POLYMER TANTALUM CAPACITORS FOR ADVANCED HIGH RELIABILITY APPLICATIONS

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INTRODUCTION

Tantalum capacitors have been used for decades in many applications for their reliability, long service life and stability. Their traditional cathode material - manganese dioxide - started to be replacing by conductive polymer material in past decades. Both cathode types have its benefits and drawbacks. Manganese dioxide provides high temperature and mechanical stability, but conductive polymers offer lower ESR (thus higher ripple current capability), better capacitance retention at higher frequencies and benign failure mode. Using of manganese dioxide parts in high reliability applications has a long tradition and covers space, military, deep drilling, medical or automotive customers. Polymer capacitors have started being promoted into some of those domains relatively recently. One of major challenges of polymer capacitors is humidity and oxygen sensitivity that has impact on its long life performance as well as on DCL and capacitance behavior. So protection against external conditions like those leading to excessive drying, humidifying, water condensation is essential. Several approaches of protection can be used, but only real hermetic sealing will assure that capacitor is protected under extreme conditions.

GENERAL CONSTRUCTION

Tantalum capacitor is produced by using tantalum powder which is pressed with embedded tantalum wire and sintered. Prepared sponge like structure with high internal surface undergoes anodic oxidation in diluted electrolyte based on phosphoric acid. This process leads to oxidation of tantalum on the surface and resulting thickness of created dielectric (tantalum pentoxide) is proportional to applied voltage during this anodization process. Contacting of dielectric by cathode is provided by conductive polymer, carbon layer and silver paste. External part of tantalum wire is welded on metal leadframe.

Discussed type of hermetically sealed tantalum capacitor is protected against mechanical and environmental threads by its housing in ceramic case which is filled by inert atmosphere and sealed [1-4]. Standard type of AVX hermetically sealed polymeric capacitors is offered in the size CTC21D. The case is made of ceramic material with hermetically sealed metal contacts through its bottom and tantalum capacitors are attached to internal contacts. Anodic part – tantalum wire - with welded leadframe is further welded to internal contacts of the case, negative part – silvered surface of the cathode - is attached to the internal case contact by conductive silver loaded epoxy. Construction of the case allows more capacitors to be mounted in parallel and thus reduce ESR and increase ripple current capability of the final device (Fig. 1). Also used materials allow reducing final weight, typically capacitors weight is 2.2g, so for example TCH 9 22uF/100V delivers CV/g as much as 1000uF.V/g, for TCH 9 150uF/35V even 2380uF.V/g.

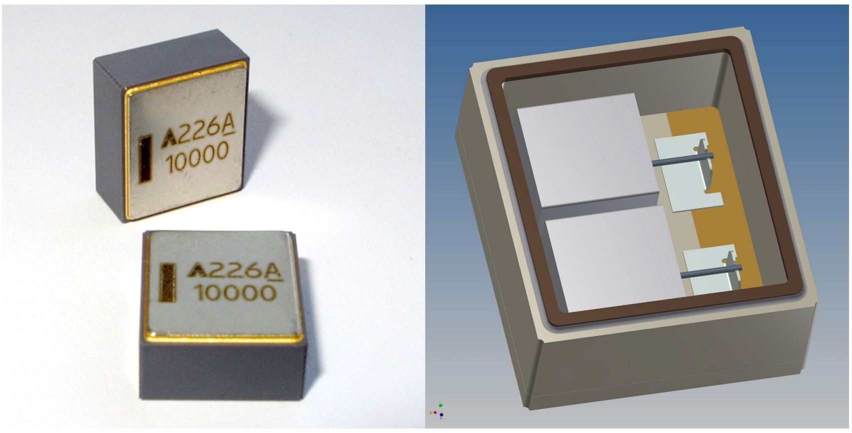

Fig. 1 AVX's TCH Low ESR Hermetic Series SMD tantalum capacitors with conductive polymer electrodes in a hermetically sealed package

Mechanical robustness of this solution comes out from firm welding connections between tantalum wire – leadframe and internal contacts. Using of the leadframe also enables some flexibility and thus additional stability under shocks, vibrations and thermal cycling. In order to further increase mechanical robustness, capacitor pellets after attachment to the case can be coated by additional inert, electrically not conducting material. This also can improve the heat conduction and efficient cooling of capacitor body under electrical stress. Capacitor is dried, the rest of internal space is filled by inert atmosphere and hermetically sealed. Sealing is performed by welding of metal lid on a metal ring attached on the top of the ceramic base.

Modification of current design can lead to modular solutions [3] with more in parallel connections that can offer very low ESR values and can suite some specific applications requiring high ripple current capability. Some solutions are presented on Fig. 2.

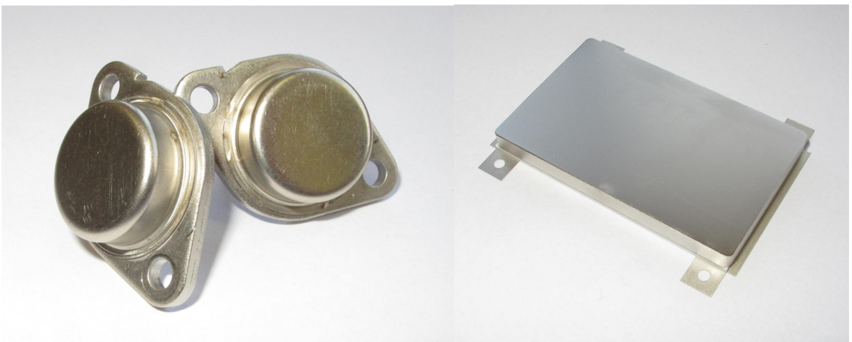

Fig. 2 hermetic cases TO3 and customized low profile hermetic case

Special attention was paid to external leads. Standard version is based on undertab (facedown) design where leads do not extend from the base of the case (Fig. 3). For additional contact between case and substrate, so called J-lead/L shape leads are attached on undertab leads by high temperature solder. (Fig. 4).

