2013 Applied Power Electronics Conference
Advances in Capacitors and Ultracapacitors for Power Electronics

The Capacitance Company KEMET CHARGED.

High Voltage Polymer Aluminum and Tantalum Capacitors

Jayson Young

Outline

- Terms
- Why High Voltage Polymer Capacitors?
- Barriers to Higher Voltage Polymer Capacitors
- Break Down Voltage for High Voltage Polymer Tantalum Capacitors
- Reliability of High Voltage Polymer Tantalum Capacitors
- Development of High Voltage Aluminum Polymer Capacitors
- Summary

2 *2013 Applied Power Electronics Conference*

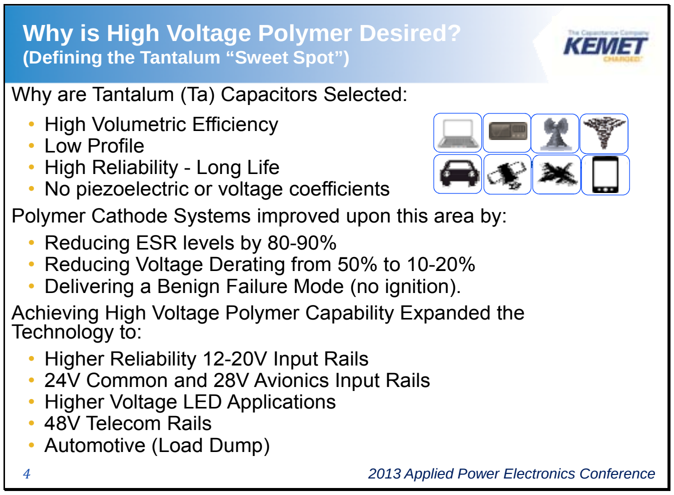
Terms

Terms:
- Voltage Ratings of ≥16V may be referred to as:
  - High Voltage Polymer Capacitors
  - Pre-Polymerized PEDOT (poly ethylenedioxythiophene)
- Voltage Ratings of <16V may be referred to as:
  - Low Voltage Polymer Capacitors
  - In-situ Polymer or Chemical Polymerization Method
    - PEDOT
    - Electrochemical Polymerization (EC Poly)
    - PPy (Polypyrrole)

Note: Some overlap in polymerization methods does exist in the industry today with products in the 16-25V range.

3 *2013 Applied Power Electronics Conference*

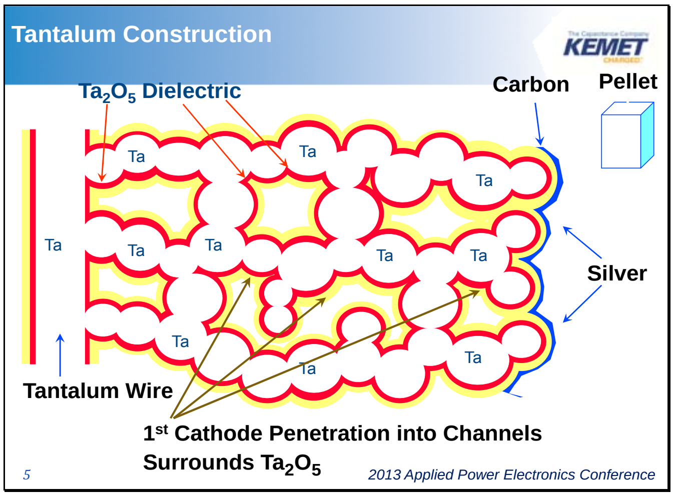
An explanation of common terms used in this presentation.



If you are not addressing with one of these "sweet spots", you are most likely not thinking about Ta capacitors. Due to the higher cost of Ta capacitors, they are not the first capacitor of choice. Areas that routinely find needs for Ta capacitors include portable electronics and other high density circuit designs, medical or military applications requiring high dependability or applications such as automotive, enterprise or telecom infrastructure which require many years of reliable service in the field.

Polymer technology improved upon the sweet spot by adding additional benefits. The significant reduction in ESR resulted in improved ripple handling as well as a reduction in piece count or case size due to higher retained capacitance as higher frequencies. Due to improved robustness during exposure to high temperature board mounting, the recommended voltage derating guidelines were greatly improved. Finally, a side benefit of the technology is a benign failure mode, which allowed for the movement away from safety Ta capacitors with built-in fuses.

As Polymer Tantalum and Aluminum Capacitors became the solution of choice for many applications of 20V and less, designers working with higher voltage applications had limited or no options with the new polymer technology - until today.



