

For the past fifteen years, the tantalum capacitor has had enormous improvements in ESR because of the replacement of  $MnO_2$  with a conductive polymer system. This material has also found its way into creating a surface mount, solid-state aluminum electrolytic capacitor as well.

**Progression to better performance in tantalum capacitors**

- Process manipulation – Thicker  $MnO_2$
- Geometry manipulation – Parallel Pellets
- Replacing  $MnO_2$  with Conductive Polymer
  - Need self-healing for decreasing failure rates with time
  - Removed oxidizing agent in  $MnO_2$  – ignition failures
- Tantalum-Polymer device
- Tantalum-Polymer device with multiple pellets
- Aluminum-Polymer device

APEC 2011 #2

A progression listing of changes over the last 20 years in the pursuit of better capacitors with lower parasitic elements, more benign failure modes, and improved reliability.

**Larger Particles, Larger Pores, Thicker  $MnO_2$**

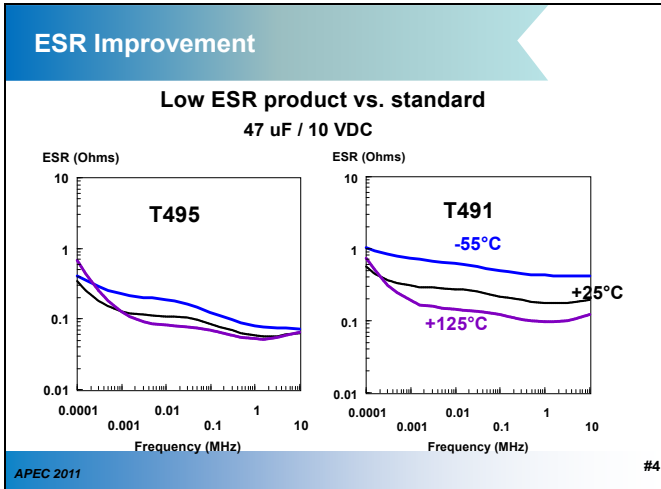
The diagram shows two cross-sections of tantalum pellets. The left one shows a smaller pellet with a thin  $MnO_2$  layer on the surface of the pores. The right one shows a larger pellet with a much thicker and denser  $MnO_2$  layer that penetrates deeper into the pores. Labels include  $Ta_2O_5$  and Ta.

Thicker / Denser application of  $MnO_2$

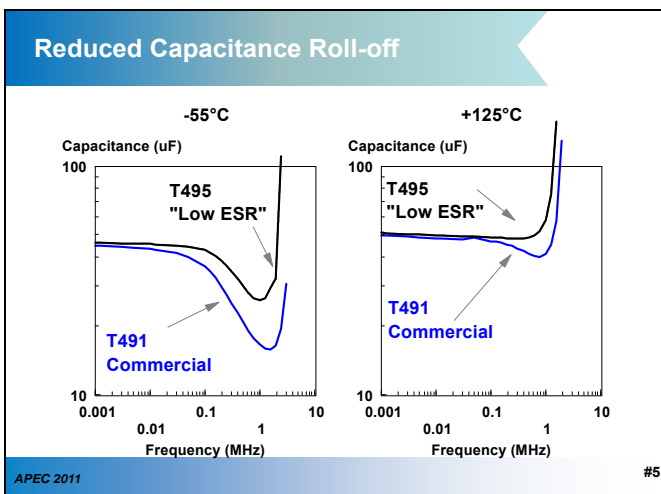
APEC 2011 #3

In the tantalum pellet structure, within the finer pores of the newer powders, a deposition of  $MnO_2$  is made with the intent to assure 100% coverage of the dielectric (100% capacitance recovery). We measure this efficiency by comparing the “wet” to “dry” capacitance to assure near complete coverage.

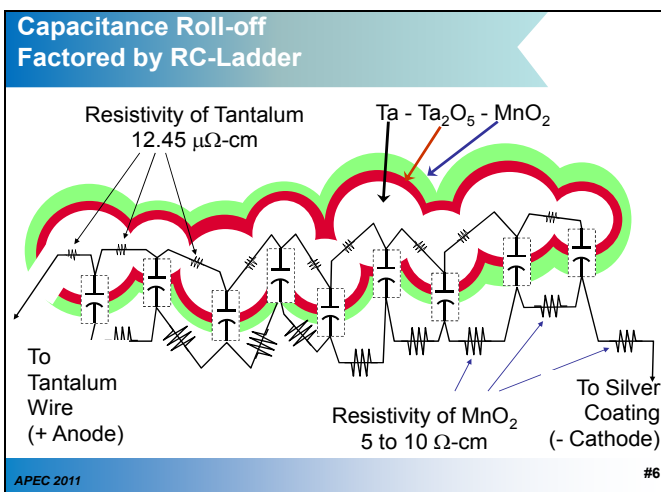
With the low-ESR device, the decision was made to use the larger pores to assure full penetration and coverage well beyond 100% , to create a thicker, more conductive film of the  $MnO_2$  as it penetrates deep into the core of the pellet.