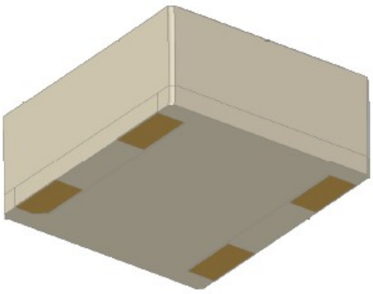

Fig. 3 Undertab version of TCH and THH tantalum solid electrolytic capacitors

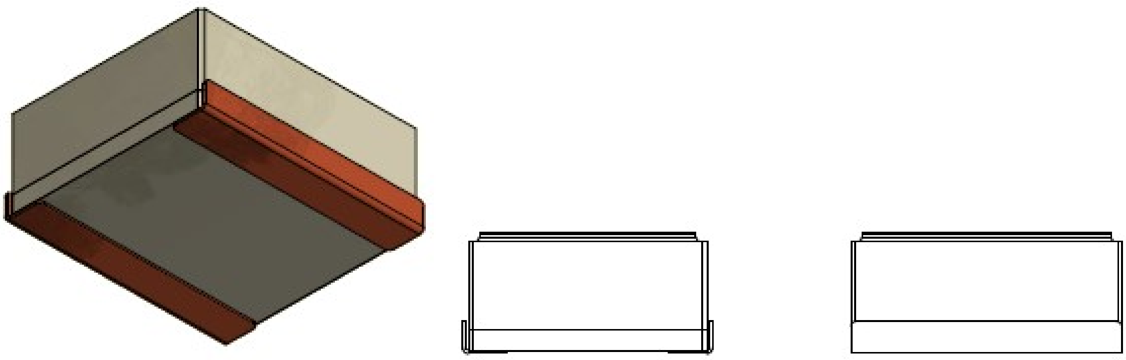

Fig. 4 L-shape‘ J-lead version of TCH and THH tantalum solid electrolytic capacitors

MECHANICAL TESTING

Tests and results of mechanical tests are summarized in below table. Also the mechanical robustness of the package was tested for THH type using the same ceramic case and construction solution, but with MnO_2 cathode. Here the shock capability was MIL-STD-202, Method 213, Condition D (500g) and for vibrations MIL-STD-202, Method 204, Condition E (50g).

Mechanical Test	**Method Reference**	**Result** (tested on TCH 9 22uF/100V)
Shock	MIL-STD-202, Method 213, Condition C	PASS
Vibration	MIL-STD-202, Method 204, Condition D	PASS
PIND	MIL-STD-883, Method 2020, Condition A	PASS

MIL-STD-202, Method 213, Condition C = half-sine shock, 100g, 6ms duration, 6 times in three mutually perpendicular axes of the test specimen (total 18)

MIL-STD-202, Method 204, Condition D = simple harmonic motion having amplitude of either 1.5mm double amplitude or 20g whichever is less, cycle of 10-2000-10Hz with logarithm variation lasting 20 minutes, 4 hours in each direction (12 hours in total).

MIL-STD-883, Method 2020, Condition A = 20g, 33-2000Hz, 0.017oct/s

RIPPLE CURRENT, HEAT DISSIPATION

There are two major factors influencing the ripple current capability – ESR and heat dissipation. Low ESR is assured by tantalum anode design, multiple anodes in parallel connection, but also by material chosen for the cathode – conductive polymer. Such solution is able to offer very low ESR levels going below 4 mOhms (Fig. 5) if 40 anodes in parallel were used [3]. The other benefit of polymeric cathode is its conductivity almost independent on temperature, so in comparison with systems based on liquid electrolytes with ionic conduction, the ESR and capacitance is not significantly afflict by low temperatures (Fig. 5, 6).

Heat dissipation depends on application setup (design of board, active or passive cooling), but also design of capacitor itself is important. Massive heat sinks-like case of TO3 design (Fig. 2) is very efficient in heat dissipation, but also heat transport from the body of tantalum capacitor towards the case must be provided. Fig. 7 shows result of experiment, where importance of internal material is manifested. Hermetically sealed polymer capacitor (TCH 9 22uF at 100V) was prepared with various internal materials: air, nitrogen, syntactic foam powder filler, silicone or heat conductive silicone. Test accelerated by ripple current exceeding specification almost 5x (8A AC at 20kHz, ambient external temperature, 10V bias) was carried on for each type of internal filler and temperature of external wall of the case recorded. Temperature of case with air rose above 200°C within one hour and led to destruction of the capacitor soon after this. Replacement by nitrogen increased life under the same conditions about five times, but addition of heat conducting material led to 25 times life increase. Results of temperature increase obtained for TO3 design (100uF/100V) or multianode solution (400uF/100V) on applied ripple current is presented on Fig. 8.

