Advances in Polymer Hermetic Seal (PHS) Tantalum Capacitors

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KEMET Polymer hermetic seal (PHS) Tantalum capacitors have been presented in earlier publications.[1-4] A combination of the flawless dielectric technology (F-Tech) with pre-polymerised (slurry) Poly (3,4-ethylenedioxitheophene) (PEDOT) allowed significant increase in breakdown voltage (BDV) and, thereby, working voltage of Polymer Ta capacitors.[1,5-7] Fig. 1 shows breakdown voltage of Tantalum capacitor with F-Tech anode and different cathodes as a function of the dielectric thickness.[7]

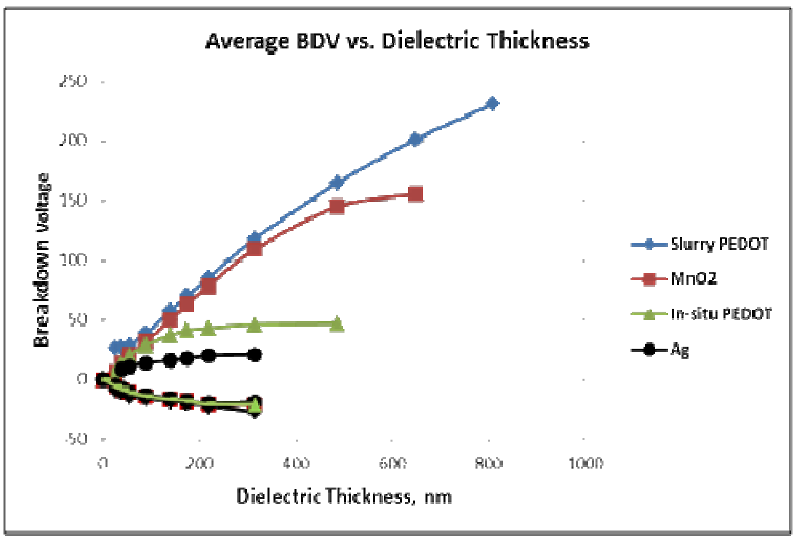


Fig. 1. Breakdown voltage as a function of the dielectric thickness [7].

As one can see BDV about 250 V was achieved only on Tantalum capacitors with F-Tech anodes and slurry PEDOT. This allowed manufacturing of Polymer Tantalum capacitors with working voltages up to 125 V never achieved earlier on any solid Tantalum capacitor.[7]

This record high BDV in Polymer Tantalum capacitors with F-Tech and slurry PEDOT was related to very low DC leakage (DCL) in these capacitors that remained low with increasing applied voltage ("flat" I(V) characteristic).[8] According to [8], the interface between the dielectric and slurry PEDOT cathode with p-type semiconductor properties plays a critical role in limiting current in these capacitors similarly to that in silicon-based metal-insulator-semiconductor (MIS) structures.

The important discovery was also utilization of moisture in Polymer hermetically sealed (PHS) Ta capacitors that allows stabilization of DCL during long testing and field application.[9] Fig. 2 presents DCL in 75 V PHS Ta capacitor with controlled amount of moisture (left) and dry (right) during 2000 hours Life test at rated voltage and 85 ºC.[9]

