Performance Improvements with Polymer (Ta and Al)
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Improvements with Polymer Cathodes in Aluminum and Tantalum Capacitors

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Abstract – **Reducing ESR in the tantalum capacitor has been the key driver in the application of polymer as a replacement for the MnO_2 cathode material. Expanding this material into aluminum capacitors where the polymer replaces the wet electrolyte not only creates another low-ESR device, but introduces the aluminum capacitor to full surface-mount capability.**

Parasitic Elements in Capacitors

No capacitor exists without some parasitic elements. The equivalent series resistance (ESR) exists because the conductive plates are not perfect conductors, and there is some loss of power involved with the dielectric's behavior of aligning itself with the electric field between the plates.

Because the current into and out of the plates must follow a path defined by the dimensional properties of the capacitor's plates, the paths are restricted and the current must be crowded into these paths. This restriction of allowable current movement defines the effective series inductance (ESL) of the capacitor. The greater restriction over a longer path increases the ESL of the capacitor.

The electrical performance of the capacitor is usually depicted as a series arrangement of these elements as in Fig. 1. Many of the parasitic elements of each capacitor type are defined by the materials and the packaging of the materials in the construction of these devices, and changes in these materials will realize changes in the parasitic elements of the capacitors.

Plates and Plate Extensions in Electrolytic Capacitors

With electrolytic capacitors, both plates do not form direct contact to the dielectric, as is the case with ceramic, film, or glass capacitors. The nature of the chemically formed dielectric and the extremely thin nature of this dielectric create major hazards in attempting to bring both plates in physical contact with the dielectric.

The contact of the anode plate is direct because with these electrolytic capacitors, the base metal or valve metal forms the base material upon which the oxide layer or the dielectric is formed. Along the inner barrier regions between valve metal base and oxide formation, the plate to dielectric contact is realized in perfect alignment with the contours of the surface. This cannot be anything but a direct contact. The dielectric is formed as a duplicate surface of the valve metal, copying undulations with peaks and valleys. The surface created by the oxide is never flat, and any attempt to contact this dielectric with another "flat" hard surface can only result in intermittent points

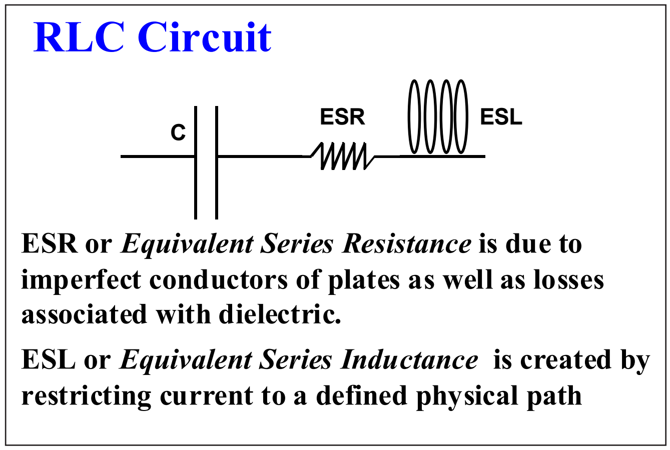


Fig. 1. RLC Circuit representative of capacitor.

of contact. These intermittent contacts not only greatly diminish the plate area for the cathode but they can also lead to mechanical scraping, and any scraping of the dielectric can result in a "shorted" capacitor.

The contact for the cathode plate must be such that it can conform to the surface irregularities of this device. It must be chemically deposited (as with the MnO_2 in the solid tantalum), or must be form-dependent as a liquid penetrant.

As shown in Fig. 2, the contact of the cathode to the surface of the dielectric must be made through an additional medium or plate extension, be it a liquid or surface deposited, that copies the undulations of the dielectric surface. There is an additional requirement of this media, which relates to healing of fault sites within the dielectric (this will be covered as a topic

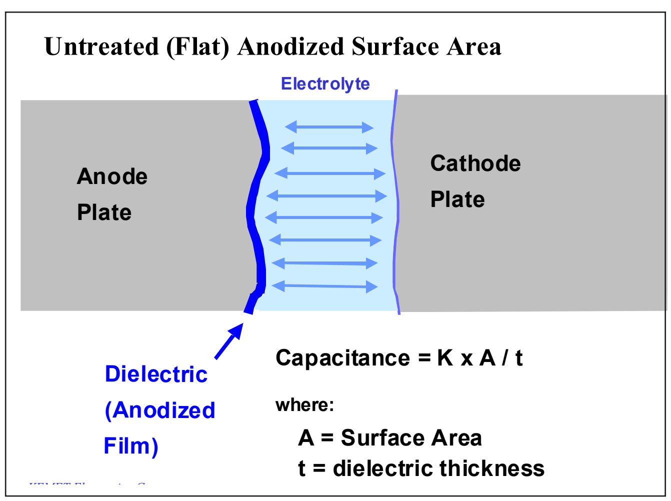


Fig. 2. Plate and plate extension through electrolyte.

of each capacitor). This medium acts as a plate extension of the cathode plate to the surface of the dielectric, opposite to the surface of the anode contact.

Since the dielectric constant of these oxides is relatively small (9 for Al_2O_3 and 26 for Ta_2O_5), the large capacitance has to be achieved with extremely thin dielectrics and enormous surface area.

The ESR in Tantalum Capacitors

The drawing in Fig. 3 is one area of one plane in the three-dimensional tantalum pellet. Here the small particles of tantalum are at first pressed together at some density well below the density of tantalum. A wire can be inserted in the die during the press or can be welded to the formed pellet at a later time. The connection of the riser wire is to the tantalum pellets, and after sintering, all the tantalum particles are electrically interconnected. This pressed pellet reveals an enormous amount of particle surface area. There are an enormous number of channels that snake their way through the pellet structure, leaving an apparent surface area of tantalum exposed to the outside atmosphere.

Here is where the huge benefits of surface area arise with this construction. The surface area of this porous pellet structure is the most dominating condition that allows the tantalum capacitor to have more volumetric efficiency over any other type of static capacitor.