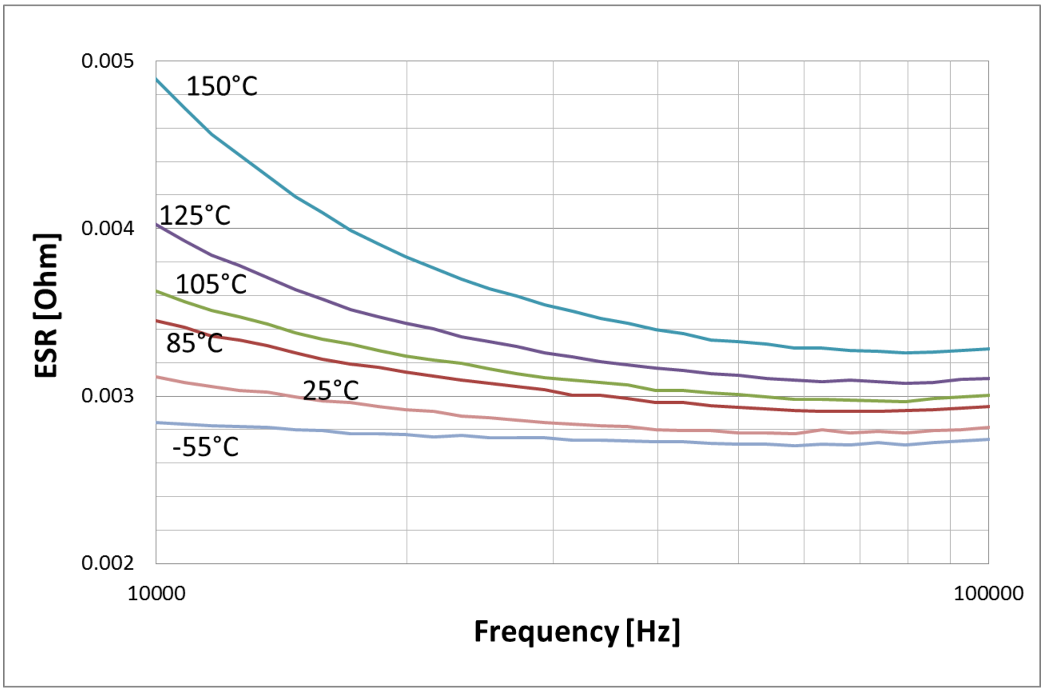

Fig. 5 ESR for 400uF at 100V in low profile hermetic package

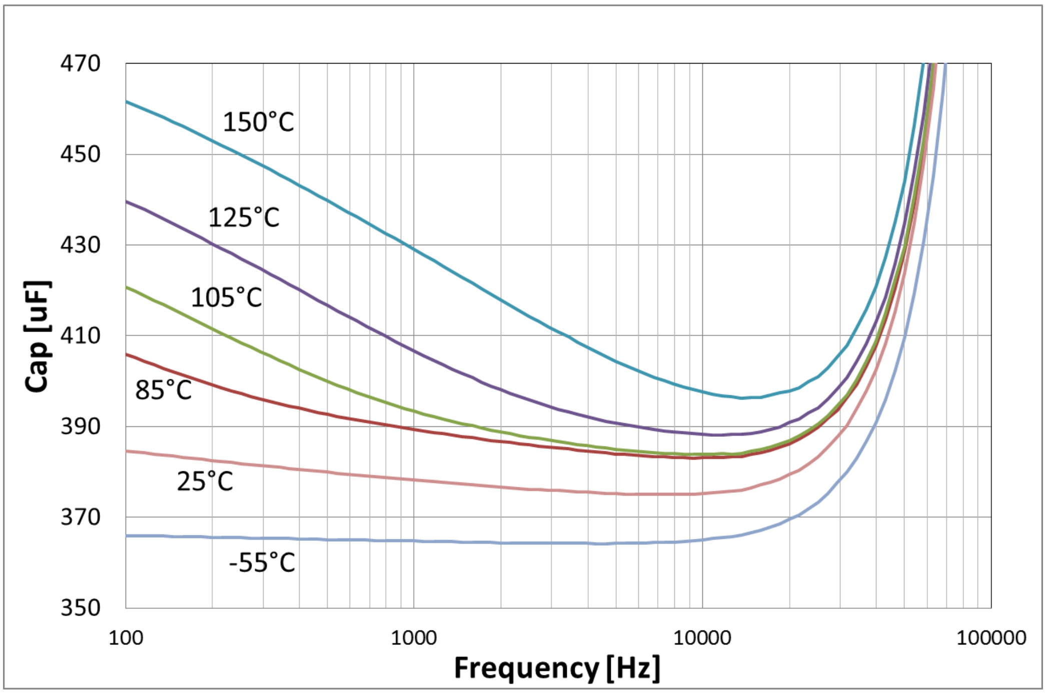

Fig. 6 Capacitance for 400uF at 100V in low profile hermetic package

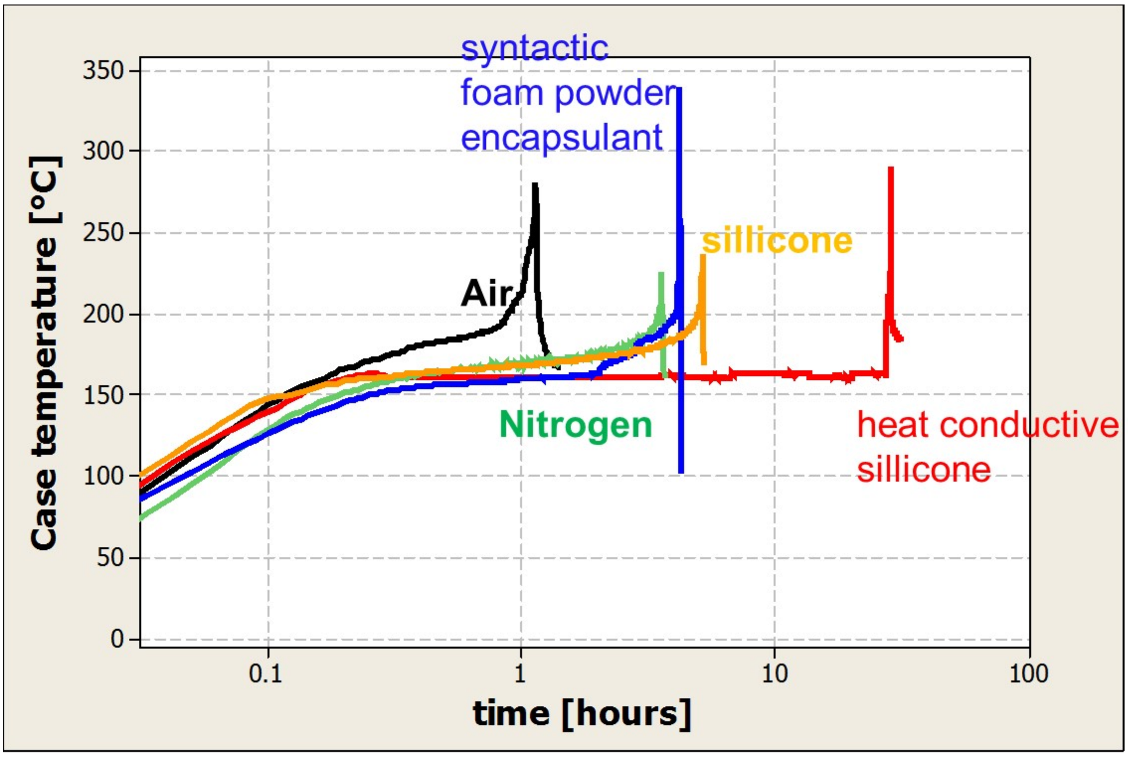

Fig. 7 Accelerated ripple current test (TCH 9 22uF/100V, 8A AC at 20kHz, ambient external temperature, 10V bias) for various materials used for filling the internal cavity of package