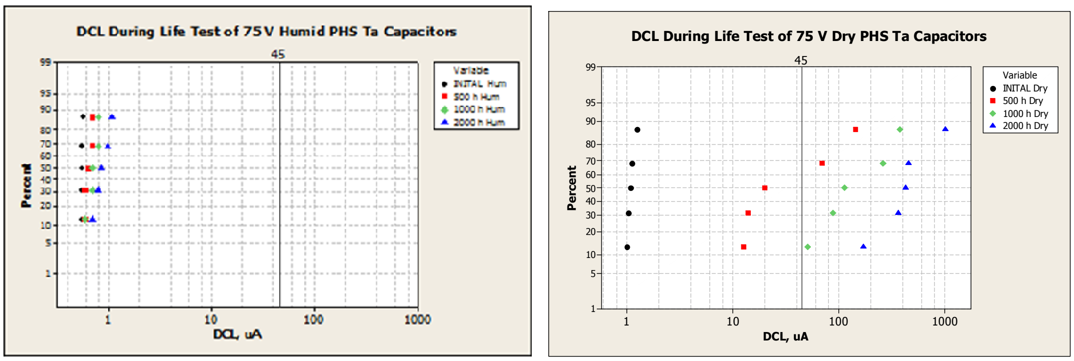


Fig. 2. DCL distribution during Life test in 75 V PHS Ta capacitors with moisture (left) and dry (right) [9].

As one can see, very little change in DCL was observed in PHS Ta capacitors with controlled amount of moisture, while in dry capacitors DCL was increasing with time, causing parametric failures of the capacitors. In Polymer Ta capacitors moisture works as plasticizer, allowing proper orientation of the PEDOT molecules at the dielectric/polymer interface to form potential barrier that limits current flow through the capacitor.[7,8] Besides DCL stabilization, moisture also eliminates anomalous transient and DC currents in Polymer Ta capacitors.[10]

Additional technique included in PHS technology is simulated breakdown screening (SBDS).[11] This technique allows screening parts with low BDV without any damage to the population of the capacitors. Fig. 3 demonstrate actual BDV distribution before (black) and after (red) SBDS tested on 50 pcs sample from the same batch of Ta capacitors

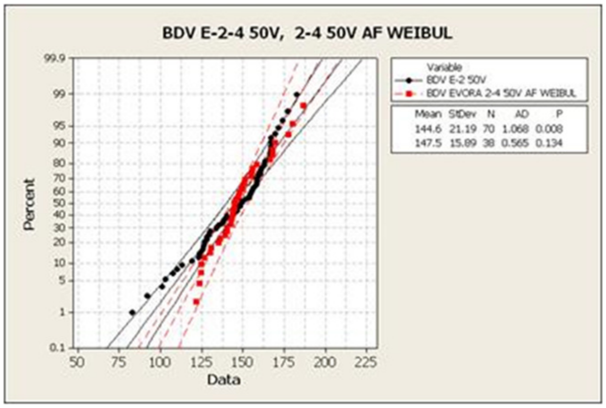
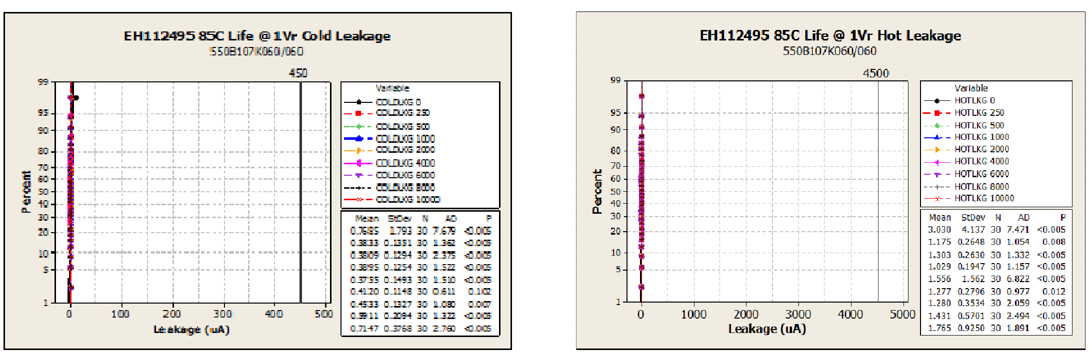


Fig. 3. BDV distribution before (black) and after (red) SBDS

As one can see, Ta capacitors with low BDV were screened by SBDS, while BDV distribution of the population of the capacitors was practically the same before and after SBDS indicating no damage during the screening. Since BDV correlates with the long-term performance in Ta capacitors, removal of the parts with low BDV provides higher reliability (lower failure rate) and lower de-rating capability to the population of the capacitors.