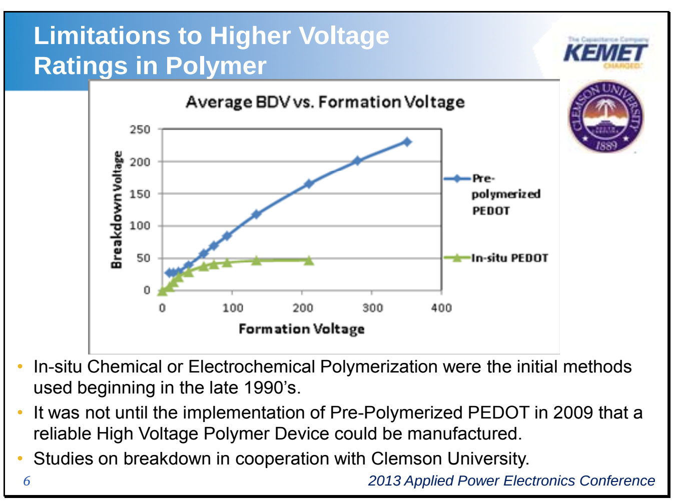
The tantalum pellet structure shown here with thousands of channels of tantalum connected to the riser wire, that comprise the extremely porous pellet structure of the capacitor.

Base metal is tantalum (a valve metal). The pellet is dipped into an electrolyte solution with liquid in contact with every exposed surface of the tantalum particles, and biased to create a dialectic (Ta_2O_5) film formation on these surfaces.

The 1st cathode systems are applied:

- For MnO_2, a dip-and-dry conversion process includes a manganous-nitrate solution near room temperature and a conversion at +270°C, the MnO_2 cathode layer is created over the dielectric..
- For the in-situ polymer, the porous pellet is dipped in a monomer solution, then an oxidizing solution to enable polymerization to take place on the exposed surfaces to dielectric.
- For the polymer slurry, the polymer is prepared in a solution and dipping in the solution and drying leaves a polymer film on the exposed dielectric surfaces.

A coating of silver over the anode pellet structure allows easier electrical connection for the outside world. Direct application of the silver over the 1st cathode would create high interfacial resistance, and carbon (graphite) is coated over the 1st cathode prior to the silver to eliminate this. The silver is solder to a wire or conductive epoxied to a leadframe for cathode connection. The riser wire is welded to a wire or leadframe for anode connection.



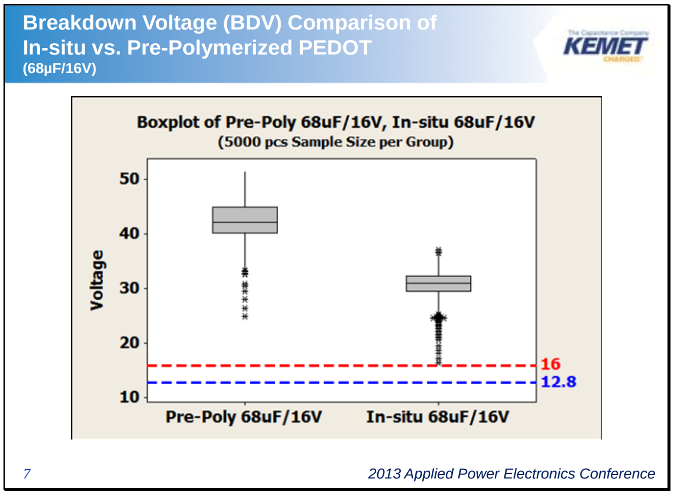
This plot shows a comparison of breakdown voltage vs. formation voltage for capacitors made with pre-polymerized dispersions (polymer slurry) vs. in-situ chemical polymerization.

As formation voltage increases, the breakdown voltage of both the pre-polymerized and in-situ polymer increase. But, at around 48V, the BDV of the in-situ polymer levels off while that of the pre-polymerized dispersion continues to increase.

In fact, the BDV of the pre-polymerized dispersion continues to increase even at formation voltages as high as 350V!

To understand the differences in behavior between these two polymer processes would extend beyond the scope of this presentation so we will just note that the in-situ process does have limitations in achieving higher BDVs.

