Derating differences in Tantalum-MnO₂ vs. Tantalum-Polymer vs. Aluminum-Polymer

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Abstract

Derating is practice that is recommended by the capacitor manufacturers to their users to apply less than rated voltage to these parts in applications. The intent is to reduce the failures for these devices. The recommended derating for the three devices covered by this paper are 50% (Ta-MnO₂ : use at 50% of rated voltage), 20% (Ta-Polymer : use at 80% V-Rated), and 0%, or 'No Derating' (Aluminum-Polymer : use at rated voltage). The impact of the materials and processes on these three devices is explored with emphasis on fault creation due to the changes. The internal structures where the dielectric oxide and the cathode system interface is the focal point of the analysis. The differences related to circuit performance are indicated through the Step Stress Surge Testing (SSST) as previously defined and presented at CARTS 2001[1].

Long-term reliability predictions

The failures that the manufacturers are most concerned with are related more to turn-on or infant mortality types of failures. Based on the typical bathtub, failure-rate and time relationship, long-term failures are never reported to the component manufacturers, but turn-on failures are a very divisive issue. The tantalum manufacturers defend that there is no wear-out mechanism in the tantalum capacitors because of this history and the declining failure rates exhibited in long term life testing.

Failure Rates vs. Time

Figure 1. Bathtub reliability curve.

Failures related to a stress application over a long period of time can be found in the documentation related to this exposure, MIL-HDBK-217F Notice 2 [2], for almost all types of capacitors.   The calculation result is the FIT or the failures in time (expressed as parts per billion piece-hours).

A brief example of the relationships expressed can be seen in Figure 2, for a "Tantalum Capacitor with a Solid Cathode" system. Formula (1) in this figure represents the FIT calculation factored by quality, voltage, temperature, and environmental factors. Formula (2) allows a choice between the CWR (tantalum SMT chips) versus the CSR (tantalum leaded). From this example it is important to note that the multiplier for the application voltages above 60% of rated, has a tremendous impact on this reliability prediction as this ratio is then raised to the 17th power.

Tantalum Solid Cathode / Chip – Notice 2

$$\lambda_p = \lambda_b \pi_T \pi_C \pi_V \pi_{SR} \pi_Q \pi_E \times 1000$$

$$\lambda_b = .00005$$

$$\pi_T = \exp\left[\frac{-0.15}{8.617 \bullet 10^{-5}} \left(\frac{1}{T_{Amb}} - \frac{1}{298} \right) \right]$$

$$\pi_C = 1.0 \bullet C^{0.23}$$

$$\pi_V = \left(\frac{S}{0.6} \right)^{17} + 1 \qquad S = \frac{Application - Voltage}{Rated - Voltage}$$

$$\pi_{SR} = Lookup\, Table$$

$$\pi_Q = \sqrt{\left(\frac{Pcs.Fail}{Pcs.Tested \times Hrs.Tested} \times 100,000 \right)}$$

$$\pi_E = Lookup\, Table$$

CR (Ω/V)	π_{SR}
> 0.8	0.66
0.6 - 0.8	1.0
0.4 - 0.6	1.3
0.2 - 0.4	2.0
0.1 - 0.2	2.7
< 0.1	3.3

Environment	π_E
G_B	1.0
G_F	10
G_M	20
N_S	7.0
N_U	15
A_{IC}	12
A_{IF}	15
A_{UC}	25
A_{UF}	30
A_{RW}	40
S_F	0.50
M_F	20
M_L	50
C_L	570

Figure 2 . MIL-HDBK-217F, Notice 2, formulas and tables for CWR Type tantalum chip.

The relationships, exponential powers and base multipliers vary depending on the type of capacitor, and vary considerably for film, ceramic, and aluminum electrolytic types. With the complexity of the calculations and the varying elements of these calculations, the FIT generation is not simple. KEMET does offer a "FIT Calculator" which can be accessed readily as downloadable Windows® software from the KEMET web site, and an example of the calculator can be seen in Figure 3. The application and environmental factors can be manipulated by the operator do define any unique circumstances of the circuit.
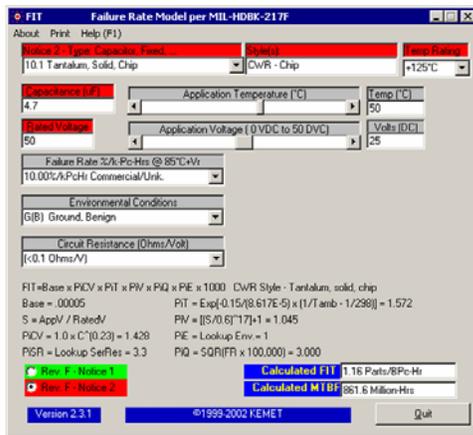
Figure 3. FIT Calculator software available at www.kemet.com.

