Derating Review of Ta-MnO_2 vs. Ta-Polymer vs. Al-Polymer vs. NbO-MnO_2[1]

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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-MnO_2: use at 50% of rated voltage-V_R), 20%-10% (Ta-Polymer: use at 80% V_R for V_R >10VDC, at 90% V_R for V_R <=10VDC), 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 are 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[2].

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

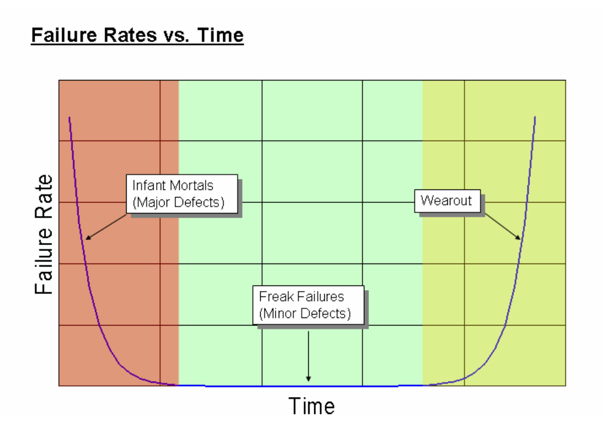

Figure 1. Bathtub reliability curve.

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.

testing.

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 [3], 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. The first formula 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.

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 manipu-

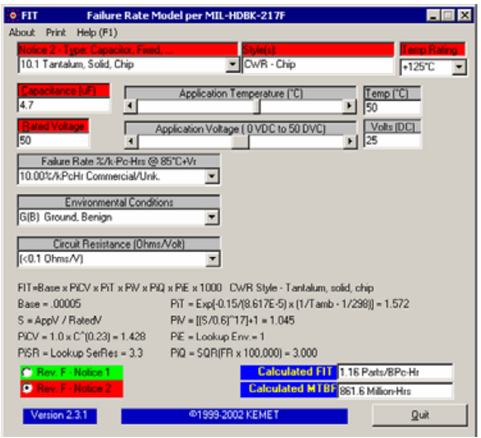

Figure 3. FIT Calculator software available at www.kemet.com.

lated by the operator do define any unique circumstances of the circuit.

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.

	MnO_2 (27Batches)	Ta-Poly KO V_R>10VDC	Ta-Poly KO V_R<=10VDC	Alum-Poly AO
100 PPM FR % V_{Rated}	68%	126%	197%	235%
@50% V_{Rated} FR(PPM)	9	0	0	0
@80% V_{Rated} FR(PPM)	458	4	1	0
@90% V_{Rated} FR(PPM)	1,700	12	2	0
@100% V_{Rated} FR(PPM)	6,310	35	8	0

Figure 4. Failure levels based on SSST data.

SSST Testing

We rely on SSST (Surge Step Stress Test [2,4]) 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 (high voltage, V_R>10VDC or most recent product introductions), Ta-polymer (low voltage), 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 126% of V_R for the higher voltage Ta-polymer devices, 197% of V_R for the lower voltage 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 higher voltage Ta-polymer's projected failure rate of 4 PPM at 80% V_R, and 2 PPM at 90% V_R for the lower voltage Ta-polymers. The fourth 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.

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 depths of the channels. As these materials are different

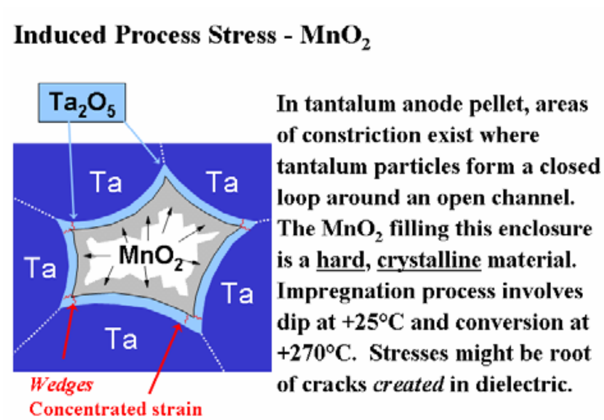

Figure 5. MnO_2 as contributing force to cracks.