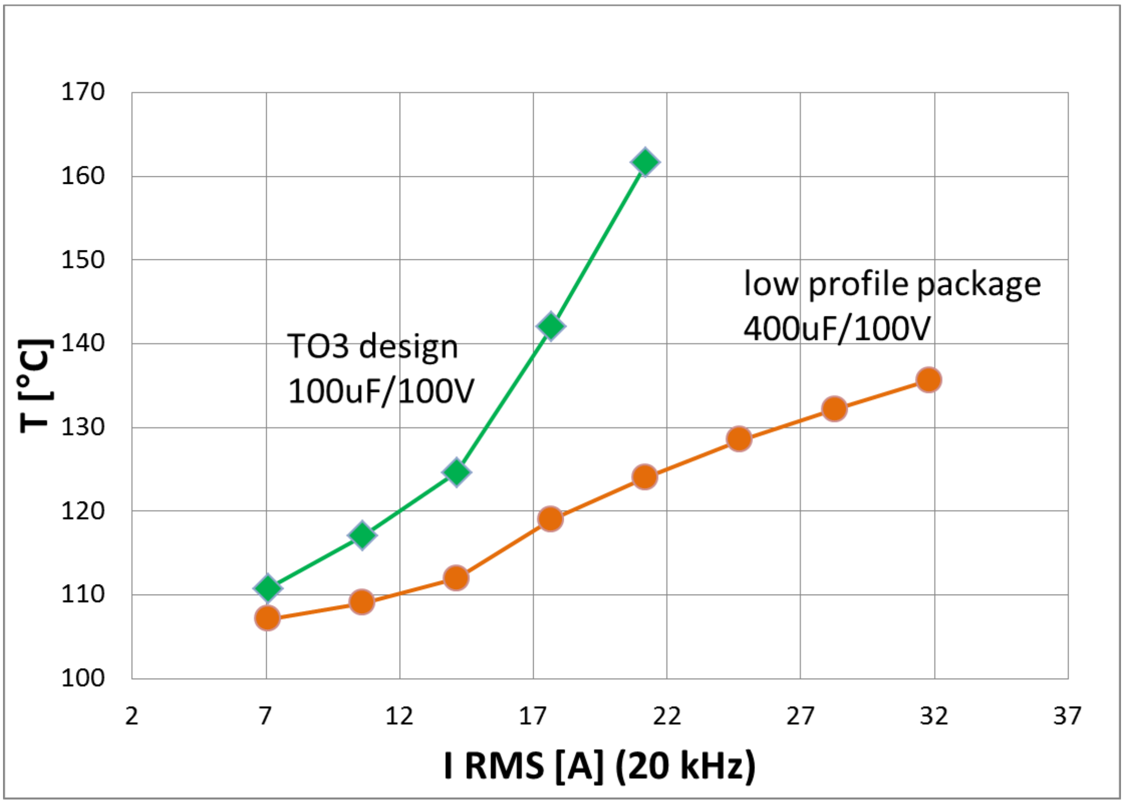

Fig. 8 Temperature change of parts measured at 105°C at ripple current

POLYMERIC CATHODE

Cathode construction

The latest cathode materials used for tantalum capacitors are conductive polymers. Polypyrrole or PEDT are the most frequently used compounds. They reduce the drawbacks of the other commonly used cathode material - manganese dioxide – polymers do not have enough oxygen in its molecules to support tantalum vigorous oxidation and their higher conductivity allows ESR reduction. They also allow self-healing by locally reduced conductivity due to overheating and thus insulating the spot of the leak. Special prepolymerized types of conductive polymer allow to increase BDV [5-7] and lower DCL so that nowadays there are capacitors available rated up to 125V [8]. Major drawbacks of conductive polymer cathode are connected with chemical instability of such material. Polymers are prone to oxidative degradation at elevated temperatures and such processes are accelerated in presence of oxygen, this limits also their ratings typically to 85-125°C. High levels of humidity can also induce chemical degradation [9, 10]. These mechanisms lead to ESR increase and capacitance drop. Also, both types (polymeric and manganese dioxide) of capacitors using solid electrolyte have common issues with capacitance recovery – not 100% of dielectric is contacted and this can lead to capacitance changes with humidity, especially in case of conductive polymer, where moisture can increase contacted surface.

Moisture Effects

Fig. 9 shows capacitance dependency on temperature and humidity level for capacitors of nominal value 47uF/25V. Standard polymeric cathode or experimental cathode was tested. Units were excessively dried – 4h at 125°C (DRY) before hermetic sealing, excessively humidified 24h under 60°C and 90% RH (WET), or humidified under standard conditions 24h at 22°C, 55% RH (STD). Temperature increases capacitance as well as humidification level. The exception is at temperature of liquid nitrogen, where capacitance is independent of previous humidification.

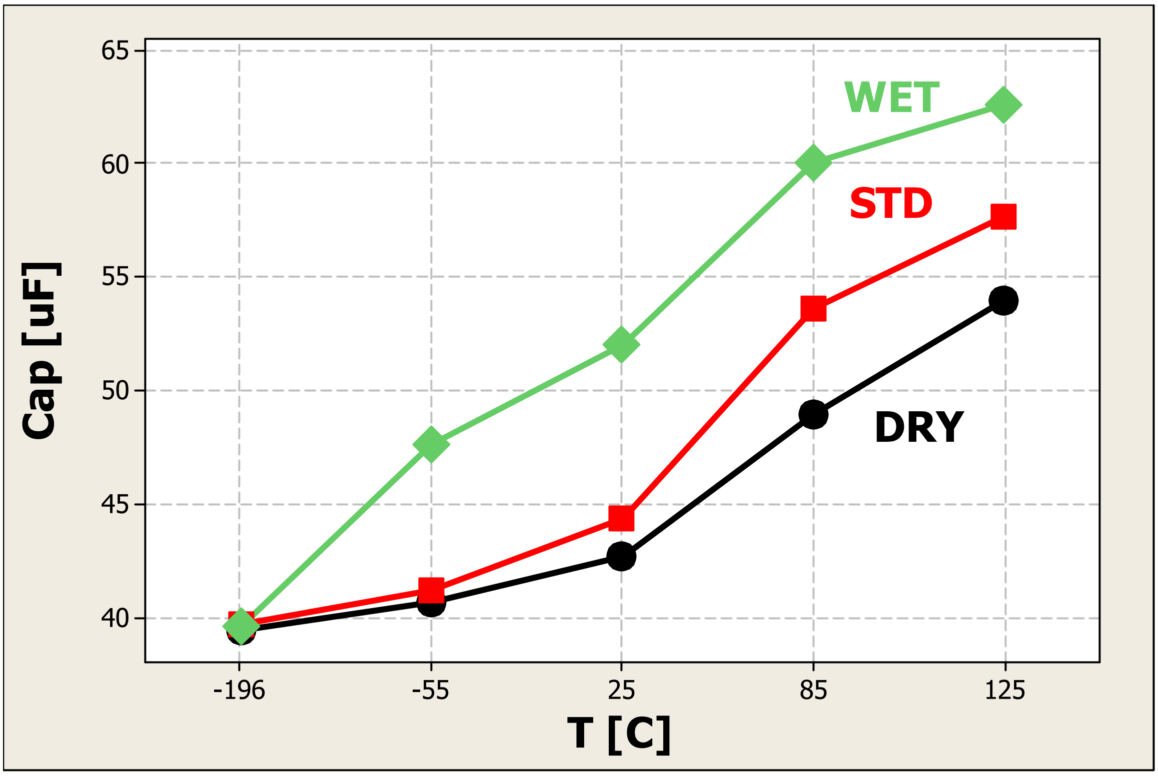

Fig. 9 Temperature and humidity dependence of capacitance (hermetically sealed polymer capacitors 47uF/25V)

Another moisture depending phenomenon of tantalum capacitors with conductive polymer cathode is so called "anomalous current". It was described in [11] as anomalously high current measured when peak voltage was applied on capacitor. Also slowly decreasing DC leakage current under voltage was described in [2] that related to the same phenomenon. Both [11] and [2] report significance of presence of water in polymeric cathode to limit above mentioned behavior. Next Article [12] brings evaluation of dry and humidified hermetically sealed capacitors under accelerated life conditions with conclusion that higher stability of DC leakage and BDV is for humidified units. On the other hand, report [13] at page 40 concluded, that under highly accelerated conditions dried units exhibited no degradation, but hermetically sealed humidified units failed short circuit. AVX approach is not to use intentionally humidified parts for hermetic sealing. Parametric stability exceeding 10,000 hours are presented later in this article.