During the dielectric formation, the pellet is immersed in an acid-based electrolyte solution, and connected to an energy source to create a current flow. As the voltage is increased, the oxygen is taken from the electrolyte solution and driven into the surface of the valve metal. The higher the voltage, the greater the depth of penetration and the thicker the resulting oxide film. The voltage capability of the device varies with the dielectric thickness, and the thickness determines the intended application voltage of this device.

Now two elements of the capacitor have been created: the anode and the dielectric. The cathode for the solid tantalum capacitor is applied by dipping the pellet in $Mn(NO_3)_2$ solution which is then heated to ~270°C, for conversion from solution to MnO_2. This step is repeated until a thick and continuous coating of the MnO_2 creates the cathode contact to the dielectric [1].

At the outer surfaces of the pellet, a silver coating is applied to allow a low-resistance connection to the outside. Prior to the silver application, a coating of graphite is applied to eliminate any interfacial resistances due to contact and silver oxide formation at the interface region.

The RC-Ladder in Tantalum Capacitors

As shown in Fig. 4, this structure creates a distributed capacitive network with the connecting media for the capacitors' anodes being the tantalum particles (Ta ~ 12.5 x 10^{-6} ohm-cm) and the connecting media for the cathodes being the MnO_2 material (5 to 10 ohm–cm). This arrangement creates an increasing resistance to those capacitive elements that are located farther into the center of the pellet structure [2,3,4].

If the distributed capacitive elements are of equal capacitance (and in this structure, they should be), then the time constants for the internal elements should be longer than those elements near the surface covered with silver. An electrical presentation of these interconnections is shown in Fig. 5. Since the resistivity of the MnO_2 is so much greater than that of the tantalum metal, the model diverts to single resistive elements connecting the cathodes and the anodes being common [5].

This effect is noticeable in measurements taken from frequency scans as well as time domain responses to current pulse injection [2]. The response must address the loss of capacitance, and the simple RLC circuit, as in Fig. 1, does not allow this. The model now becomes some representation of the RC-Ladder with inductive (ESL) elements added.

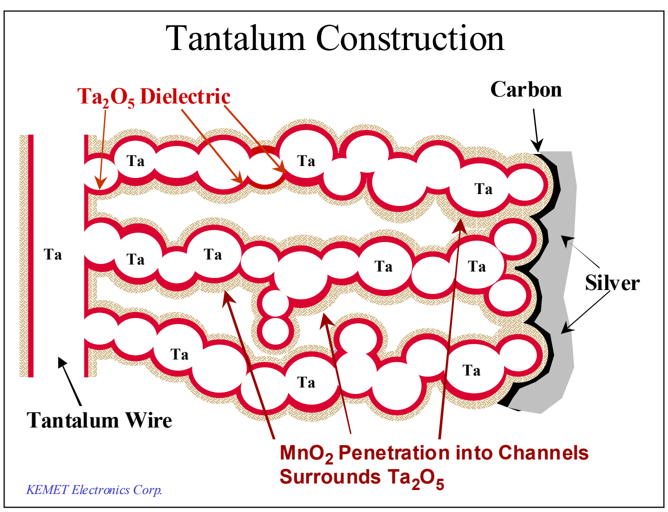


Fig. 3. Anode and cathode plate structures in tantalum pellet.

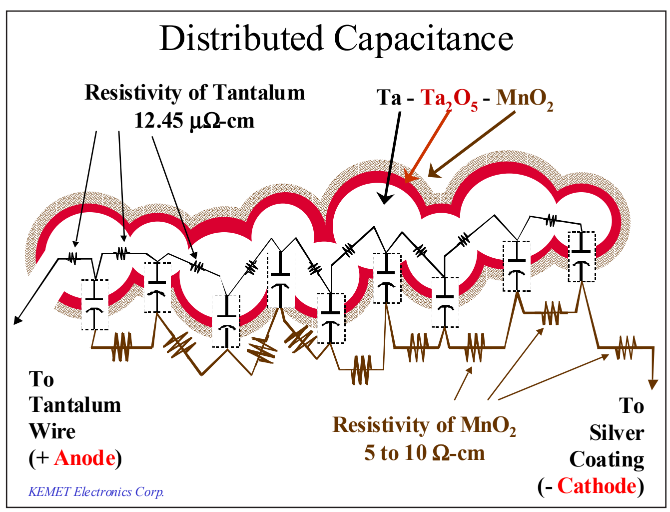


Fig. 4. Distributed capacitive elements as shown in pellet structure.

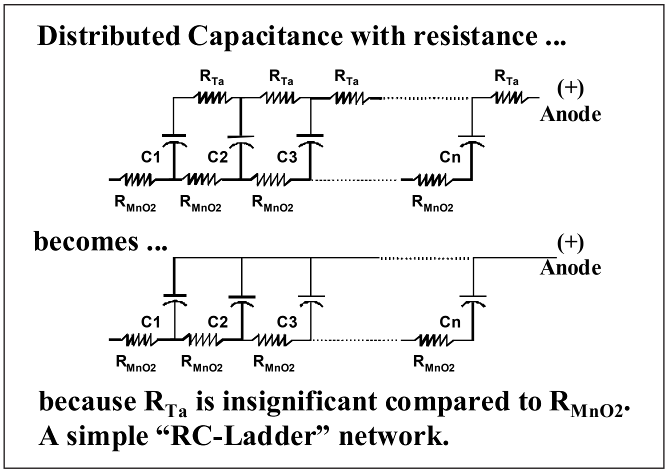


Fig. 5. RC-Ladder effect due to high resistivity of MnO_2.

Progression of Low-ESR Tantalum

The improvements in the ESR of tantalum capacitors has been well documented and I will not cover the steps here [1,2,3]. These steps include:

1. Larger tantalum pellets and larger channels.
2. Material and process changes to MnO_2, graphite, silver and leadframe elements.
3. Reduction of the pellet penetration depth through multiple, thinner anode pellets.

These steps have reduced the effects of the MnO_2 within the final package, but they all still carry the MnO_2 material within their structures. This material has additional unwanted characteristics besides its high resistivity.