This represents the improvement achieved in this device. Both are 47  $\mu\text{F}$ , 10 volt rated, 'D' case size devices. The improvement in lower-ESR is apparent in these frequency scans of ESR.



Hand-in-hand with the reduced ESR, is the effects on the capacitance roll-off. By reducing the resistive elements of the RC-Ladder, the capacitance roll-off is moved to a higher frequency.

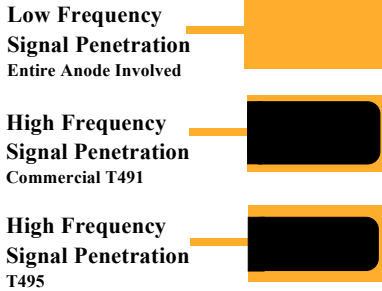


Capacitance roll-off is a byproduct of the RC-Ladder established in the translation from the outside to the center of the pellet structure. Electrical connection to all capacitive elements is through the tantalum for the anode (+) connections and from the silver, then carbon, through the  $\text{MnO}_2$  channels, for the cathode (-) connection. The path between each capacitive element is connected through the associated resistances of the common materials: tantalum for the anode and  $\text{MnO}_2$  for the cathode. The resistivity of the  $\text{MnO}_2$  material is listed as 5 to 10 Ohms-cm, whereas the tantalum is listed as 12.45  $\text{m}\Omega\text{-cm}$ . At minimum, the ratio of the  $\text{MnO}_2$  to the tantalum is over 400,000 to 1.

We have manipulated some structure and geometries in lowering the ESR, but we are still burdened with the poor conductivity of the  $\text{MnO}_2$ . An obvious goal is to replace this material.

**T495 Increased Anode Penetration**

**Cross Sectional View of Anode**

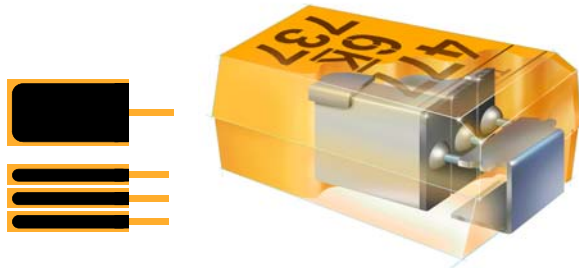


APEC 2011

#7

If we look at the volumetric efficiency of a tantalum pellet, we might observe that the full volume of the pellet responds the circuit stimulus at low frequencies. At some elevated frequency, the RC-Ladder effect restricts the penetration to a short thickness, close to the silver overcoat of the pellet. With the T495, low-ESR product, we improved the RC-Ladder effect to allow deeper penetration at the same frequency, but we still lose a large portion of the center volume.

**Multiple Anode Tantalum (MAT) T510**

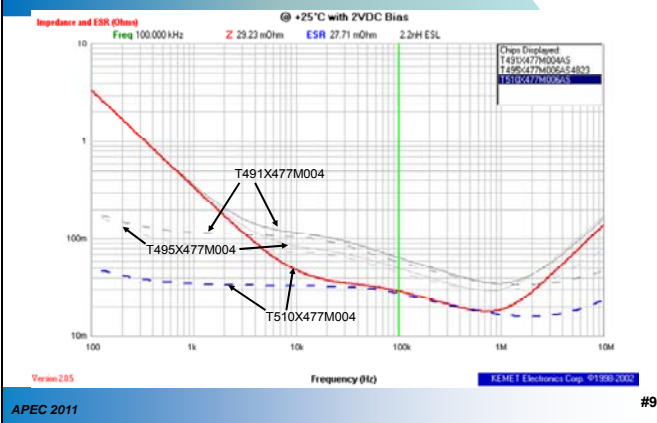


APEC 2011

#8

If penetration is at a fixed depth and the thickness of the pellet is reduced, the percentage of penetration is increased. This is the principle behind the T510, multiple anode package ('X' case shown here – EIA 7343). From the outside, it would appear as a 'normal' or the same as a single pellet tantalum chip capacitor. Only when you open the package or x-ray the device can you be certain of the multiple pellets inside. The other size available is our 'E' case size (EIA 7260), with 6 pellets in parallel.