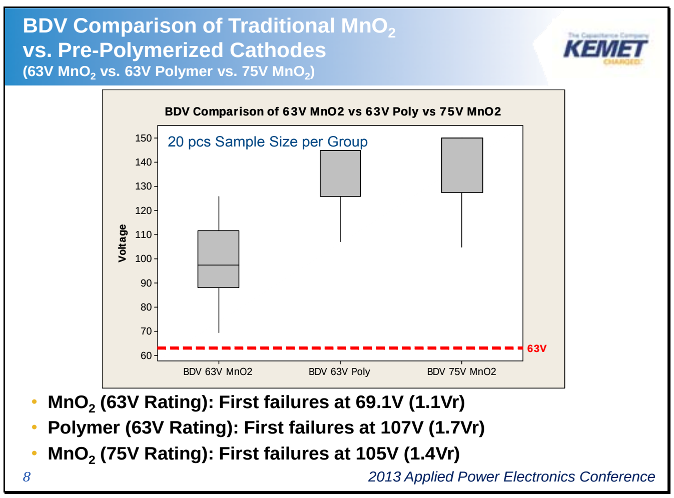
Studies of in-situ breakdown limitations were completed in cooperation with Clemson University.



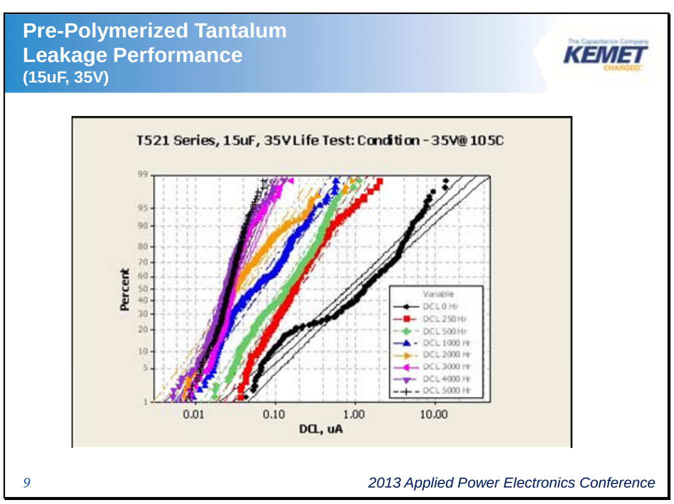
A batch of 68µF/16V tantalum polymer capacitors were processed using the same anode design, dielectric thickness and cathode processes with the exception of polymerization. The batch was split into two groups at polymerization. The two groups included In-situ PEDOT and Pre-polymerized PEDOT processing. Once processing was completed, the two groups were subjected to Breakdown Voltage (BDV) Testing. Overall, both groups demonstrated acceptable BDV values for the bulk of the population. However, the overall BDV values for Pre-Poly were significantly higher. After reaching 35V, 99% of the In-situ product had reached its BDV compared to only 1% of the Pre-Poly having reached its BDV.

Lower voltage BDV outliers (shown as asterisks in the plot) were observed with both batches. In-situ product reached the earliest BDV starting at 16.4V while the Pre-Poly product did not experience the first BDV until 24.9V.

While both groups were robust to BDVs of 16V, the In-situ product would present a higher risk for a failure at the recommended maximum continuous duty voltage of 12.8V.



- Next, we collected 20 pc samples of a 63V MnO_2 design and compared it to a Pre-Poly design with the same dielectric thickness. (first and second box plot)
- In assessing the two, 63V designs, we can observe that the MnO_2 design experiences a lower range of BDV that is just above the rated voltage of the device. We can also observe that the bulk of the population does reach BDV well before the Pre-Poly devices approach BDV. As noted earlier, both of these designs had equal dielectric thicknesses thus indicating the role that the cathode material is playing in BDV performance.
- Due to the limited sample size, we are confident that a complete understanding of the BDV distribution could not be established. However, the limited sample size does demonstrate a clear advance in robustness when using Pre-Poly.
- For further comparison, a 20 pc group of 75V MnO_2 parts was also tested and included in the plot. The BDV ranges of the 75V MnO_2 designs were found to be comparable to the 63V polymer slurry designs. As noted above, a larger sample size would be needed to characterize the full products distribution.
- In order to achieve the same breakdown results for MnO_2 as pre-poly, the voltage rating of the MnO_2 needs to be higher.



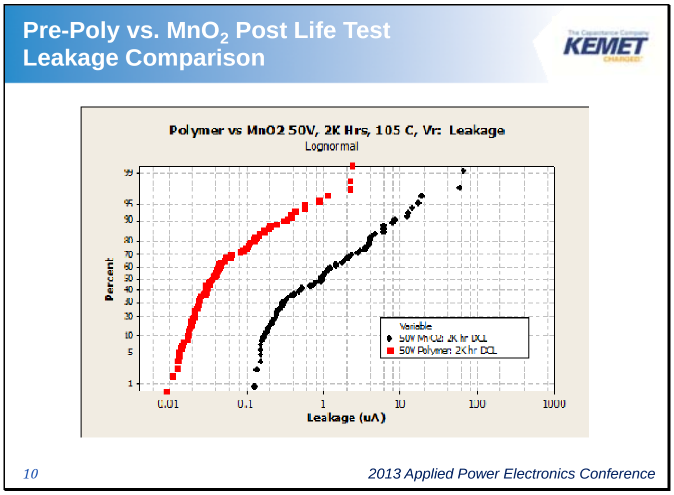
Reliability of the Ta Polymer Capacitor can be determined through its leakage performance over time. Leakage performance relates to the health of the dielectric over time.

