Tantalum Polymer Capacitors: Hermetic Packaging Solutions for Space Applications

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Introduction:

In common with commercial applications, demand for established reliability solutions with higher bulk capacitance and lower ESR continues, along with the need for increasing the volumetric efficiency and reducing real estate / payload. Interestingly, voltage trends remain fairly stable within avionics and aerospace as common bus voltages from 5v to 28v remain unchanged; however, there remain a number of higher voltage applications (48v+), while the number of lower voltage applications requiring regulated power in the 1.5v to 3.3v range (as higher speed ASICs and CPUs are introduced) continue to increase.

One technology that has emerged as being a common solution for high bulk capacitance and very low ESR across a wide span of voltage ratings is tantalum conductive polymer. Originally introduced as a purely commercial technology, molded conductive polymer technology has advanced to the point where it can meet the environmental requirements of automotive qualifications (AEC-Q200) and is amenable to high reliability conditioning associated with flight applications, including voltage aging and surge test.

This paper discusses the technology behind, and characterization of, the latest developments in hermetically sealed surface mount low ESR conductive polymer capacitors for aerospace applications, that ensure high long-term parametric stability over a wide working voltage range. Examples are given of their use in a variety of applications, from pulse power to high speed switching circuits in mission critical applications.

1.0 The evolution of Tantalum Conductive Polymer Capacitors

1.1 Solid Tantalum Capacitors – Materials and Construction Recap.

There are many useful references that describe the construction and manufacture of solid tantalum capacitors[1] – the main facts to recap for this discussion are that tantalum, a conductive metal, when subjected to electrolysis grows a very thin layer of tantalum pentoxide, a non-conductive material that has excellent dielectric properties. If the tantalum metal is taken in powdered form, pressed into a pellet, and sintered in a vacuum at high temperature, the individual powder particles fuse together resulting in a continuous porous matrix of extremely high internal surface area.

Taking the standard capacitance equation:

$$C = \frac{\varepsilon A}{d}$$

in which C = capacitance,
ε = dielectric constant,
A = surface area of the capacitor plates, and
d = distance between the capacitor plates.

It can be seen that the tantalum / tantalum pentoxide system, combining high internal surface area, with a thin dielectric with good dielectric constant, has the necessary attributes to form the basis of a very useful capacitor technology, and has been a staple for power supply filtering applications over many decades.

But to make this into a working capacitor, you need terminals. A wire embedded and co-sintered into the body, over which the dielectric is grown for insulation, will provide one terminal contact (this is also referred to as the anode riser wire). For the other contact, a material is needed that can impregnate the entire structure, coating the surface of the interior dielectric to form the opposing plate of the capacitor, and provide an electrical contact on the outside of the pellet.

Traditionally, this material has been manganese dioxide, which is introduced by dipping the dielectric coated pellet into manganese nitrate, and then growing manganese dioxide crystals in place throughout the structure by thermal decomposition of the nitrate, and repeating the process until a thick layer is built up on the outside of the pellet. Subsequent layers of conductive graphite and silver epoxy are applied to the outer surface of the pellet to make the second terminal, the whole system being referenced collectively as the counterelectrode.

Because the dielectric is grown anodically, the wire contacting the internal powder matrix is positive, while the manganese dioxide, graphite and silver system is negative, and collectively referenced as the counter-electrode. For correct operation, the positive terminal (known as the anode) should always be maintained at positive voltage in relation to the counter-electrode.

The combination of materials used, particularly metal anode, amorphous insulating dielectric layer, and solid semiconducting crystal cathode make this a robust technology, very stable over time and temperature.

1.2 The Development of Conductive Polymer Technology.

Over the years, the base technology has been refined, using finer powder particles for higher surface area and development of processes compatible with thinner dielectric formation (which also results in a lower voltage rating, but remaining well matched to ever decreasing digital application voltage requirements) to significantly boost the available capacitance per unit volume, while improvements in the counter electrode materials, combined with pellet geometry, have helped reduce the Equivalent Series Resistance (ESR).