Not only moisture, but also temperature of measurement is influencing parameters. Current measurement on applied voltage (Fig. 10) shows different patterns for low (23°C) and high (125°C) temperatures. At high temperature, current is increasing with voltage the same way regardless of humidification level. For room temperature, measured current is very low and just weakly voltage dependent if parts were not dried and have some traces of water. For dried parts at low temperature current increases with voltage steeply. This unexpected result comes from fact, that DCL was not stabilized within measured time (current was measured with voltage increase rate of 1V per 80s). Time needed for current stabilization depends on temperature and humidification level. Similarly on Fig. 11, where DCL is measured for dried and hermetically sealed capacitor or unsealed part at various temperatures (unsealed unit can get some water from external environment), DCL decreases slowly at low temperature under dry conditions.

Such observation is in accordance with work [2] where the slow DCL decrease after applied voltage was described in the case of dried capacitors and low temperature. Explanation was based on barrier creation between dielectric and cathode material that reduces current. Creation of such barrier under voltage is faster if polymers forming cathode have higher mobility – under presence of water or at higher temperature.

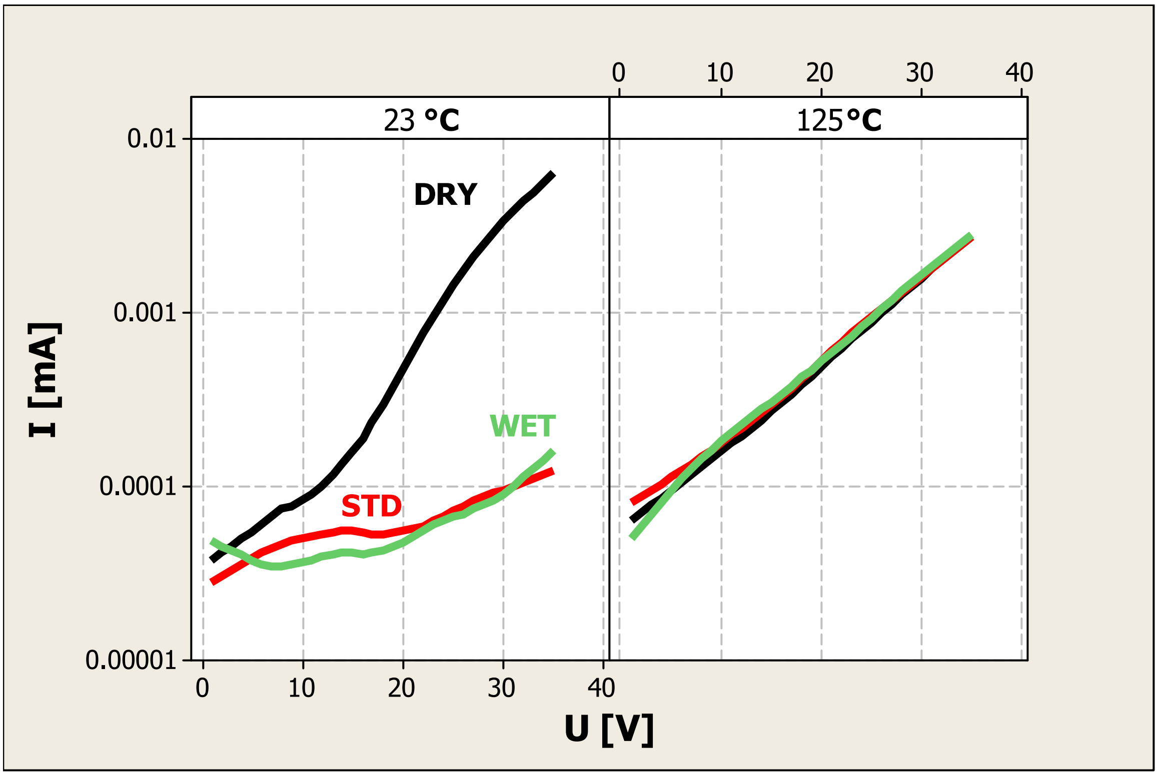

Fig. 10 Current dependence on applied voltage (voltage increase rate 1V per 80s), (hermetically sealed polymer capacitors 47uF/25V)