MnO_2 Good and Bad Characteristics

The MnO_2 material selection was created with the first solid-tantalum capacitor [6]. Until then, the only tantalum capacitors available possessed "wet" electrolytes. This wet electrolyte worked in much the same manner as the wet electrolyte in aluminum capacitors. The "wet" solution penetrated the structure of the pellet, establishing a cathode plate contact to the surface of the dielectric opposite the anode. This "wet" solution also allowed fault clearance. When a site in the dielectric began to conduct higher currents, the dielectric formation was mimicked, and new oxide regions could develop at these fault sites, creating a self-healing effect.

No electrolytic capacitor is created with perfect and continuous dielectric film. There are contaminants with the valve metal as well as in the formation electrolyte solution. These contamination levels can be in the low PPB range, but with the enormous surface areas involved, it only takes one site to create the debilitating fault current. MnO_2 was chosen as a proper replacement because it has a dual nature capability. When a fault site begins to conduct current, the MnO_2 in contact with that site will heat up locally (Fig. 5). Since its resistivity is substantial, enough heat can be generated to cause the MnO_2 to release oxygen and change composition to a lower oxide state such as Mn_2O_3. These lower oxide states have much higher resistivity, effectively creating a cap over the fault site to pinch the current off [4,7].

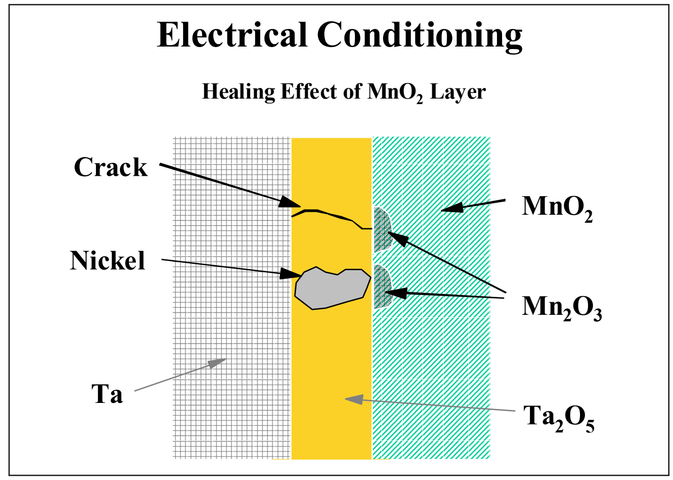


Fig. 6. MnO_2 Self-healing properties.

This self-healing or MnO_2 conversion requires two elements: sufficient current and time. If the current is insufficient, then the conversion process never takes place as enough heat is never generated, and the fault site never heals. If the current is very high, then at the same time the MnO_2 begins heating, the dielectric also begins to heat. The heat required for the MnO_2 conversion is estimated at about 470°C. The dielectric can heat up rapidly to a point where it converts from amorphous or glassy structures to a crystalline structure (this taking place at temperatures around 520°C). The crystalline structure will spread out from the original site, eliminating any possible converted Mn_2O_3 cap from covering the spreading fault site and plugging off the current. As this is taking place, great deal of oxygen is being evolved. The tantalum in contact with the fault site is heated, and it starts to rapidly absorb oxygen. The result is an exothermic reaction commonly referred to as ignition. This sequence is depicted in Fig. 7 [4,7].

Polymer Replacing MnO_2 in Tantalum

The poor conductivity of MnO_2 has been the primary motivation for eliminating this material. Even if the theoretical gains can be realized with heat and atmospheric treatment processes, the improvements in ESR will not be large steps, but only small, fractional improvements [1].

Conductive polymers have been around as "antistatic" treatments for clothing and such. The conductive polymers recently utilized for this cathode substitution purpose were initially presented by some Japanese manufacturers [8]. These polymers not only have an improved conduction property, but they also possess some characteristics that allow the self-healing condi-

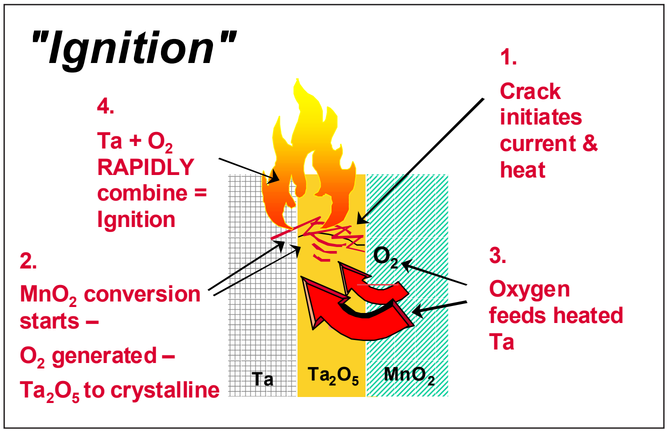
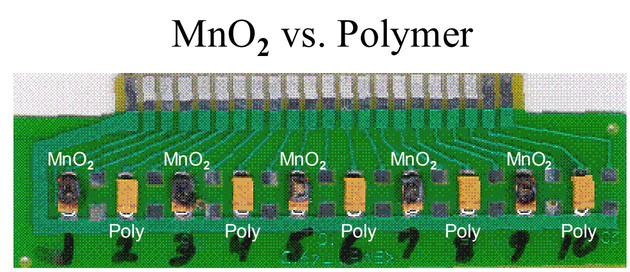


Fig. 7. Theoretical ignition failure sequence.



Test card with capacitors subjected to 2x Rated Voltage, applied with reverse polarity and > 20 amperes current capability.

Fig. 9. Pieces pushed to ignition failure.

tion to continue.

The self-healing property can be the realization of one of two possible theories. One theory suggests that the polymer is locally heated at the point of contact with the fault. The polymer here reaches temperatures to activate vaporization , vacating the connection to the fault site. The second theory suggests that the polymer absorbs oxygen from the surrounding areas as it is heated. This increase in oxygen content causes the resistivity of the polymer and, just as with the MnO_2 healing mechanism, the leakage site is capped by this higher resistance connection. Both of these theories are shown in Fig. 8, with both creating the self-healing mechanism for the replacement of MnO_2 to become effective.

Elimination of Ignition

The desire to replace the MnO_2 was driven by the need to lower the ESR of the tantalum capacitor. An additional benefit realized with the polymer material was that it also allowed the elimination of the excessive amounts of oxygen associated with the MnO_2 material.

