability and reliability in dry air or vacuum (space) applications.

The most advanced Ta capacitors using effects of moisture to enhance performance and reliability are T550/T551 PHS Ta capacitors that implement all the above technologies and screening techniques as well as controlled amount of humidity inside the sealed can.[13] Fig. 5 compares major electrical parameters of Ta capacitors on different stages of their evolution.

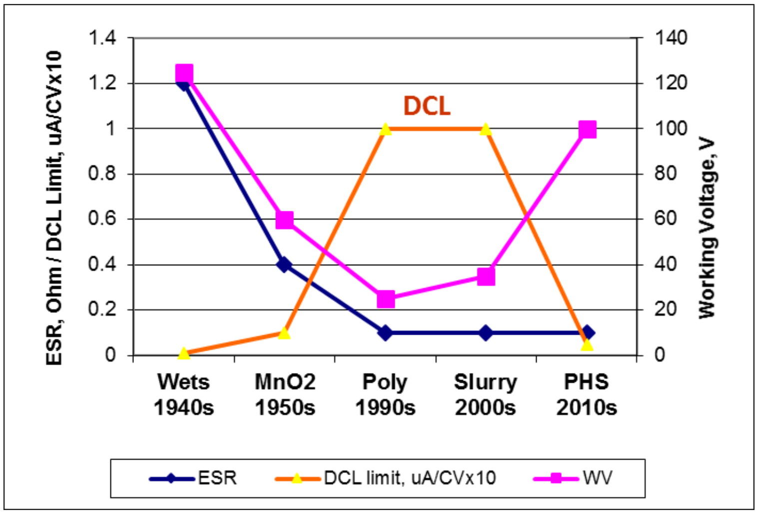


Fig. 5. Evolution of Ta capacitors

According to Fig. 5 Wet Ta capacitors with liquid electrolyte cathode have the highest working voltage and the lowest DCL; however, Wets also have the highest ESR, which increases rapidly at low operating temperatures due to increase in the liquid viscosity and decrease in the ion mobility. High ESR causes capacitance loss with frequencies and limits ripple current. That's why reducing ESR and, thereby, increasing the range of operating frequencies and ripple current capabilities is one of the major moving force in evolution of Ta capacitors. Solid Ta capacitors with MnO_2 cathode have lower ESR in comparison to ESR in Wets; however, maximum working voltage is significantly lower than that in Wets, while DCL is higher than DCL in Wets.

Polymer Ta capacitors with a PEDOT cathode have lower ESR in comparison to ESR in Ta/ MnO_2 capacitors due to the higher conductivity of the polymer cathode in comparison to MnO_2. The advantage of Polymer Ta capacitors is also non-ignition failure mode, which is especially beneficial in higher voltage capacitors. At the same time, maximum working voltage of initially developed Polymer Ta capacitors was very low while DCL was higher than for Ta/MnO_2 capacitors. Replacing of in-situ polymerization of PEDOT with pre-polymerized slurry PEDOT/PSS eliminated the contamination of the dielectric/cathode interface with by-products of the chemical reaction and allowed some increase in working voltage, while DCL remained high.[20,21]

The T550/T551 PHS Ta capacitors, developed by KEMET, have working voltages and DCL comparable to these in Wets while ESR is low and practically independent on temperature, which is typical for Polymer Ta capacitors. Moreover, due to the 20% de-rating in PHS in comparison to 50% de-rating in Wets actual maximum applied voltage in PHS exceeds that in Wets. The dimensions of the PHS Ta capacitors are practically identical to these in the corresponding Wets, which allows direct replacement without any change to the circuit board. High capacitance retention with temperature and frequency due to the low and stable ESR allows replacement of six and more Wets with one PHS, especially, in larger size capacitors. The reduction in weight-load due to the replacement of multiple Wets with one PHS is especially important in the aero and space application. Soldering inside hermetic can in PHS capacitors provides higher mechanical robustness in comparison to Wets with formed anodes squeezed between plastic bushings. Failure mode in PHS is more benign vs. Wets where failure can cause cracks in the can and aggressive electrolyte leaking and destroying the circuit board. The T550/T551 PHS Ta capacitors with working voltages up to 100 V demonstrated outstanding reliability, passed the most rigorous qualification tests according to MIL Specs and were approved for Mil and Aerospace applications.[22] These capacitors are now successfully implemented by the most demanding customers.

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