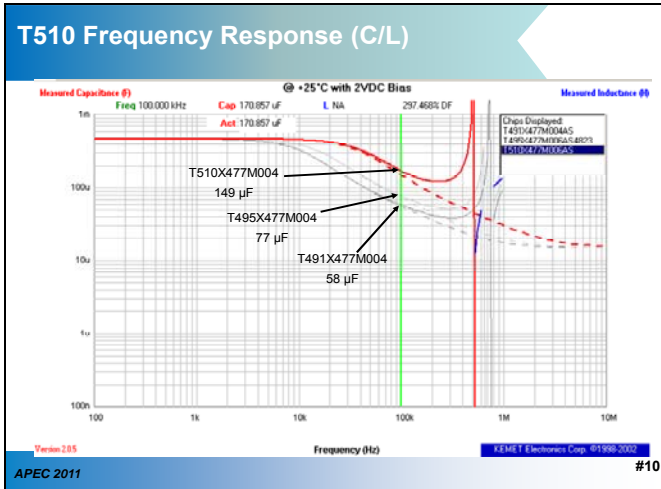
**T510 Frequency Response (Z/R)**



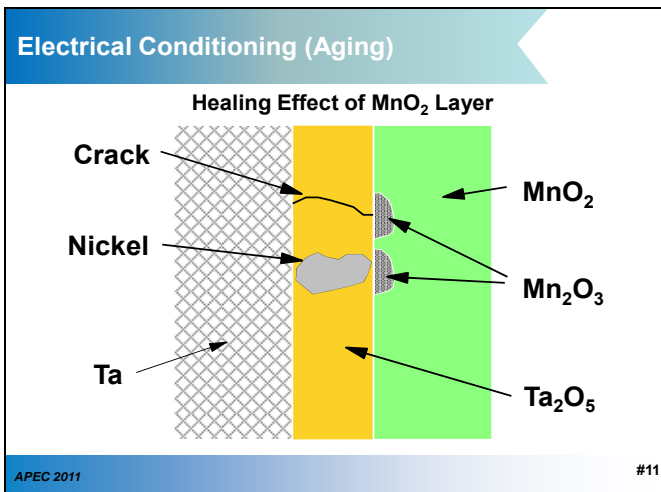
APEC 2011

#9

The efficiency of three pellets in parallel replacing one pellet is shown in this plot. The T510 impedance and ESR versus frequency, compared to a T495 (low-ESR, single pellet), and T491 (commercial, single pellet). All these devices are 470 uF devices rated at 4 Vdc.



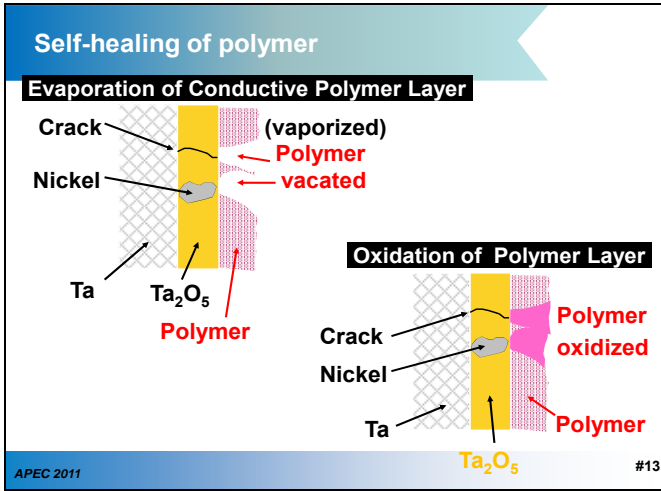
Here are three devices plotting capacitance versus frequency. The retained capacitance for the T510, T495, and T491 are 149 µF, 77 µF, and 58 µF, respectively.



We need the self-healing capability of the MnO<sub>2</sub>, because of the extremely thin (100 to 2000 angstroms) and PPM defect nature of the tantalum-pentoxide dielectric. There are faults in every capacitor built and we need the healing capability of the cathode contact to eliminate these faults from the capacitor.



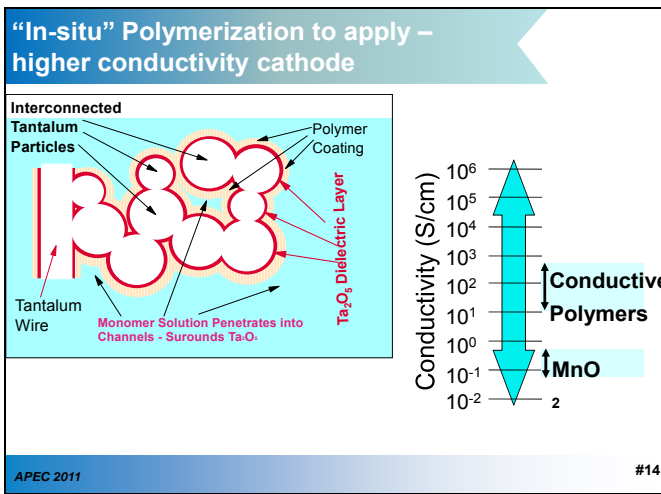
Since the first solid-state capacitor built in AT&T's Bell Laboratories using MnO<sub>2</sub> as the cathode material, a substitute cathode material is found – conductive polymers.