Arguably, after capacitance itself, ESR is the second most important electrical characteristic for high capacitance tantalum capacitor applications. While low capacitance ratings are suited to general decoupling or bypass applications, the higher capacitance devices are ideal for DC power supply filtering, with the ESR of the capacitor being a large factor in the reduction of ripple current in the output. For effective power filtering in the frequency range of 100kHz – 1MHz, some ESR reduction can be achieved by capacitor geometry and the conductivity of materials used in the counter-electrode layer, but ultimately there is a limit set due to the intrinsic resistivity of the manganese dioxide. Over the last 10 – 15 years, a higher conductivity alternative to manganese dioxide has been developed – conductive polymer – that enables lower ESR levels to be achieved. Capacitor elements with a conductive polymer counterelectrode share the same dimensions and external contacts as those with manganese dioxide counterelectrodes, and can be assembled into finished SMD capacitors in the same way (molded body with external lead-frame terminations). As the base for a counterelectrode system, it does change the electrical characteristics of the device in the following ways[2]:

- Conductive Polymer has lower ESR at room temperature, and has lower variance over temperature compared to the manganese dioxide system, which has a negative temperature coefficient (lower ESR at higher temperature, but increasing ESR at low temperatures).
- Conductive polymer has higher intrinsic Direct Current Leakage (DCL) – typical specification limits are 10x that of a manganese dioxide system device.
- Conductive polymer is able to support higher voltage rating designs (currently up to 125v compared to the 50v – 63v ceiling for manganese dioxide devices).

Apart from characteristic electrical parameters, there are additional differences in long-term performance between the two systems. The reliability characteristic for dielectric breakdown is essentially the same in both systems (same dielectric), but the counterelectrode also governs the self-healing of the device during operation. Both have the capacity for self-healing, but in the case of the manganese dioxide system, the oxygen within the counterelectrode which promotes self-healing during steady state operation can impact the failure mode should a random failure occur during a surge event, so the recommended voltage derating in an application is typically given as 50%. This same mechanism does not exist with the conductive polymer system, so less voltage derating is recommended, typically in the 10% to 20% range.

The next distinction arises from the material differences between the two systems – manganese dioxide is a solid inorganic crystal system, which is relatively time-independent, contrasting with conductive polymer, an organic material more susceptible to changes over time and temperature. Conductive polymer material can show increased resistivity if exposed to prolonged, harsh environmental conditions (combined high temperature and high voltage for prolonged periods above specification). This has been reflected in the specifications for conductive polymer SMDs, which often have lower temperature operational limits and less severe environmental test requirements then their manganese dioxide counterparts. It should be noted that, despite almost 20 years since the technology was introduced, while it has been widely adopted with great success in many consumer applications (computer, handheld etc.) and has now been developed to provide much higher voltage ratings than manganese dioxide counterelectrode devices[3] it is only within the last 2 years that new product has been developed within the industry that is able to meet the environmental test requirements of the AEC-Q200 automotive standard (notably biased humidity test - 1000hrs endurance at 85ºC / 85% RH with rated voltage applied).

2.0 The Development of Hermetic Packaging for Conductive Polymer Capacitors.

2.1 Benefits of Hermetic Packaging,

Now we are at the stage where molded SMD conductive polymer technology can provide specific series of automotive grade product compatible with AEC-Q200, this is a good juncture to see how special packaging can be used to harness the full capabilities of the conductive polymer system for more critical applications.

When we consider time-dependent effects within a material system, this can usually be defined in terms of a reaction taking place the rate of which can often be modeled using Arrhenius' methodology. In the case of conductive polymer in molded SMDs, the prime mechanism is due to oxidation – the molded body is not hermetic and the internal capacitor element will be influenced by the surrounding environment. If, instead of molding, the capacitor element is packaged hermetically in an enclosure filled with inert gas, then the prime mechanism will be eliminated.

2.2 Construction of Hermetically Packaged Conductive Polymer Capacitors.

Once the conductive polymer capacitor element is completed (as would be used in a molded SMD) one method of final assembly into a hermetic package is to weld a leadframe to the positive riser wire (anode connection) and, using a silver conductive adhesive, connect a contact to the outside body of the element (cathode connection).

The element is then placed inside a ceramic housing having gold contacts internally for anode and cathode connections; the anode connection being welded in place and the cathode connection glued with conductive adhesive. Depending on the size of the package, a single element can be packaged, or multiple elements connected in parallel resulting in a single high capacitance module.

Next, in a chamber filled with inert gas, a lid that is placed on an upper surface of the ceramic package side walls. The lid is typically made of metal and sealed to the side walls by resistance welding. Following this, a hermeticity test is performed on all manufactured parts.