It was shown earlier that the MnO_2 is an oxidizing agent that can contribute to the evolution of failure from a localized short to a self-consuming ignition. The polymer does not carry this abundance of oxygen. If the polymer absorbs oxygen, it becomes more resistive. In Fig. 9, equal parts of MnO_2 and polymer were built and pushed to failure by applying a reverse voltage that was twice the rated voltage, with a power supply capable of delivering 20 amps continuously. We alternated the placement of the MnO_2 parts with the polymer to eliminate position as being a factor, and the test card shows the results. All the MnO_2 parts failed and ignited, whereas the polymer parts failed, but there was no evidence of ignition or even mild scorching. Though the polymer parts did fail in a “short” mode, the elimination of oxygen in the cathode system did not allow the tantalum to rapidly oxidize [7].

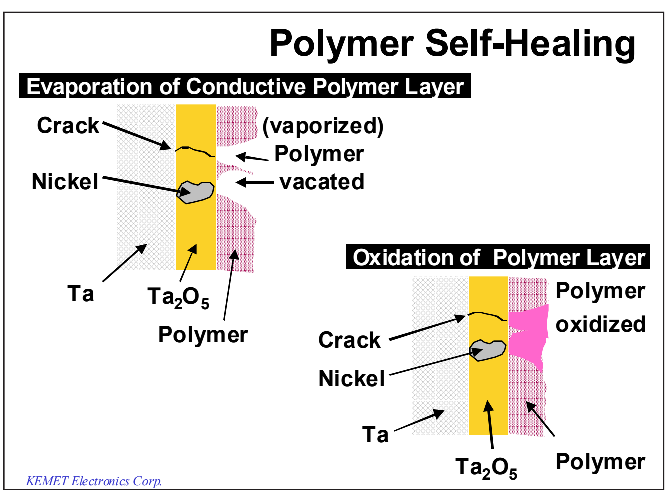


Fig. 8. Self-healing mechanisms possible with polymer.

Changing the Derating Recommendation

The changes in materials for the tantalum-polymer capacitor did not change the structure of the device. The polymer is a straight material substitution for the MnO_2 in the assembly.

Although this may appear to change little, it does eliminate some mechanical problems associated with the MnO_2 material and process. As this pellet structure is an extremely porous structure with bonded tantalum particles, there are many instances where these particles can create an enclosed tunnel as in Fig. 10. The tantalum particles encircle an area, with the points of contact between the tantalum particles creating sharp wedges or crevices. These crevices still exist after the oxidation creates the glassy dielectric film, but now they are filled with the cathode material.

With the MnO_2 devices, this deposited material is hard and brittle, resulting in a layered creation of tantalum-dielectric-cathode materials in these crevices. The application of the device into the $Mn(NO_3)_2$ solution occurs at, or near room-ambient temperatures. The conversion of the MnO_2 out of this solution requires an exposure of the dipped pellet to temperatures near 270°C. The dip and cure process is repeated several times to ensure complete and consistent coverage of the MnO_2.

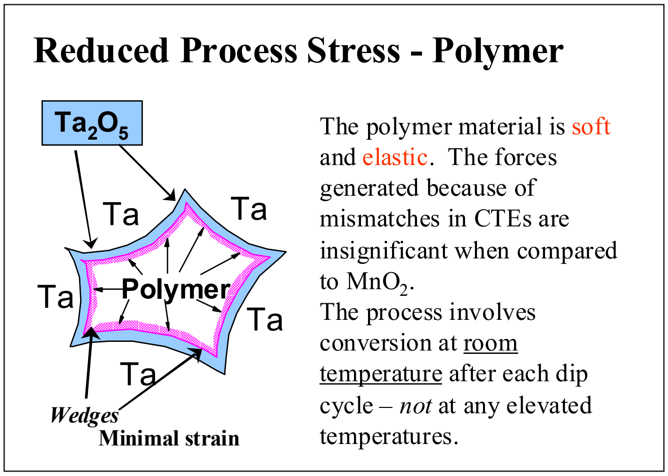


Fig. 10. Converging particles creating layered wedges.

The heating and cooling of this pellet may be responsible for cracks created in the glassy dielectric because of forces created by mismatches in coefficients of thermal expansion (CTE) of these three materials over this temperature range. The wedge areas would probably be the points of greatest susceptibility to these stresses.

With the polymer application, the dip is into a monomer solution near room-ambient temperatures and the dry occurs at near room-ambient temperatures. This eliminates the huge temperature changes associated with the MnO_2 process. The polymer material is also elastic, leading to very little force generation between this material and the glassy dielectric as the material can defeat any forces with a displacement of itself [4,7].

This reduced stress in the dielectric has realized a more robust dielectric. The most prevalent failure presentation today for tantalum capacitors is power-on failures. We have devised a test that subjects the part to high current turn-on pulses, in which we use parallel FETs, a bank of 12,000 uF capacitance, and high current power supplies to achieve predictability for this failure. We start at ½ rated voltage, charge the unit, then discharge the unit. We repeat this pulse with increasing voltage until we achieve a failure. We run samples between 60 and 200 pieces and then plot the cumulative percentage failures versus the voltage level where the failure occurs in a Weibull plot. From this plot, we can then extrapolate the lower PPM levels that are important to our customers.

The chart in Fig. 11 details the comparison of polymer to MnO_2 pieces for these tests. We show the voltage levels at which we expect 100-PPM failure rate and we show the projected failure rates at 50%, 80%, and 90% of rated voltage.

It has historically been a recommendation that the tantalum capacitor be used at application of 50% derating in order to achieve low PPM failure rates. From this chart, we see that the failure rates at 50% of rated voltage for the MnO_2 are actually bettered at 80% of rated voltage for the polymer. Based on this response, the recommended derating factor for the polymer-based tantalum will be 20% of rated (or recommended application is up to 80% of rated voltage).

Electrical Performance

The main purpose in bringing this material change to the tantalum capacitor was a desire to improve performance. Secondary characteristics of eliminating ignition and reducing the derating factor, though extremely beneficial to all, were not the primary drivers in looking at this alternative material. The primary force was to reduce the ESR and the RC-Ladder effect.