Earlier exposure to these elements on a commercial basis was with the introduction of 'anti-static' sprays for clothing. There are some conductive polymers that will melt and evaporate in high heat environments – answering the need for self-healing .

We have evidence of two possible methods that might be taking place in the self-healing – one, the evaporation method, and two, the absorption of oxygen when heated, creating a higher resistive, pinch-off effect (very much the same as the MnO<sub>2</sub> self-healing effect).

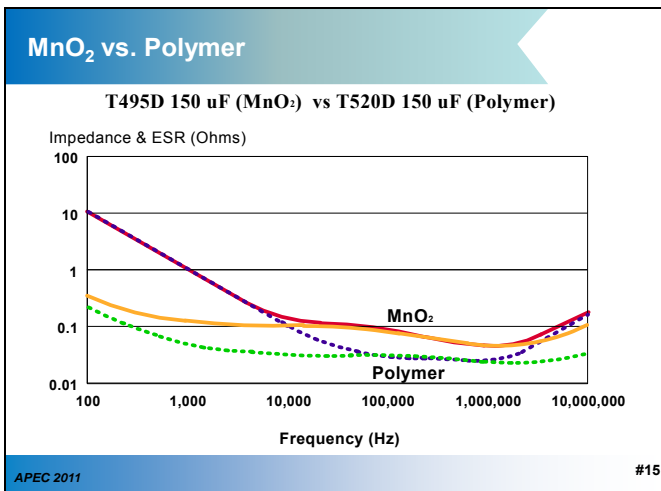
It is important to note that oxygen in this polymer is undesirable. As such, it removes any oxidizing agent in the ignition cycle as available with the MnO<sub>2</sub>. The result is no ignition in these polymer devices!



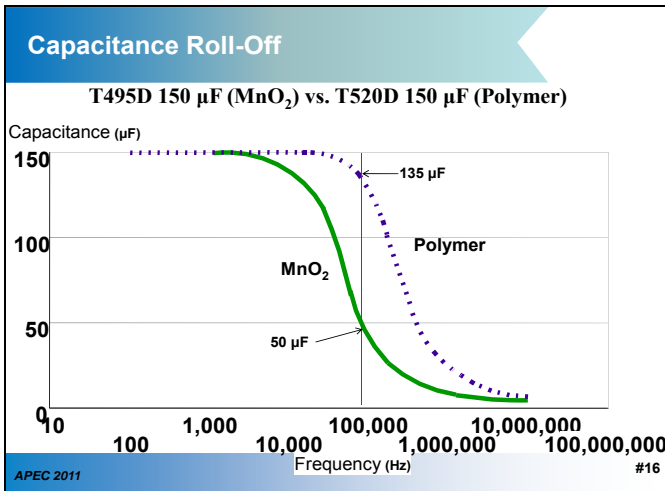
The application of the polymer on the surface of the oxide dielectric is through a polymerization process. We dip the dielectric covered tantalum in pellet form into a monomer solution, followed by an oxidizing agent, a rinse, and then dry.

The material itself is much more conductive (less resistance) than that of the MnO<sub>2</sub>. This makes the resistive elements of the interconnecting cathode structure much lower. This lower material resistance is immediately evident with lower ESRs in the capacitors; but it is also evident as the capacitance remains through higher frequencies than that of the MnO<sub>2</sub>.

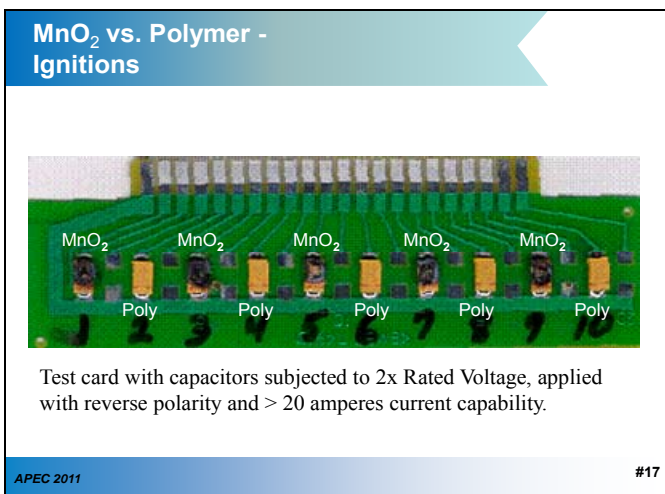
In addition to the higher conductivity this material carries almost no oxygen, eliminating ignition problems. Although this characteristic should have been sufficient to drive the change, it was its conductivity in search of lower ESR that brought this change about.