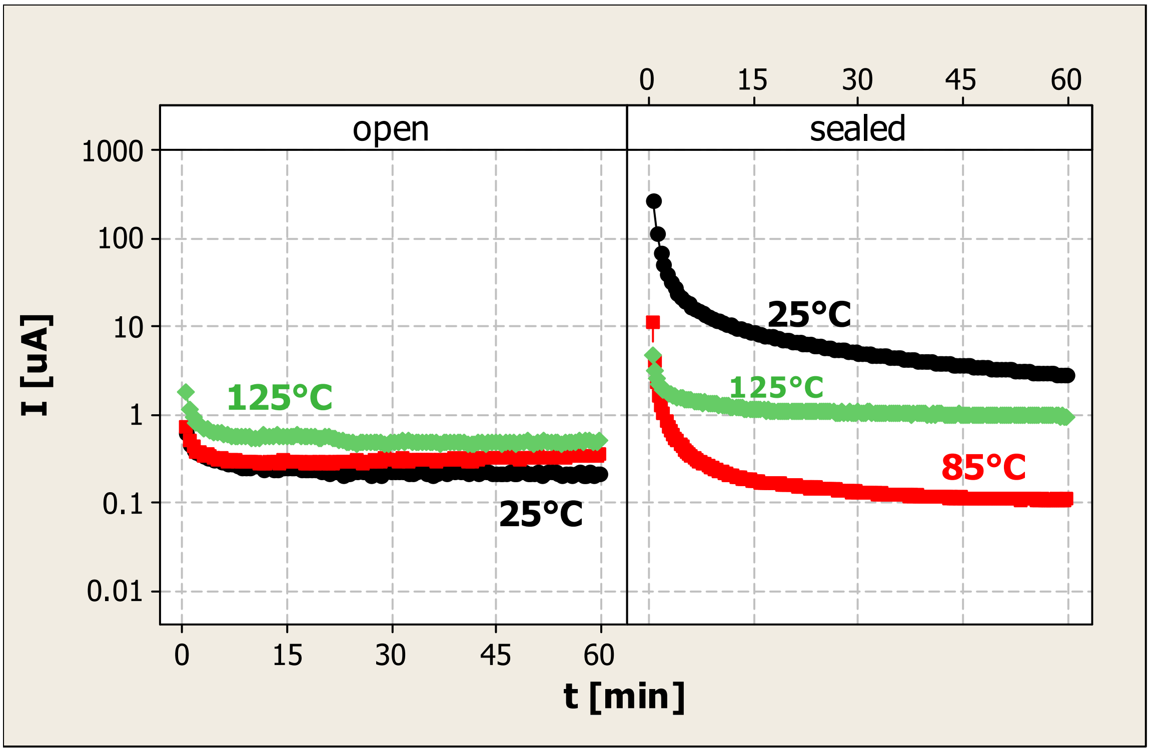

Fig. 11 Hermetically sealed and unsealed polymer capacitor 33µF at 25V, DCL measurement at rated voltage

LIFE PERFORMANCE

Static life testing results for TCH 9 100uF/35V are presented at Fig. 12. Parameters are stable over measured period 18000 h, measurement of DCL at temperatures 25, 85 and 125°C prove low DCL, slower DCL stabilization at lower temperature is again apparent (Fig. 13). Life and storage tests for TCH 9 22uF/100V are summarized at Fig.14.