As mentioned earlier, the structure of the tantalum capacitor did not change with the polymer cathode. As such, the RC-Ladder effect still exists as in Fig. 5, but the change in material reduces the resistive elements to a lower resistance. This effect does not eliminate the capacitance roll-off, but moves the roll-off to a higher frequency range.

Fig. 12 shows the change created in two devices, with the only difference being the material of the cathode. The polymer still loses capacitance at a frequency so high that the self-

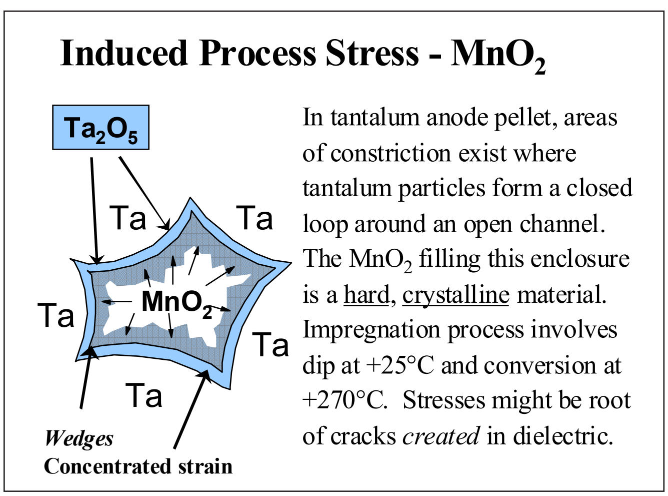


Fig. 11. Projected failure rates for MnO_2 versus polymer.

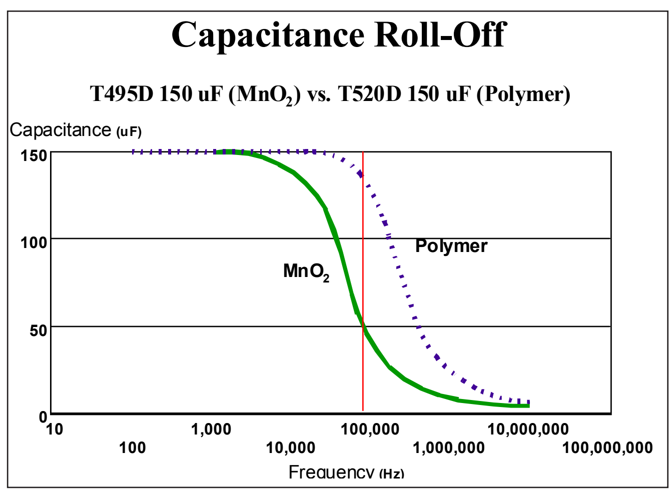


Fig. 12. Capacitance roll-off for MnO_2 versus polymer.

resonance hides any negative effects. As shown in the chart at 100 kHz, the MnO_2 loses 67% of its capacitance, while the polymer at this frequency loses only 10% [4,7].

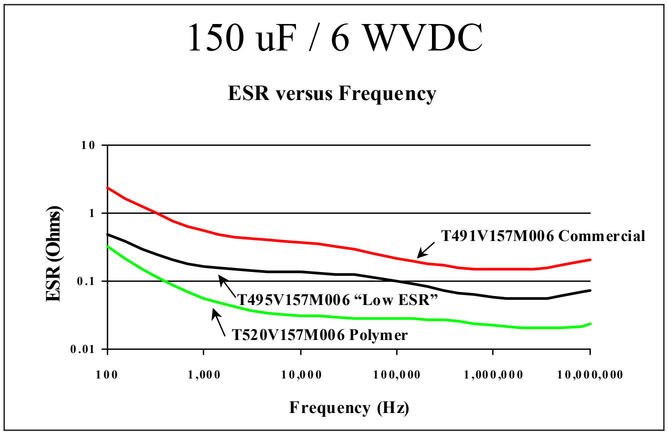


Fig. 13. ESR versus frequency for tantalum capacitors.

The effects on ESR are shown in Fig. 13, with ESR versus frequency plotted. An early commercial MnO_2 device and a "Low-ESR" MnO_2 device are plotted against an equal size, capacitance, and voltage design using the polymer cathode. This highlights some of the improvements that were made to lower the ESR while retaining the MnO_2 cathodes.

This lower ESR and higher capacitance roll-off can also be viewed in a time domain. In Fig. 14, the *dv* versus *dt* is plotted for polymer versus MnO_2 cathode structured tantalum capacitors. The *dv* is expressed as volts per ampere, as the current is another independent variable with this response. In addition, the *dv/dt* response for the ESL element is not plotted here, as the *di/dt* becomes a fourth independent variable.

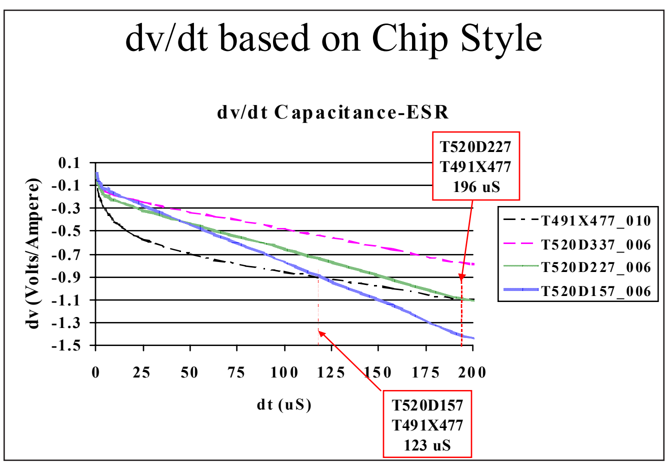


Fig. 14. Impact of polymer capacitors on time *(dv/dt)* response.

It is important to realize that this plot shows that equal or lower *dv* responses can be achieved with lower capacitance, depending on the ESR and subsequent capacitance roll-off features. The 150 uF polymer capacitors create less dv than the traditional 470 uF capacitors if the pulse response is less than 120 uS. If the pulse response is less than 196 uS, then a 220 uF polymer tantalum can give a better response than the traditional 470 uF tantalum. Although not shown, the 330 uF polymer device crosses the traditional 470 uF response at 860 uS.