First evidence of the lower resistance is presented with lower ESR, and therefore lower impedance (Z) at higher frequencies.. These parts are identical as they were started with the same anode and same dielectric formation. The batch was split for the application of the cathode material: one-half processed with the conductive polymer, and the other half with the MnO<sub>2</sub>. With impedance, the polymer difference appears from 10 kHz and higher.

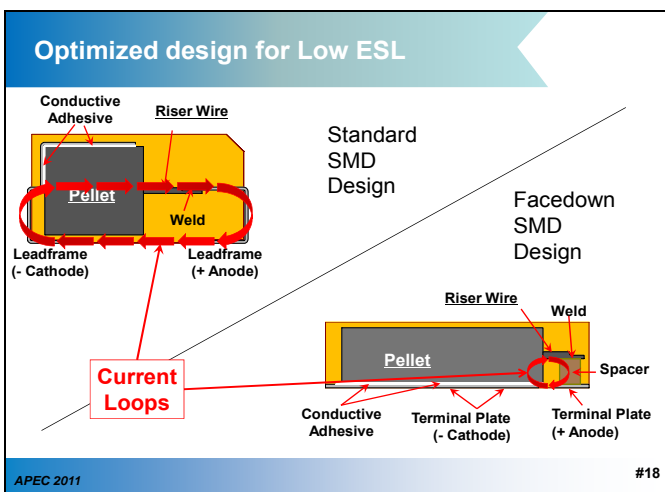


Closer examination of the frequency scans reveals that the capacitance roll-off occurs at higher frequencies. At the 100 kHz point, the polymer device loses only ~10% of its capacitance, whereas the  $\text{MnO}_2$  device loses ~66%.

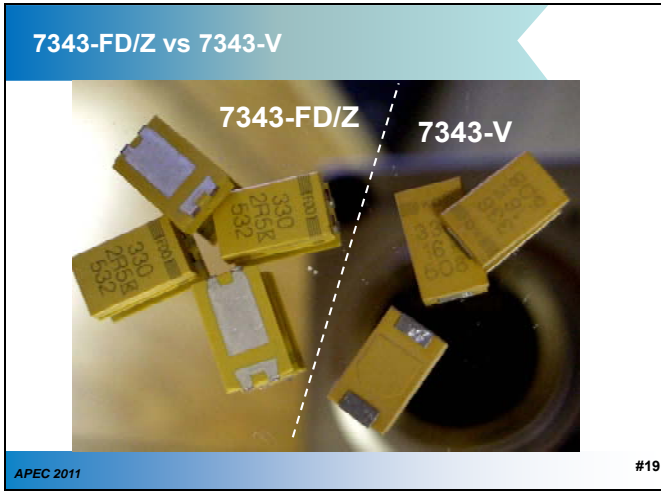


The elimination of the ignition is readily apparent.

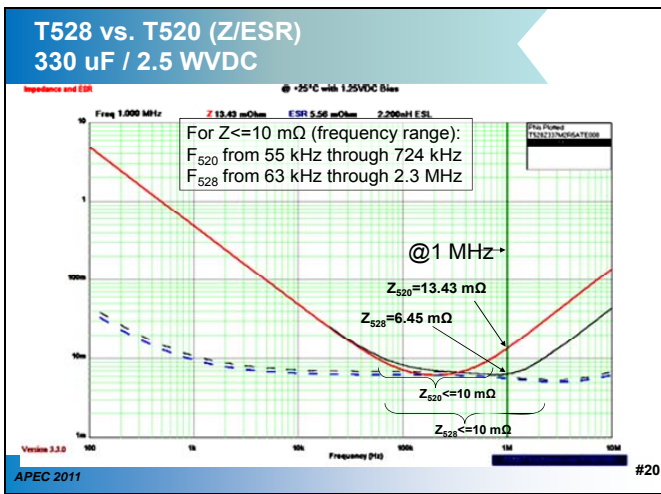
The  $\text{MnO}_2$  product all ignited. Though the polymer product all failed (dielectric breakdown), the 20 ampere current level only scorched the sides of the plastic bodies..