In this slide, the overall leakage performance is demonstrated through long term testing of a 35V rated device that was board mounted using two Pb-Free reflow passes and placed on test at rated voltage and 105 C.

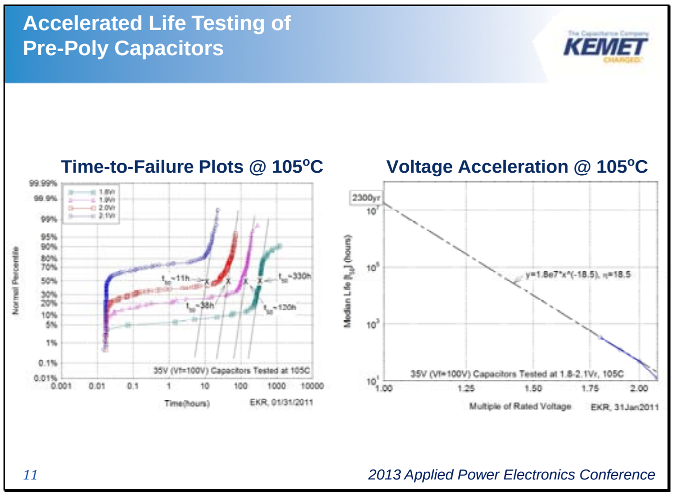
Initial long term testing of the 35V product found that the leakage performance immediately following board mounting delivered much lower than expected leakage.

Following extended testing time at rated temperature and rated voltage, the leakage performance of the devices continued to show reductions in leakage through 3000 hrs.

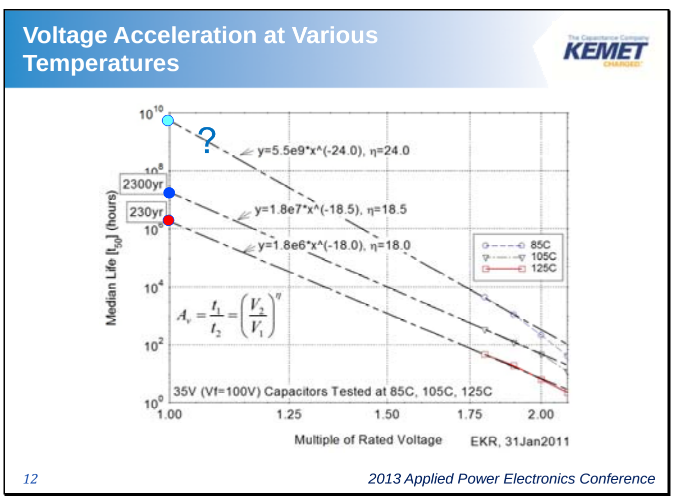
Testing the parts through 5000 hours, a point of component wear-out had not been reached.



- Historically, In-situ and Electrochemical Poly products maintain a higher leakage value than the traditional MnO_2 products.
- However, as we move into higher voltage ratings, we find that the leakage performance of Pre-Poly product is actually better than the MnO_2.
- This plot shows that after 2000 hours of life test for both 50V Pre-Poly product and 50V MnO_2 devices at rated voltage and 105°C, the Pre-Poly parts have much lower leakage than MnO_2 50V parts.

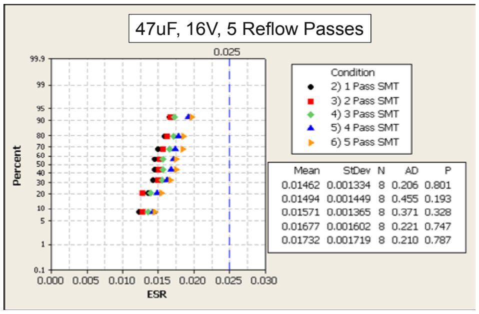


- ✓ An extensive reliability study of a 35V Pre-Poly design was recently conducted to fully characterize the life expectancy of Pre-Poly designs.
- ✓ Typical voltage acceleration conditions for tantalum dielectrics range from 1.32•Vr to 1.5•Vr.
- ✓ To achieve results within a reasonable time (10-1000 hours), testing for Pre-Poly products had to be performed at very high voltages (1.8•Vr, 1.9•Vr, 2.0•Vr & 2.1•Vr).
- ✓ Early failures disappear below ~1.6-1.7•Vr, but it takes a very long time for parts to wear out (>1000 hours).
- ✓ The estimated t_{50} times on the first graph (noted with "X") are plotted on the second graph in blue.
- ✓ Using the t_{50} times, an extrapolation back to 1.0•Vr is made. At Vr, the expected life at 105°C is 2300 yrs.
- ✓ The "Kink" in the curve (second graph) above 2•Vr indicates that test was accelerated too much which resulted in a new failure mechanism.