Aluminum RC-Ladder

As with the tantalum capacitor, the greatest contributor to ESR has been one of the cathode materials. These materials consist of the cathode plate (aluminum) and the electrolyte solution. A solution is used because this allows a full penetration into the depths of the tunnels created in the anode plate to increase surface area and capacitance. It is in this solution where the highest resistivity element resides.

This solution also enables some self-healing to occur at fault sites in the dielectric. As the proper bias voltage is the same polarity as the formation voltage, when a defect site is created in the dielectric, the dielectric is "reformed" at the bias voltage. Because this solution is so caustic, though, the dielectric can deteriorate with no DC bias over time and require a "refresh" application of increasing DC bias to restore the dielectric.

The RC-Ladder (Fig. 15) is created as the electrolyte solution extends into the depths of the tunnels etched to increase surface area. Here the channel narrows (the aspect ration of length divided by diameter can easily exceed 800), and the common connection of the cathodes must be completed with the electrolyte.

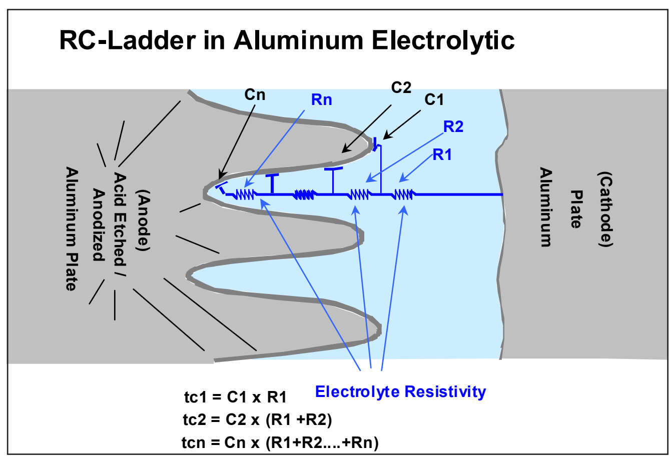


Fig. 15. RC-Ladder in wet aluminum electrolytic.

It is this effect that is also responsible for the huge decay in capacitance as temperature decreases below 0°C Celsius. The dielectric constant remains the same but, because the resistance of the RC-Ladder increases for the electrolyte, the roll-off of capacitance occurs at lower frequencies. Though a capacitance measurement does not change frequency when measuring at room-ambient and early subzero temperatures, the fact that the capacitance roll-off now starts at a lower frequency results in a lower capacitance measurement at the same frequency.

Rolled Foil to Stacked Plates

The traditional construction used for aluminum electrolytic capacitors involves the use of a rolled foil (anodized), blanketed with an absorbent spacer soaked with the electrolyte, then with the cathode plate, and finally another separator soaked with the electrolyte (Fig. 16). The entire roll was placed in a cylindrical package, the voids filled with electrolyte, then sealed with some type of organic seal to prevent the electrolyte from escaping. The can was tied to the cathode connection, and the anode connection was brought out through the organic seal. The wet condition of the cathode plate extension into the package prevents this device from ever achieving full surface mount capability. In addition, the high resistivity of the electrolyte creates the capacitance roll-off in the lower frequency range.

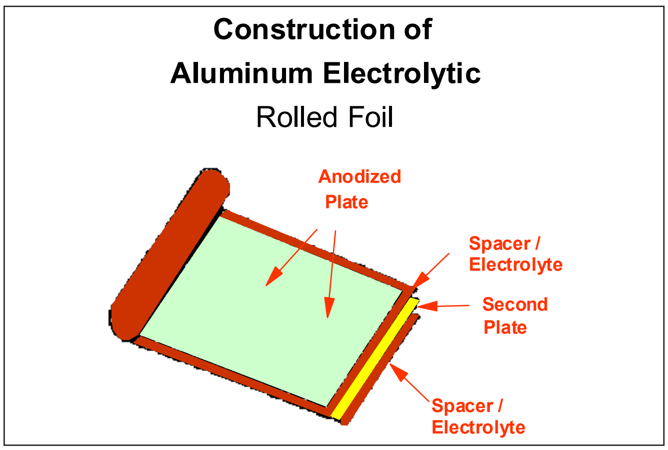


Fig. 16. Rolled-foil construction.

This rolled-foil technique was adapted to the first solid state replacement of the wet electrolyte. In this adaptation, a molten salt was poured into the structure after the foils and spacers were loosely wound. This salt (TCNQ) filled the voids between the cathode and Al_2O_3 surfaces as well as the etched tunnels within the anode plate structure. As this salt solidified at room temperature, it created a lower resistivity extension from the cathode plate to the Al_2O_3 surface, thereby reducing the overall ESR dramatically. As this ESR is reduced, the capacitance roll-off is also diminished to the point where the roll-off occurs above the self-resonant frequency and is not a factor in the frequency response of the device.

The rolled-foil structure still requires a spacer to prevent the potential rubbing of the cathode foil against the anode film and creation of a "shorted" capacitor. This construction technique therefore prescribes a large gap between the foils in this structure.

This structure does not lend itself well to the application of the polymer. The application of a conductive film over the surface of the dielectric through polymerization develops a thin covering of the surface. This thin covering does not lend itself

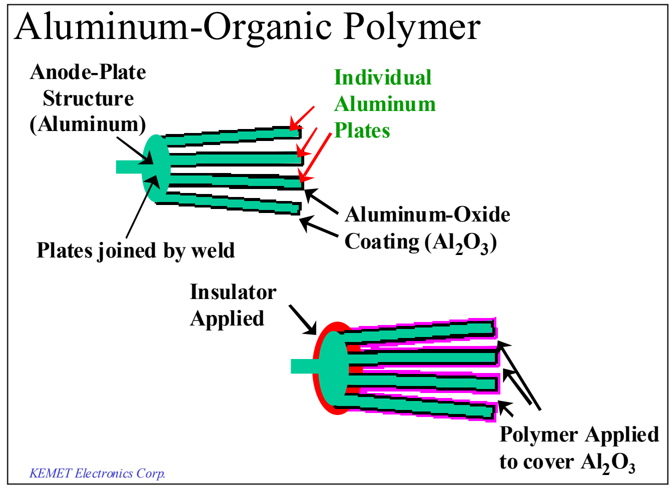


Fig. 17. Stacked-plate aluminum polymer construction.

well to filling a large void that exists between the cathode plate and the dielectric surface through any type of spacer.