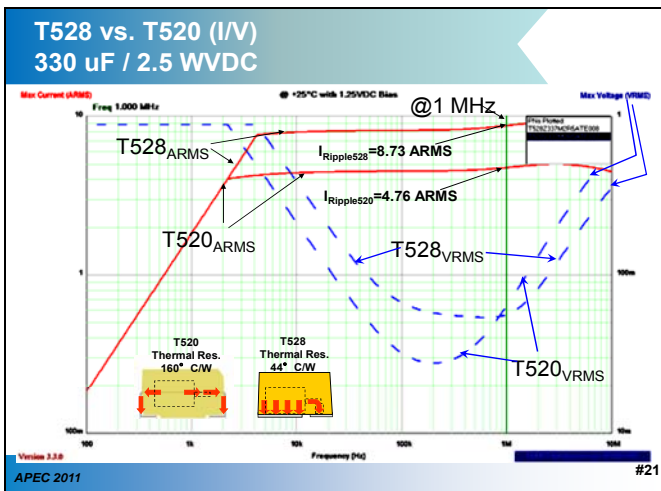
ESR was reduced to the point where ESL became a noticeable constraint. The 7343 chip device was designed to minimize the ESL by keeping the gap between the cathode plate and anode plate, as well as the loop for the current as small as possible. This device was never intended to fit existing pad dimensions for the 7343 chip.



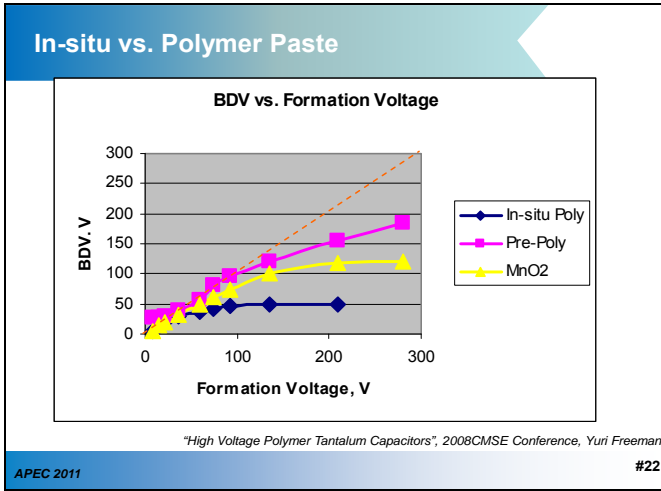
Side-by-side views of the facedown leadframe termination versus the standard leadframe termination.



Here is a plot of the impedance and ESR versus frequency of the facedown versus the standard leadframe. It should be pointed out that the standard (T520) has a maximum ESR of 7 mΩ while the facedown has a maximum ESR of 8 mΩ. This difference does half a slight impact on the minimum impedance and capacitance roll-off, but these differences are insignificant when looking at the impact of the lower ESL. At 1 MHz, the T528's impedance of 6.45 mΩ is less than half of the T520's (13.43 mΩ). Looking at the range where the  $Z < 10 \text{ m}\Omega$ , the T520 runs from 55 kHz to 724 kHz (slightly lower ESR) and the T528 runs from 65 kHz to 2.3 MHz.



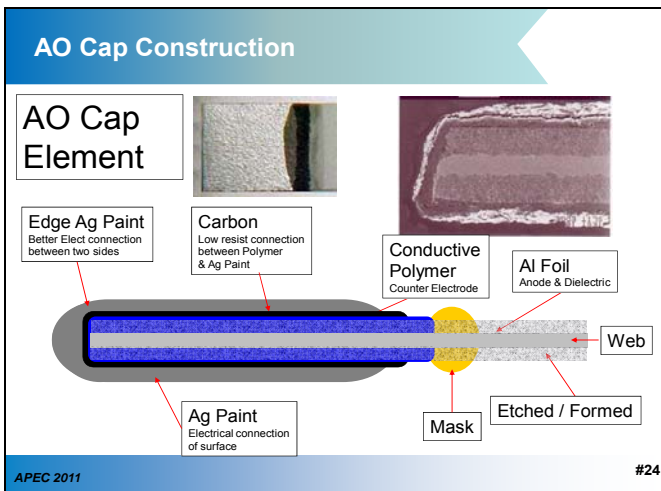
The power capability for these capacitors is dependent on the ESR and the physical structure of the package to conduct heat from the pellet structure. Here there is another large advantage for the facedown package (thermal resistivity of 44°C/W for the T528, and 160°C/W for the T520) as it can stay cooler with more power (current) passing through it. To achieve +20°C temperature rise at 1MHz, the T520 would be restricted to 4.74 ARMS (125 mW), while the T528 will allow 8.73 ARMS (450 mW).