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

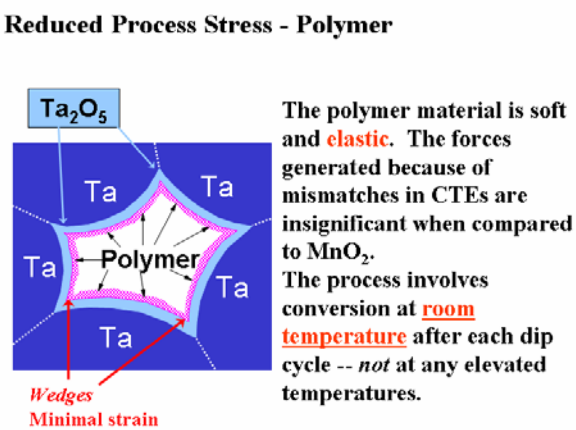

Figure 6. Compliant polymer minimizes forces.

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 tantalums; 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

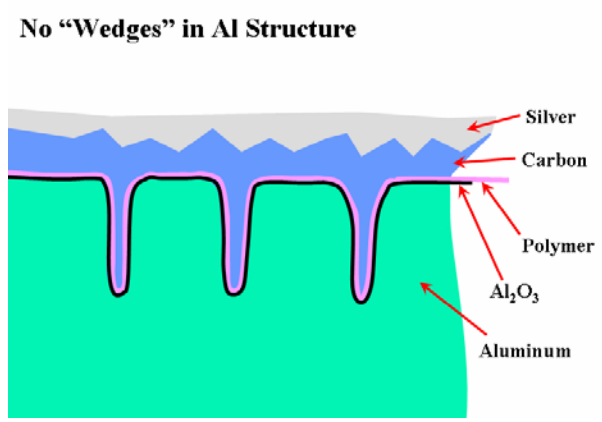

Figure 7. No 'wedges' in aluminum-polymer structure.

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 ⅔ × 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.

Niobium and Niobium-Oxide

There is a long history of poor reliability with the niobium capacitor. Typical processing of this capacitor normally involved creating excessively thick dielectrics to overcome this deficiency. The poor reliability is thought to occur because of the instability of the preferred oxide (Nb_2O_5) as oxygen tends to migrate into the valve metal anode, depleting the insulative property of the dielectric. Doping the niobium with nitrogen alleviates this to some degree, but doping the niobium with oxygen (NbO) appears to be an even better solution.

Yet even this solution does not bring the niobium dielectric to an even capability with that of the tantalum. The electrolytic capacitors are never created with the minimum dielectric thickness (rated voltage) but depend on a safety factor with the dielectric created at some multiple of the rated. Typical ratio of formation to rated for the tantalum capacitors is 3:1 to 4:1.

In the plot of Figure 8, the distribution of dielectric failures for equal voltage niobium and tantalum parts gives a good indication of the formation voltages of each.

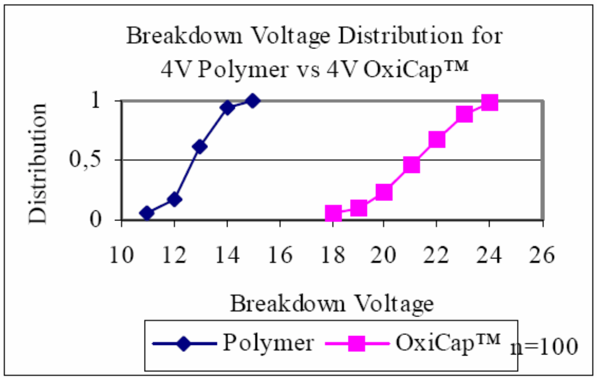

Figure 8. Breakdown chart from AVX presentation.[5]

Though the plot is indicating 'polymer' versus 'OxiCap' (NbO), the breakdown voltages are a property of the dielectric (Ta_2O_5 vs. Nb_2O_5) and not the cathode or anode elements as indicated. From this plot, we can get an estimation of the formation voltages of each type.

These capacitors are rated at 4 VDC and the breakdown level for the 'Polymer' pieces (90% cumulative failures) appears to be near 14 VDC, or at 3.5 times the rated voltage. Looking at the distribution of failures for the niobium parts, the 90% level now appears to be close to 23 VDC, or nearly six times rated. The failure rates for these NbO capacitors are very low with the formation to rated ratio near 6:1. This safety factor creates SSST results very close to those of the Ta-Polymer for rated voltages greater than 10 VDC, or allows a 20% derating (use at 80% of rated voltage). These results are not posted in the chart of Figure 4 because the samples tested were of limited numbers.

With refinement in process and materials control, this ratio can be reduced to allow higher capacitance at the same rated voltage. Some times, these reductions are forced by competitive manufacturers (chasing higher capacitance per package), and the customer may be unaware of the reduction in the safety factors here.

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