To overcome this large gap, the conductive cathode material must be processed to cover the film as it covers the dielectric. This is accomplished through the stacked foil arrangement as shown, starting with Fig. 17. Here the foils are collected after being processed through anodization, and bonded into a single structure. The bond creates a unification of the aluminum base metal, but because it may expose points of this base metal, this bonded area must be protected with an insulative coating.

Next, the structure is dipped such that the loose ends of the plates are immersed into the monomer solution. The coating polymerizes on the surface of the dielectric coating (and into the tunnels) of the anode plate structure. Once this is dried, the plates are then similarly dipped in a silver epoxy to extend the cathode connection to most of the surface of the polymer film. These plates are then bonded to the cathode leadframe using a silver epoxy, while the anode leadframe is welded to the previously bonded area of the aluminum plates (Fig. 18).

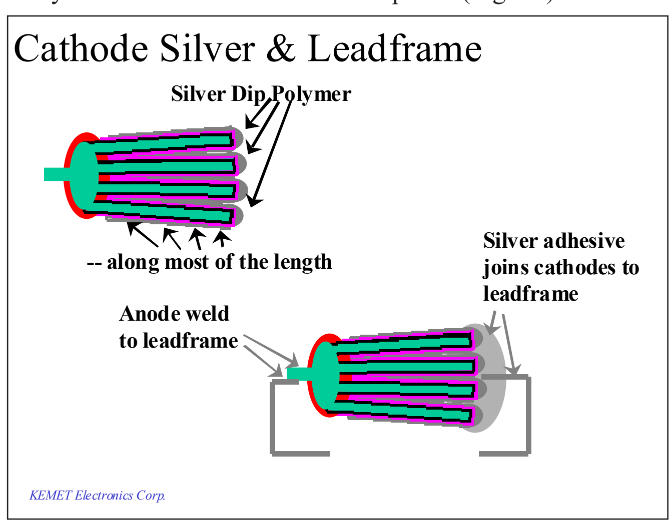


Fig. 18. Silver application and leadframe attachment.

The device is then molded in a plastic epoxy, the same as the tantalum surface-mount capacitors. These cases are dimensioned to replicate the sizes available today in tantalum surface-mount capacitors (Fig. 19).

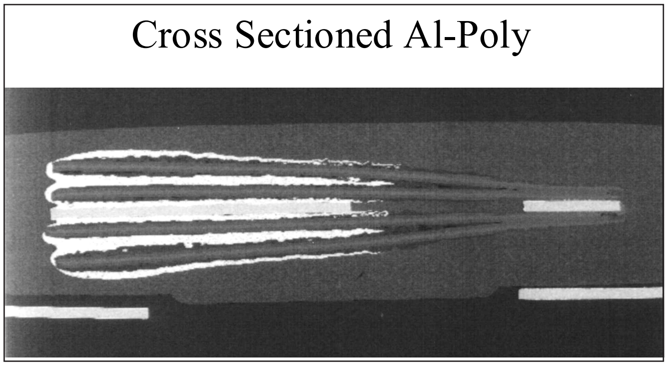


Fig. 19. Cross-section view of polymer-aluminum capacitor.

Performance Improvement

The huge reduction in ESR is attributable to both the material change and the construction techniques used. A cross section of one plate in the structure details one of these improvements. In Fig. 20, the acid-etched region of the aluminum plate as well as the solid aluminum plate are visible. The coating of the top and bottom surfaces with the polymer and graphite represents the highest resistive materials in the structure. (The graphite is added as a mechanical buffer between the silver and the polymer film.) It is important to note that the conductive path through this material is not along large expanses of the plate length, but merely the thickness of these materials coated by the silver. This reduced path length through the most resistive of the materials in this construction reveals a very low cumulative ESR.

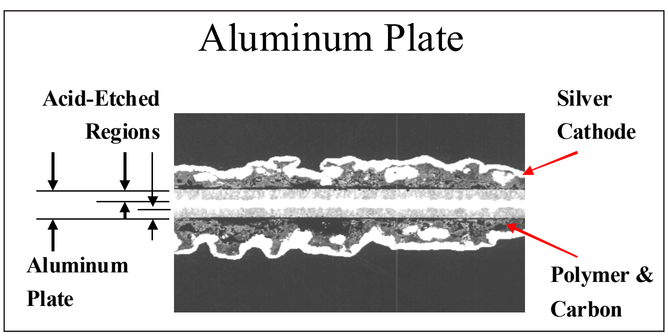


Fig. 20. Single plate structure of polymer-aluminum capacitor.

The plot in Fig. 21 shows the ESR versus frequency for a few of the four-element capacitors. The ESRs are descending below 10 milliohms for this device. With tantalum capacitors, we would not be seeing an ESR this low until we get to the 680 uF capacitance range, with a multiple-anode construction. The difference is largely associated with the limited penetration distance of the polymer into the aluminum plate tunnels, versus the longer penetration depth of the polymer into the porous anode pellet structure of the tantalum capacitor. In both of these devices, the depth of penetration is the distance from the nearest silver region, and the aluminum creates a more efficient model for this characteristic.

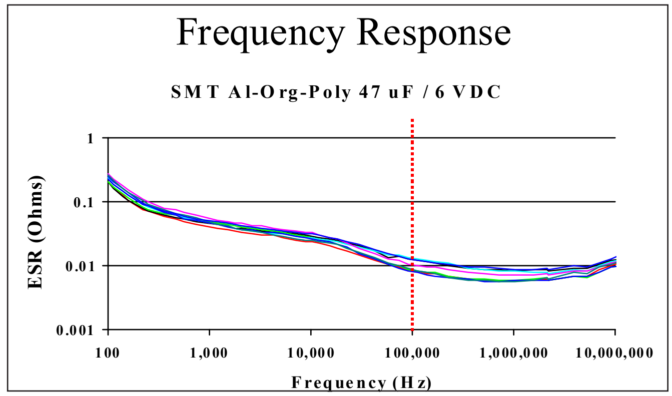


Fig. 21. ESR versus frequency for polymer-aluminum capacitors.