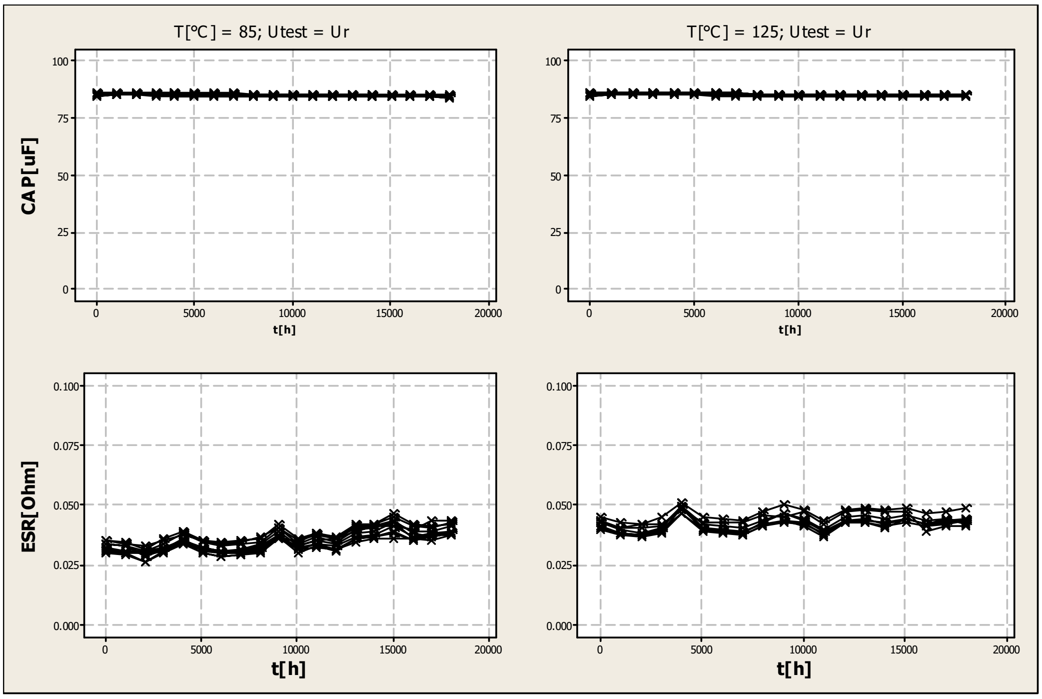

Fig. 12 Capacitance and ESR changes over time of life tests for TCH 22uF/100V

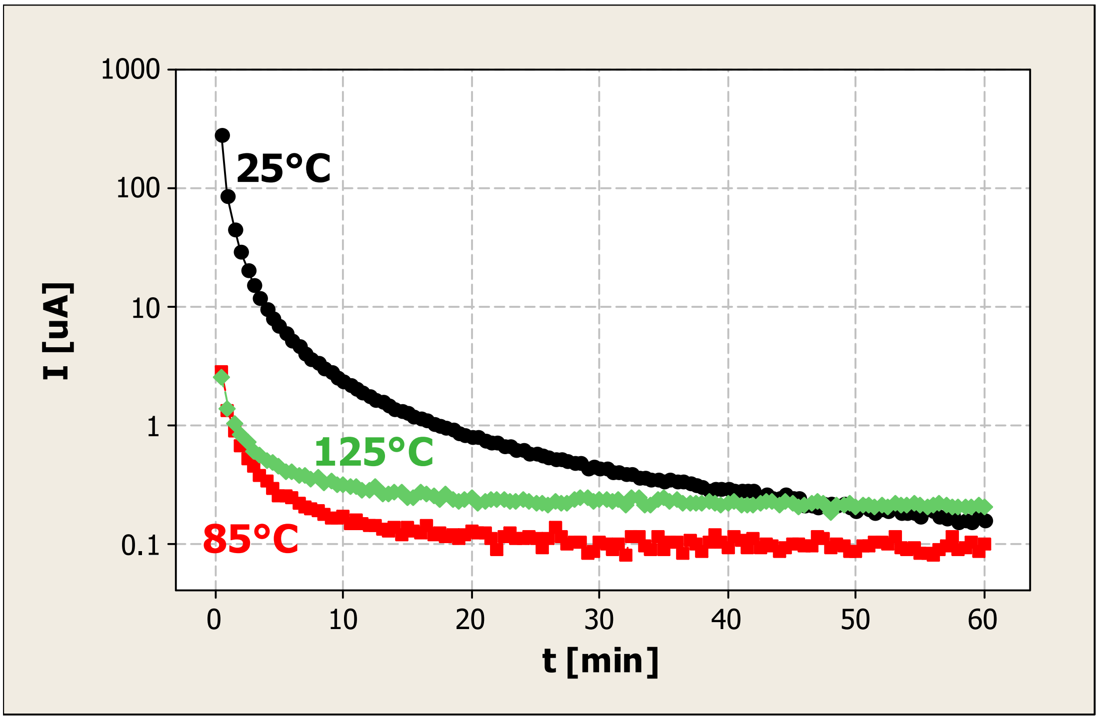

Fig. 13 Hermetically sealed polymer capacitor 100µF/35V after 10000h at 125°C/35V, DCL measurement at 35V and temperatures 25, 85 and 125°C

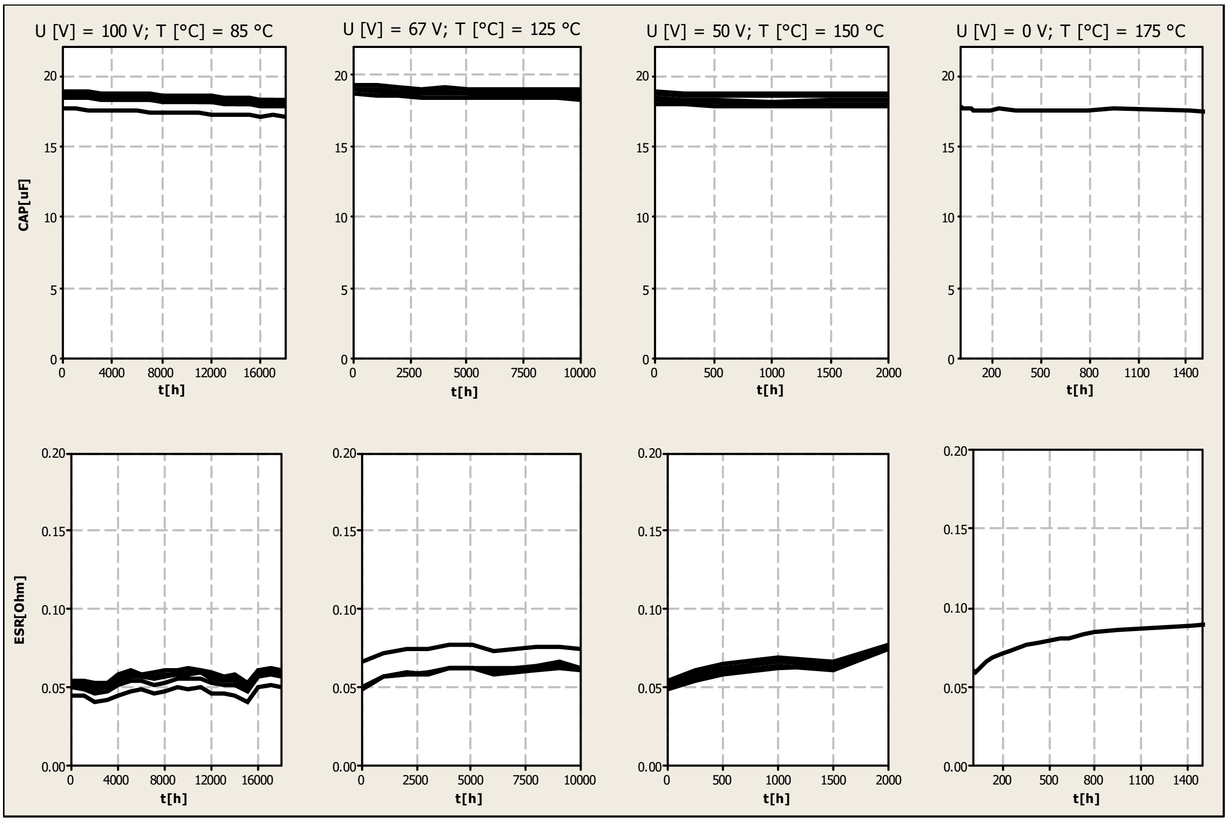

Fig. 14 Capacitance and ESR changes over time of life tests for TCH 22uF/100V

CONCLUSION

New type of tantalum polymer capacitors with unique hermetically sealed SMD construction is overviewed. Mechanically robust, lightweight solution with low ESR and high ripple current capability was presented. Ability of rated voltages up to 100V and wide range of temperatures and environments gives the best preconditions for use in high reliability applications including space.

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