A combination of the F-Tech anodes, slurry PEDOT, controlled moisture inside hermetic can and special screening technique allowed manufacturing PHS Ta capacitors with very low DCL never seen before on any type of solid Ta capacitors. As an example Fig.4 demonstrates DCL distribution during 10,000 h Life test of PHS Ta capacitors at rated voltage and 85 C.[4]



a b

Fig. 4. DCL distribution in PHS 100 uF – 60 V at room temperature (a) and 85 C (b) during 10,000 h Life test at rated voltage and 85 C [4]

As one can see from Fig. 4, DCL in these capacitors was extremely low and absolutely stable at all the readings starting from virgin parts and up to final 10,000 readings. No failures were registered. These results as well as outstanding stability at mechanical shock and vibration, thermal shock, and other tests allowed KEMET PHS Ta capacitors to be approved by defense logistics agency (DLA) for MIL and Space applications (DWG No. 1030). The last iteration of DWG No. 1030 from December 10, 2014 includes working voltages up to 75 V. The new iteration scheduled for March 2015 will include 100 V working voltage part-types, which have passed the qualification tests. The PHS Ta capacitors with operating temperature up to 125^o C have been released. All the PHS Ta capacitors, even with the highest working voltage, require only 20% de-rating.

Besides low and stable DCL, PHS Ta capacitors also demonstrate very low ESR and outstanding capacitance stability vs. frequency and temperature. As an example, Table 1 shows ESR, capacitance, and capacitance loss at -55 ^{o}C and 10 kHz in comparison to the capacitance at room temperature and 120 Hz for PHS and Wet Ta capacitors.

B-case 82 uF - 75 V	Poly	Wet
ESR, Ohm	0.1	1.4
Cap, uF @ 20 C, 120 Hz	82.1	82.3
Cap, uF @ -55 C, 10 kHz	66.4	4.5
Cap loss @ -55 C, 10 kHz	≤ 20%	~ 95%

Table 1. ESR, capacitance and capacitance loss at -55 C, 10 kHz vs. 20 C, 120 Hz

According to Table 1, Wet capacitors lose up to 95% of their value at low temperature and high frequency while PHS Ta capacitors retain capacitance within 20% of its initial value. This means that one PHS Ta capacitor can replace up to 15 Wet Ta capacitors with the same initial capacitance and rating voltage. There is even larger weight gain since a single PHS has about 25% lower weight in comparison to the same size Wet Ta capacitors. The ability of PHS Ta capacitors to retain their capacitance in broad range of temperatures and frequencies is due to low ESR in these capacitors (Table 1), which has very little dependence on temperature.

Even lower ESR and more stable capacitance were achieved in modules with PHS Ta capacitors connected in parallel. As an example, Fig. 5 demonstrates ESR and capacitance frequency scans obtained on three PHS modules 1 mF – 60 V made with 10 PHS Ta capacitors 100 uF – 60 V.