The in-situ application of the polymer created a voltage ceiling or showed an asymptotic behavior limited to 50 Vdc regardless of the formed dielectric thickness. This fell well below the MnO<sub>2</sub> product which became asymptotic at 125 Vdc. Recent advances using a pre-mixed polymer paste shows the ceiling to be above 200 Vdc. Commercial products of 35 Vdc and 50 Vdc are being created, and experiments show creation of 100 V and 125 V ratings are possible.

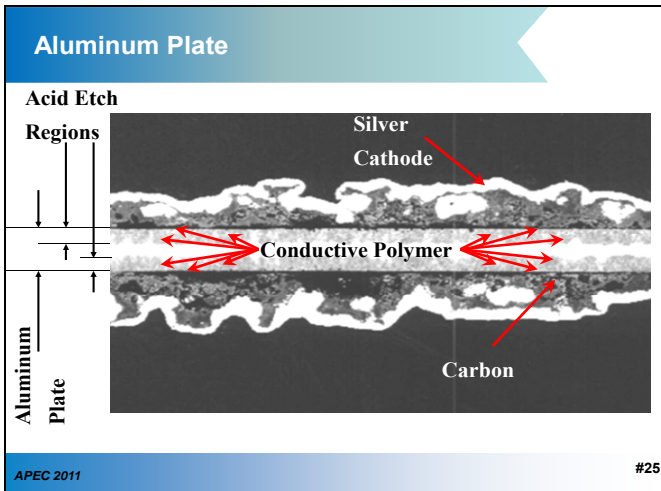


Translation of the conductive polymer cathode technology to aluminum based anode system.



Element – Web and etched / formed on both sides

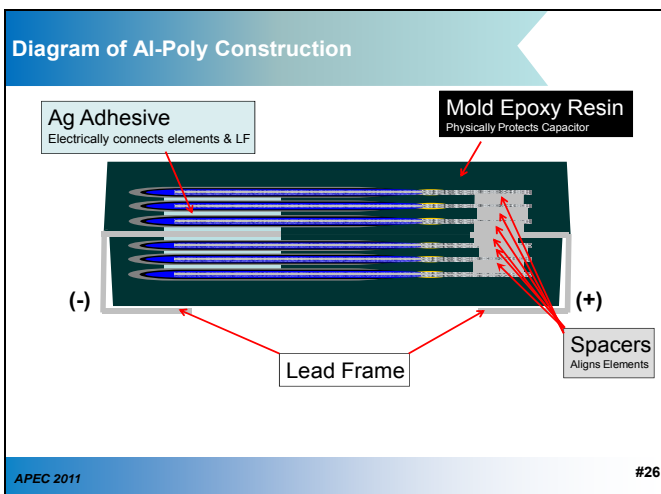
- Masking is applied to control formation and polymerization chemicals.
- Conductive Polymer is grown in etched layers and externally.
- Carbon paste is applied to ensure a robust electrical connection.
- Ag Paint edge dip improve electrical communication between sides.
- Ag Paint provides path for current.



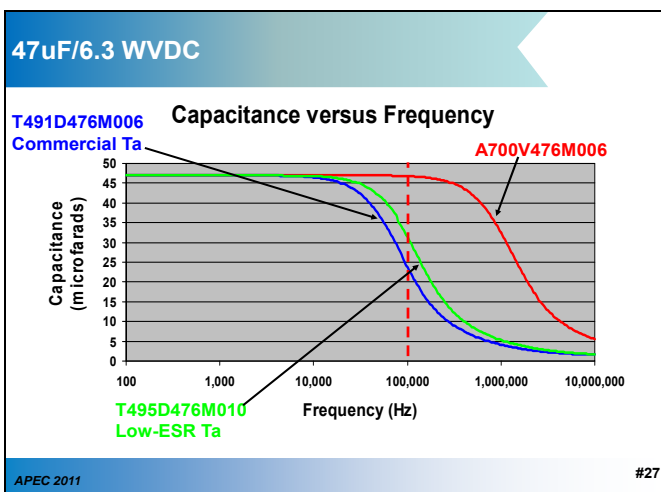
This is a close-up view of one aluminum plate. Acid-etched tunnels appear as a “gray” region from the outside surfaces, leaving the center of the plate as solid aluminum. Gray region includes thin polymer cathode as well as oxide coating of the aluminum.

Carbon overcoat creates thicker, rougher over-coat as well as a mechanical buffer between silver and polymer.

Unlike the tantalum pellet with considerable distance between outer surface and center of pellet, the aluminum structure requires the polymer to carry the charge only for a distance from the surface of the plate to one-third of the thickness of the aluminum plate. Typically, ESRs are lower for similar capacitance and voltage ratings in aluminum polymer than tantalum polymer.