- In addition to 105°C testing, 85°C and 125°C testing was also conducted using the same 4 accelerated test conditions as reported on the previous slide.
- 125°C data did fit nicely to the above slope, however, the 85°C data shows more of an effect from a second mechanism so we do not trust the extrapolation back for 1.0•Vr.
- The 85°C line probably should be closer to the same slope as 105°C and 125°C at lower voltages. However, it would take a very long test time to prove this.

Applications in Aluminum Chip Caps



- Pros: Projected 50% reduction in ESR.
- Cons: Projected 50-70% of the Capacitance found in Ta.

13 *2013 Applied Power Electronics Conference*

Early development phases are underway for using Pre-Poly with laminated Alum Polymer Capacitors.

The goal is to offer higher voltage solutions in Alum Polymer.

Alum Polymer may not achieve as high of a capacitance offering as Ta, but can deliver reductions in ESR due to the number of Alum foil layers in parallel within the components construction.

Currently, a 16V design is being assessed. While only 47µF of capacitance can be achieved (compared to 100µF offerings in Ta), the ESR is significantly reduced. As shown in the plot, an ESR range of 12-20mOhms was achieved while a similar value Ta capacitor cannot achieve ESR values below 30mOhms.

Summary

- High Voltage Polymer Processing has expanded the reach of this technology into new application.
- The Reliability and Robustness of this new cathode system reflects a level of superior performance that is commonly associated with Ta Dielectrics.
- Expansion of the new technology continues as work is initiated with Alum Polymer Capacitors.
- The full reach of High Voltage Polymer Processing remains to be determined.

14 *2013 Applied Power Electronics Conference*

Summary

- The Pre-Poly materials and processing have expanded the capability well above previous limitations..
- The Reliability and Robustness of this new cathode system reflects a level of superior performance that is commonly associated with Ta capacitors of “Wet” of “MnO_2” cathode systems.
- Expansion of the new technology continues as work is initiated with Alum Polymer Capacitors showing like capabilities.
- The full capability of High Voltage Polymer Processing remains yet to be determined.

Reference Sheet

	In-situ Poly (T520 & T528 Series)	Pre-Poly (T521 Series)	MnO_2 (T49x Series)
Max App Voltage	~12V (16V Rated)	~50V (63V Rated)	~38V (75V Rated)
Capacitance	Best	Best	Good
ESR	down to 3mΩ	down to 12mΩ	down to 10mΩ
Ripple Current	up to 7.5 Arms	up to 7.5 Arms	up to 7.5 Arms
Reliability	Par	Par	Par
Leakage	Good	Best	Better
Safety	Best	Best	Poor
Derating	Best (10%*)	Good (20%)	Poor (50%)
High Temperature	Good (85-105°C)	Better (105-125°C)	Best (125-200°C)

***16V Ratings are Derated 20%**

15 *2013 Applied Power Electronics Conference*

This table has been provided to help clear some of the confusion in selecting the desired technology for a given application.

The stated ESRs must be viewed with an understanding the normally lower ESRs are associated with higher capacitance and lower voltage devices. The pre-poly are only used in higher voltage, and therefore, lower capacitances then the other devices.

Series Names

Series Names:

- In-situ Polymer Ta
  - T520 Series: Polymer Tantalum
  - T525 Series: 125°C Rated Polymer Tantalum
  - T528 Series: Low ESL/Facedown Polymer Tantalum
  - T530 Series: High Capacitance Polymer Tantalum
  - T540/1 Series: DSCC Drawing 4051/2 Polymer Tantalum
- Pre-Polymer Ta
  - T521 Series: High Voltage Polymer Tantalum
- In-situ Polymer Alum
  - A700 Series: Polymer Aluminum
- Pre- Polymer Alum
  - TBD (Contact KEMET)

16 *2013 Applied Power Electronics Conference*

This slide is to assist in linking the desired technology to the appropriate KEMET Series.

Thank You!

Jayson Young
KEMET Electronics
PO Box 5928
Greenville SC 29606
(864) 963 6300
jaysonyoung@kemet.com