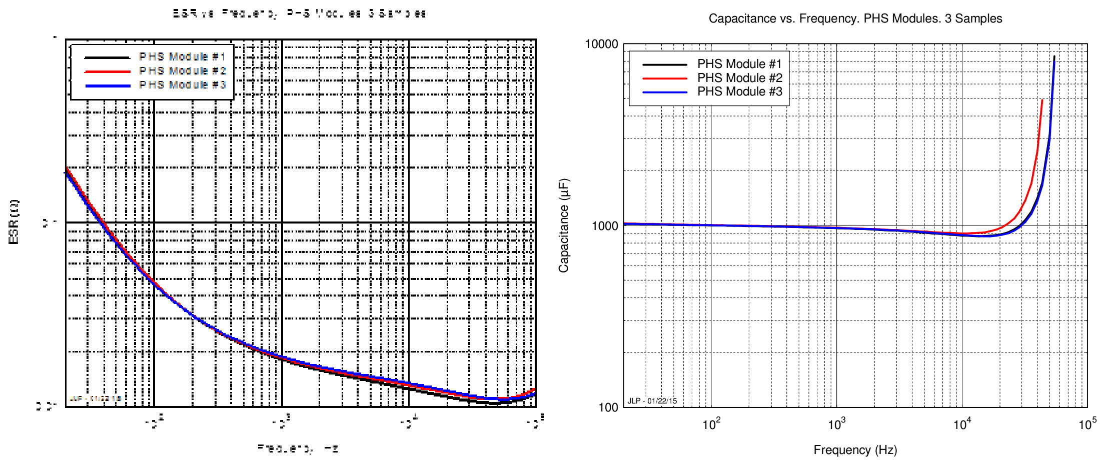


Fig. 5. ESR (left) and capacitance (right) frequency scans for 1 mF – 60 V modules with PHS Ta capacitors.

As one can see in Fig. 5, PHS modules have extremely low ESR at 100 kHz (about 0.01 Ohm) and their capacitance practically doesn't change up to the resonance frequency. A combination of high capacitance and voltage with very low ESR provides record high ripple current and power to these modules. For the PHS module 1 mF – 60 V with frequency scans shown in Fig. 5, a.c. current 5 A at 100 kHz resulted in temperature increase equal or below 5° C vs. ambient temperature. In pulse application at 55 V (20% de-rating) peak power to load achieved several kW with very little energy loss.

Recently KEMET discovered amazing property of some lower voltage PHS Ta capacitors, which has never been seen before on any Ta capacitor despite of the 75 years of the manufacturing and testing of these capacitors. This property is exceeding formation voltage without breaking the dielectric and any changes in capacitance. Fig. 6 presents breakdown test results for 10 V PHS Ta capacitor with formation voltage 28 V.

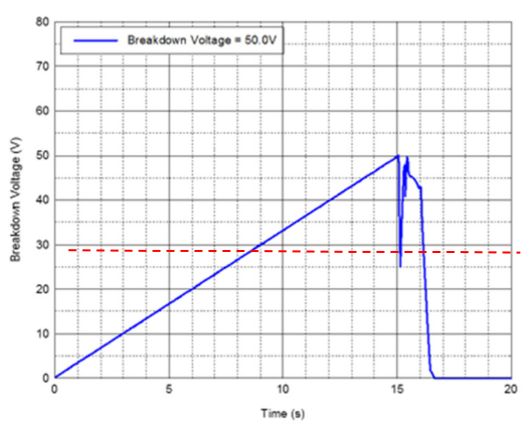


Fig. 6. Breakdown test data for PHS Ta capacitor with formation voltage 28 V

According to Fig. 6, BDV in this capacitor was 50 V, almost double formation voltage. Theoretically applying voltage above formation voltage is possible in Wet Ta capacitors due to the dielectric growth; however, thicker dielectric causes capacitance loss. A possibility to exceed formation voltage with simultaneous capacitance loss was also demonstrated earlier in Polymer Ta capacitor.[8,10] In this case effective thickness of the dielectric was increasing due to the separation between PEDOT and PSS in polymer cathode near the oxide dielectric surface. At the same time, no change in capacitance was detected in PHS Ta capacitor when BDV exceeded formation voltage until the breakdown event (Fig. 6). Moreover, even after the breakdown residual resistance of the capacitor remained high (in the range 0.1 – 1 MOhm), which is typically attributed to the "open" failure mode. These features of some lower voltage PHS Ta capacitors, BDV > V_f and "open" failure mode, are critical for the safe application of these capacitors and capacitor modules, especially, in power applications.

Conclusion

KEMET PHS Tantalum capacitors and modules combine:

- The highest capacitance retention, voltage, energy, ripple current, and power
- The lowest DCL, ESR, and energy loss
- Over-volt capability and "open" failure mode in some lower voltage PHS
- Space level reliability and DLA approval

KEMET's own supply chain for Ta powder guarantees no "conflict minerals" problem with Ta capacitors.

Acknowledgements

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