A diagram of the aluminum polymer capacitor shows the stacked plate elements, the silver coating of the polymer, and the anode bond of the plates, all in a molded plastic package.



The capacitance roll-off of this device compared to tantalums is vastly improved over the tantalum MnO<sub>2</sub> systems. There is almost no change in capacitance at 100 kHz.

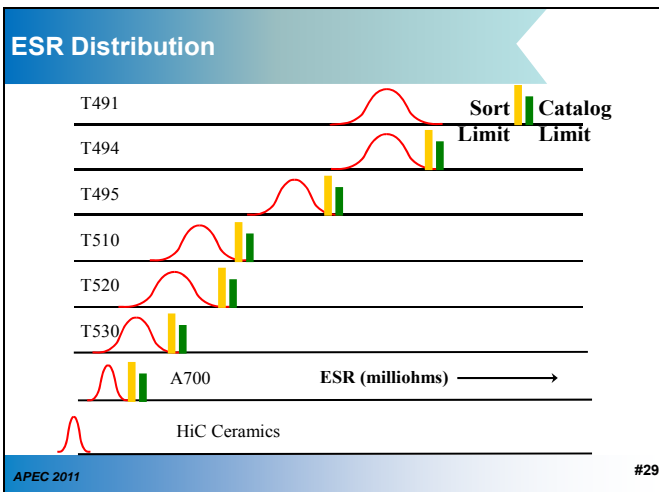
### Median Values

	MnO <sub>2</sub>	Ta-Poly KO V <sub>R</sub> >10	Ta-Poly KO V <sub>R</sub> ≤10	Al-Poly KO V <sub>R</sub> ≤10
100 PPM FR % V <sub>Rated</sub>	68%	126%	197%	235%
@50% V <sub>Rated</sub> FR(PPM)	9	0	0	0
@80% V <sub>Rated</sub> FR(PPM)	458	4	1	0
@90% V <sub>Rated</sub> FR(PPM)	1,700	12	2	0
@100% V <sub>Rated</sub> FR(PPM)	6,310	35	8	0

APEC 2011 #28

Using SSST data to look at power-on capability (defining point for derating) for the new polymer technology compared to previous. The 9 PPM failure rate at 50% of rated voltage for the Ta-MnO<sub>2</sub> is bettered by the 4 PPM failure rate at 80% of rated voltage for the Ta-Polymer device (V<sub>R</sub>>10VDC), or 2 PPM at 90% of rated voltage for the lower voltage (V<sub>R</sub><=10 VDC). Both of these are actually exceeded by the 0 PPM failure rate at 100% of rated voltage for the AO. The recommended derating for the AO is ---- nothing! Use it at rated voltage. Do not de-rate it.

These numbers are reflected in the first row of data defining the percentage of rated voltage where 100 PPM failure rates occur. For the MnO<sub>2</sub>, the 100 PPM FR occurs at 68% of rated (just above 50%), whereas the aluminum polymer's 100 PPM FR occurs at 235% of rated voltage.



Here is a view of the distributions of ESR, related to internal and catalog limits, as well as in reference to product shifts. It is important to note that the T491 and T494 have the same ESR distributions, but different limits. These devices are built exactly the same, and their 'typical' frequency responses are, again, the same. The 495 deviates lower with material and process changes. The T510 employs multiple anodes to decrease ESR. The T520 (single anode pellet) and T530 (multiple pellets) utilize polymer as the first cathode contact. The A700 is the aluminum polymer.

- ### Summary
- Nominal ESR of the tantalum polymer devices is at 4.5 mOhm, with 3 mOhm as next target
  - ESL for SMD tantalum polymer reduced from nearly 2 nH down to 400 pH
  - Higher voltage for tantalum polymer now being developed
  - ESR for aluminum polymer approaching 5 mOhm
  - Derating for tantalum polymer now at 10% for V<sub>r</sub>≤10 Vdc, 20% for V<sub>r</sub>>10 Vdc
  - Derating for aluminum polymer at 0% - no derating
- APEC 2011 #30

In summary, tantalum and aluminum polymer capacitors are now approaching 3 milliohm ESRs similar to ceramics.

ESL reductions are feasible with different terminal configuration.

High voltage barrier with polymer is being broken with 75 and 100-volt devices now possible.

Using the polymer technology with aluminum foil creates solid state, low ESR surface mountable capacitors.

Derating tantalum polymer is reduced to 10% for rated voltages 10 Vdc or lower, and 20% for higher voltages.

Derating aluminum polymers is not required.