Tantalum History

The standard practice preached by almost all manufacturers of solid tantalum capacitors has included a recommendation that the devices be used in applications where the operational voltage would be no more than ½ of the rated. This 50% derating factor assures reasonable failure rates, especially for the power-on conditions experienced in most applications. The processing and materials involved with the T520, T530, or KO-CAP® capacitors involving a polymer cathode system with the tantalum anode are radically different from those of the traditional MnO_2. This is also true for the AO-CAP® capacitor with the polymer cathode system and an aluminum anode.

SSST Testing

We rely on SSST (Surge Step Stress Test [1,3]) results as an indicator of susceptibility to power-on failures because we have seen many instances where the projected failure rates and experienced rates have been the same. Figure 4 represents the median data from sample batches run with Ta-MnO_2, Ta-polymer, and Al-polymer. This report covers similar CV batches tested from September of 1999 through March of 2002. The sample size varied

between 80 and 200 pieces for each batch. The first row lists the percentage of rated voltage where the projected 100-PPM failure rate level would occur. The last four rows show the projected failure rates (PPM) for voltage applications of 50%, 80%, 90%, and 100% of rated voltages.

Looking across the first row of values, the 100-PPM failure rates are projected to be at 68% of rated voltage (V_R) for the Ta-MnO_2, at 114% of V_R for the Ta-polymer devices, and at 235% of V_R for the Al-polymer devices. The failure rate projection is 9 PPM for the Ta-MnO_2 product at 50% V_R, and this is nearly equal to the Ta-polymer's projected failure rate of 5 PPM at 80% Vr. The third column shows that the projected failure rate for the Al-polymer at 100% of rated voltage is 0 PPM – well below the failures rates established as recommended voltage ratings for the tantalum devices.

This correlation is again borne out when looking at the mean values from the data collected. Here the projected failure rate of 11 PPM at 50% V_R for the Ta-MnO_2 correlates well with the 8-PPM failure rate for the Ta-polymer, and the 3 PPM failure rate at rated voltage for the Al-polymer devices

Stress-Induced Failures

Although the dielectrics and anode materials are the same in the tantalum devices, we believe that there may one key contributor to the variation in the SSST data. One theory suggests that the MnO_2 material, as inelastic or a hard filler deposited in the channels within the device, may create faults in the dielectric as it is being processed. If a channel is viewed as a necked-down constriction created with the tantalum particles as in Figure 5, then the MnO_2 is deposited along the inner walls of this channel, over top of the Ta_2O_5. The process of depositing the MnO_2 involves a dip in manganous nitrate solution close to room ambient temperatures, and a conversion from the solution to a solid material at about +270°C. This dip and conversion process is repeated several times to assure complete coating of the dielectric layer and continuous connection into the inner

Median Values

	MnO_2 (27Batches)	Ta-Poly KO (37 Batches)	Alum-Poly – AO (78 Batches)
100 PPM FR % V_{Rated}	68%	114%	235%
@50% V_{Rated} FR(PPM)	9	0	0
@80% V_{Rated} FR(PPM)	458	5	0
@90% V_{Rated} FR(PPM)	1,700	19	0
@100% V_{Rated} FR(PPM)	6,310	72	0

Figure 4. Failure levels based on SSST data.

Induced Process Stress - MnO_2

In tantalum anode pellet, areas of constriction exist where tantalum particles form a closed loop around an open channel. The MnO_2 filling this enclosure is a <u>hard</u>, <u>crystalline</u> material. Impregnation process involves dip at +25°C and conversion at +270°C. Stresses might be root of cracks *created* in dielectric.
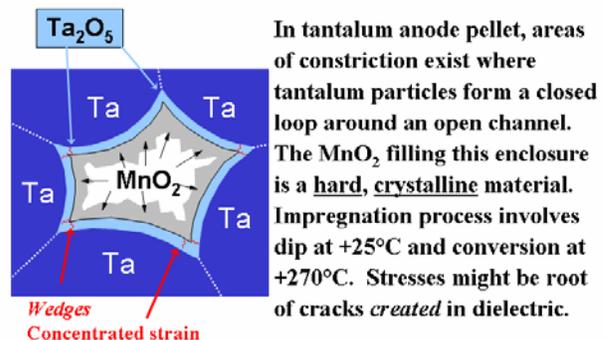
Figure 5. MnO_2 as contributing force to cracks.

depths of the channels. As these materials are different (Ta, Ta_2O_5, and MnO_2), their coefficients of thermal expansion will vary and mismatches will generate mechanical forces.