The plot in Fig. 22 shows the *dv/dt* response for this 47 uF device compared to a "surface-mount," wet aluminum electrolytic capacitor. This wet device was actually a can, packaged in a plastic case that gave the same appearance as a 7343 surface-mount tantalum. There are wet aluminum devices with lower ESR that could have been plotted, but these were chosen because they were the same size package and they were touted as being surface-mountable.

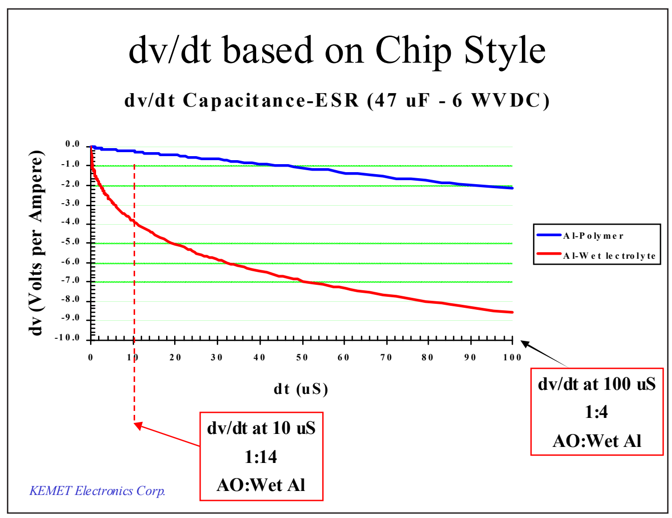


Fig. 22. Time *(dv/dt)* response of wet versus polymer.

Important points from Fig. 22 are that at 10 uS the *dv* of the wet electrolyte capacitor is 14 times greater than that of the polymer-based unit. With a response time of 100 uS, this advantage diminishes to a factor of 4. Unless these are targeted for high-speed circuits, the performance advantage is diminished and pure, bulk capacitance capability dominates.

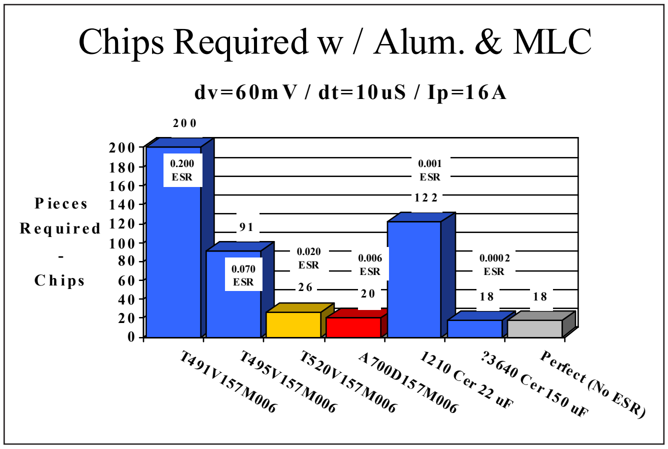


Fig. 23. Piece count solutions for *dv/dt* requirement.

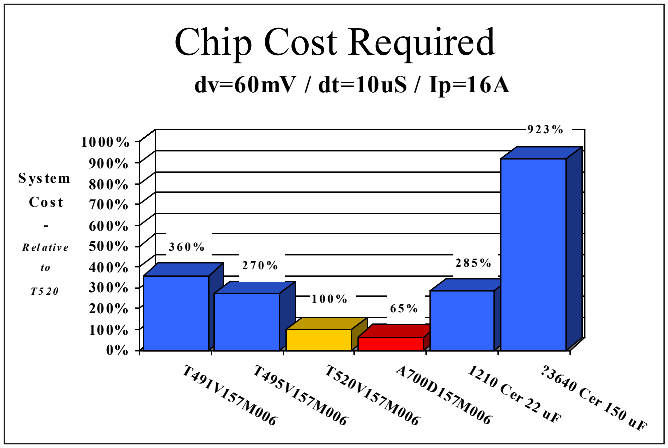


Fig. 24. Capacitors' cost for *dv/dt* solution.

Cost Factors

Regardless of improvements in performance, the bottom line is almost always a consideration of cost. For this analysis, we used a set *dv/dt* requirement with a given current demand from a bank of capacitors. We used a *dv* of 60 millivolts, a *dt* of 10 uS, and a current demand of 16 amperes. Based on the ESRs of each device and the capacitance available at the required *dt* (dependent on capacitance roll-off), we concentrated on the lower ESR offerings of the tantalum capacitors, the new aluminum-polymer capacitors, and we also added some MLC structures.

For the MLC structures, we looked at two cases: commercially available and a costly stacked-chip assembly with lead-frame attachment. The commercial MLC represents today's state-of-the-art capability in an X5R dielectric (thermally and biased stable) of 22 uF in a 1210 SMT chip. For the "cost is no issue" assembly, we used a stack of 3640 chips with the stack arrangement representing 150 uF at 16 VDC.

Based on a "perfect" capacitor with no ESR, this solution would still require 18 of the 150 uF capacitors as shown in Fig. 23. The stacked MLCs with an ESR close to 0.2 milliohms requires the same 18 pieces as the "perfect" capacitor.

Apart from the MLCs, the lowest number of 150 uF capacitors belongs to the aluminum polymer solution, with the tantalum polymer being the lowest required with tantalum.

Translating this number to component cost is revealed in Fig. 24. The "perfect" MLCs are too costly to be considered. The commercial ceramics are not only costly, but dealing with mounting these pieces becomes problematic as well. The aluminum polymer becomes the most practical solution when comparing these 150 uF solutions.

The trade-off between the aluminum and tantalum polymer will be that with the tantalum, the volumetric efficiency can overcome a value-for-value comparison and create a solution with fewer, but larger-value capacitors that should actually reduce the piece count. As the piece count is reduced, even at higher costs per piece, the capacitance solution should be lower with the tantalum. The final determination may be dictated by product availability.

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