Self-Healing Effect of Solid (MnO_2) Tantalum Capacitors

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Performance characteristics of tantalum capacitors depend on materials, design, the manufacturing process, and other factors. Defects in the dielectric that are caused by impurities in the raw tantalum powder and / or process deficiencies can cause high DC leakage and / or short the capacitor. A phenomenon of MnO_2 tantalum capacitors is the self-healing of dielectric defects.

BENEFITS OF SELF-HEALING

- Blocks the defective spot
- Repairs dielectric deficiencies
- Decreases DC leakage

GENERAL MECHANISM OF SELF-HEALING

When DC voltage is applied to the capacitor, the current density flowing through defective spots is high, and the amount of generated heat causes oxygen to be relieved from the solid MnO_2 (semiconducting material) electrolyte.

$$MnO_2 \rightarrow Mn_2O_3 + O$$

Released oxygen compensates for deficient spots in the dielectric film. In addition, by losing oxygen the MnO_2 converts to a lower order oxide (e.g. Mn_2O_3) with resistivity that is several orders higher. This blocks the defective spot, and the current flow decreases to an acceptable level.

When self-healing occurs, DC leakage decreases, without impact to the electrical AC parameters.

This mechanism is effective if the defective spot size is approximately the size of the dielectric thickness. If self-healing was not effective (the defective spot in the dielectric is too big) and the opposite effect takes place, then the capacitor will have high DC leakage, generating excessive heat that will eventually destroy the dielectric rather than repair it, causing the capacitor to short.

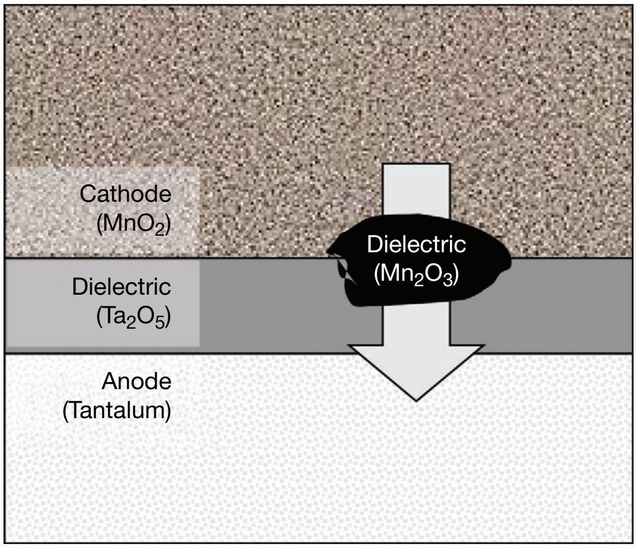

Fig. 1 - Self-healing

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A MORE DETAILED EXPLANATION

When voltage is applied to a tantalum capacitor for the first time, there are two possible scenarios that will occur at defects in the dielectric: self-healing or “killing.” The process that prevails depends on the dielectric defect size, magnitude of applied voltage, current raising rate, and ambient temperature.

If the amount of current flowing through the capacitor is high enough (due to any of the above-mentioned reasons), the dielectric layer - which is tantalum pentoxide (Ta_2O_5) - could be ruptured. The breakdown of a capacitor is characterized by a sudden increase of the leakage current. If this breakdown occurs when operating with a high level of applied voltage and at an elevated temperature, the reaction can accelerate and rapidly spread through the metal / oxide.

The high energy electron penetration through the oxide is known as the avalanche effect. This can result in various degrees of destruction, from rather small, burned areas on the oxide to zigzag burned streaks covering large areas of the pellet or complete oxidation of the metal. Adequate circuit protection and component mounting process monitoring are key to reducing or eliminating the potential for this effect.

In contrast to the avalanche effect, if the oxide defect is not too large, a healing effect prevails. In this case, the current passing through the defect generates a localized high temperature spot and the MnO_2 releases oxygen and is thermally reduced to a lower oxide of manganese, namely Mn_2O_3, Mn_3O_4, or MnO.

Released oxygen helps to repair dielectric deficiencies:

$$Ta_2O_{5\text{-}x} + O \rightarrow T_2O_5$$

The level of heat attained determines the oxide form that results. All these lower oxides have resistances that are magnitudes of order higher than that of MnO_2. The high resistance manganese oxide material then electrically isolates the dielectric defect.

Higher reliability tantalum capacitors for medical, avionics, military, and space markets have more robust designs and additional screening.