There are a number of options for hermetic packaging ranging from a CTC21D ceramic package that typically holds two capacitor elements connected in parallel to customized low profile case, holding up to 40 elements (Figure 1 below):

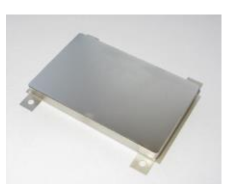
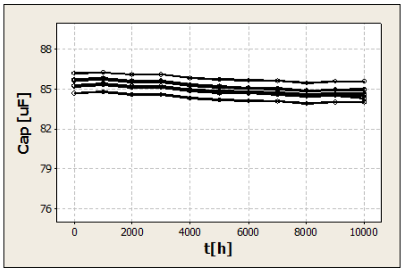
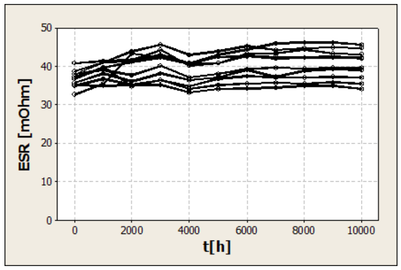


Fig 1: Hermetic Cases for twin & multiple conductive polymer capacitor elements.

2.3 Performance of Hermetically Packaged Conductive Polymer Capacitors.

To characterize the parametric stability of the hermetic package, capacitance and ESR for an 82uF / 100v rated hermetic conductive polymer device were measured over time; the results are plotted in Figures 2 & 3, plotting changes over a 10,000 hr period at 125ºC and rated voltage.





Figs 2 & 3: Capacitance and ESR respectively vs. time at 125ºC / rated Volts for 82uF / 100v rated hermetic conductive polymer capacitor.

Very little change occurred in capacitance and ESR; there being a small decrease in capacitance and just a slight increase in ESR. To put these results in context, the capacitance change required for professional grade SMD tantalum with manganese dioxide counterelectrode (e.g. TRJ series) after a 2,000 hr endurance test at 85ºC and rated voltage is + 10% and ESR must be within 1.25x initial limit. In practice, most product will perform well within these limits, typically less than 5% capacitance change and ESR remaining within initial limit, but these changes are still well above the capability of the hermetically sealed conductive polymer device at a 40ºC higher temperature and 5 times longer test period.

In terms of leakage current, steady state high temperature DCL at rated voltage (35V) measured after completion of 10,000 hours endurance test at rated voltage at 125ºC was lower than 250nA (fig. 4 below):

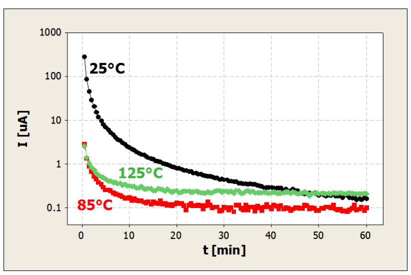


Fig 4: DCL vs. charging time at 25ºC, 85ºC and 125ºC time post 10,000hrs endurance test at 125ºC / rated Volts for 82uF / 100v rated hermetic conductive polymer capacitor.

This is more than 2 decades lower than the initial limit for a standard tantalum (manganese dioxide counterelectrode device) and more than 3 decades lower than the initial limit for a conductive polymer counterelectrode device. Based on these results, we can conclude that this applied combination of technologies leads to an extremely stable, low ESR, low leakage capacitor.

3.0 Conclusion.

Hermetically sealed polymer capacitors have been proven to provide stable performance and reliability during long life testing exceeding 10,000 hours, even at elevated temperature and in high humidity conditions.

The combination of the best available technologies and materials is enabling long-term stability on high voltage tantalum polymer capacitors, exhibiting super-low DCL and low ESR performance – better than has ever been possible before. The key elements of the new technology are: an optimized anode; a hermetically sealed case; and the use of special ageing and screening processes.

Extremely low DCL levels measured at steady state can make possible a new class of polymer capacitors with low DCL specifications. These hermetically sealed tantalum polymer chip capacitors (AVX TCH Series) are ideal for aerospace, avionics, and defense applications, as well as for automotive applications, in which ever-higher reliability and safety specifications are paramount.

References:

1. Basic Tantalum Capacitor Technology, by John Gill, AVX Tantalum Division.
2. Basic Guidelines - Conductive Polymer Capacitors, by S. Zedníček, J.Petržílek & P.Vanšura, AVX Czech Republic s.r.o.
3. Next Generation of High Voltage, Low ESR SMD Tantalum Conductive Polymer Capacitors Exceeds 100V Milestone, by T.Zedníček, M.Bárta, J.Petržílek, M.Uher, I. Horáček, J. Tomáško AVX Czech Republic s.r.o.