Of critical importance is the "wedge" area where the glassy Ta_2O_5 fills a crevice created where two tantalum particles come together. This in turn creates a "wedge" of dielectric, which is filled by the cathode material. Any forces created with the MnO_2 in this area may be enough to crack or fracture the dielectric. Considering the temperatures involved in the processing, this theory is very plausible, and the faults *may* be generated as the cathode system is being built..

The T520 or KO-CAP capacitor has the same constricted channel structures, but the fill is created with a polymer – a soft, elastic material (Figure 6). Any mismatches in expansion will cause an elastic displacement of the polymer out of the wedge site. Additionally, the polymer deposition process involves a temperature range from +25°C to +65°C, hardly enough to generate
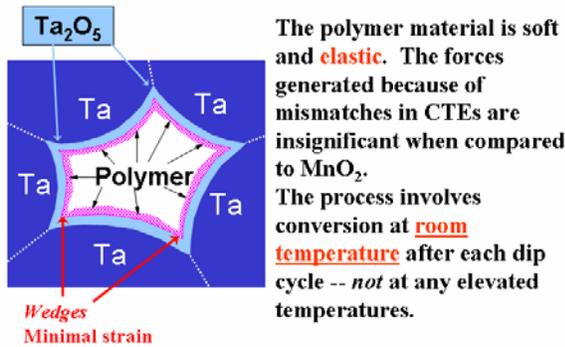
Reduced Process Stress - Polymer

The polymer material is soft and elastic. The forces generated because of mismatches in CTEs are insignificant when compared to MnO_2.
The process involves conversion at room temperature after each dip cycle -- *not* at any elevated temperatures.

Figure 6. Compliant polymer minimizes forces.

forces even if it were as hard and brittle as the MnO_2.

The Al-polymer structure is very different from the pellet structure of the tantalum capacitors. It is not a pellet comprised of randomly linked particles that define the "wedge" formations as in the tantalum pellets. It is a plate structure with channels etched into its surface to increase the total surface area presented to the formation of the dielectric, and subsequent contact to the cathode (polymer). Its smooth continuous surface creates a like coating of aluminum oxide and the absence of the singular particle-to-particle wedges may be the most dominating contributor to its higher voltage capability (as in Figure 7).

Recommended Derating Factors

We will keep the 50% derating factors as a recommended practice for the MnO_2 cathode system tanta-
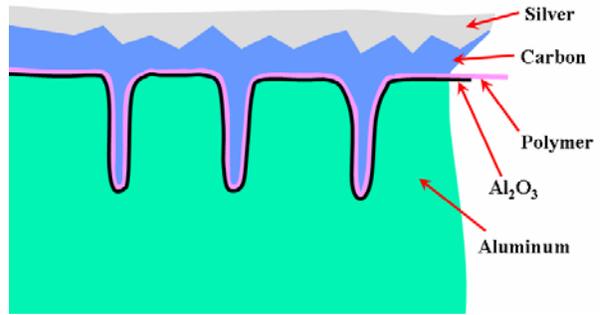
No "Wedges" in Al Structure

Figure 7. No 'wedges' in aluminum-polymer structure.

lums; but for the polymer-based cathode systems of the T520 and T530 series of the KO-CAP tantalum capacitors, we will recommend a 20% derating factor. This will allow the capacitors to be used at 80% of the rated voltage. For the aluminum A700 series of capacitors, there is no derating; use these devices at 100% of rated voltage.

Because of the polymer chosen for these capacitors, they can have application ratings up to +125°C. With the tantalum devices, the same temperature derating of the voltage must be applied, as with the MnO_2 devices (V_R up to +85°C, and 2/3 x V_R at +125°C), and with the aluminum, there is no temperature derating of the voltage.

Again, these derating factors are intended to remove the infant mortal failures. We use the same long-term reliability factors for the polymer based devices as the MnO_2 versions that are established in MIL-HDBK-217F, because no other failure rates have been established. Based on the difference in dielectric quality indicated with the SSST data, we believe these failure rates to be aggressive for the polymer versions, but we will stay with these until the lower rates are established.

Bibliography

[1] Marshall, J. and Prymak, J., "SSST Testing for Tantalum Capacitors", CARTS 2001, , St. Petersburg, FL., Components Technology Institute, Inc. March 2001

[2] MIL-HDBK-217F - Notice 2, Department of Defense, Washington, DC, February 1995

[3] Prymak, J., "Performance Issues for Polymer Cathodes in Aluminum and Tantalum Capacitors", CARTS 2001, St. Petersburg, FL., Components Technology Institute, Inc. March 2001