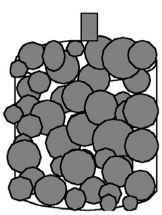
DC LEAKAGE FAILURE MODE

Abstract

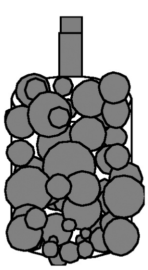
This paper is submitted as an educational medium for use by anyone who has interest in solid tantalum chip capacitor performance. It represents technical phenomena that are generic to all solid tantalum chip capacitors. The intent is to provide a greater depth of understanding amongst users, purchasers and manufacturers of these capacitors. This paper provides a general description of tantalum capacitor construction; a discussion of DC leakage failure mechanisms, and some process controls relating to these failure mechanisms.

Tantalum capacitors are classified as electrolytic capacitors and as such they are composed of four parts: anode, dielectric, electrolyte (solid or liquid), and cathode.



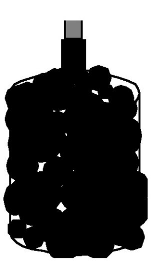
Anode = Tantalum powder pressed into a pellet

In the pellet type of tantalum capacitor, the anode is a porous tantalum pellet made from pressed, high purity tantalum powder. This pellet is sintered under high vacuum at a very high temperature, typically in the 1300 °C to 2000 °C range. This structure yields a pellet with a large surface area relative to its volume because of its high degree of porosity.



Dielectric formed on the surface

The dielectric is a film of tantalum pentoxide, Ta205, formed on the overall surface of the tantalum particles by means of an electrochemical oxidation. This film is very thin, ranging from a few hundred angstroms to a few thousand. The thickness is controlled by the voltage applied during the electrochemical oxidation and is defined so as to allow the capacitor to withstand the rated voltage applied to the finished capacitor, with a large security factor. The oxide grown is amorphous, not crystalline. This property is very important since the amorphous oxide has the very high electrical resistance needed to perform as a dielectric. Crystallized tantalum oxide on the other hand is a conductor, and does not offer the properties needed for a dielectric.



Electrolyte - MnO2 formed in situ

The electrolyte in the solid tantalum capacitor is provided by a solid state oxide semiconductor, manganese dioxide (MnO_2). The manganese dioxide is formed in situ by the thermal decomposition of a manganese salt. The oxidized pellet is impregnated with a solution of this salt and then heated to convert the salt to the solid manganese dioxide. This impregnation-heating step is repeated several times in order to coat the porous pellet with the solid semiconducting MnO_2.

Cathode = carbon and metallic conducting coating

For contact purposes, a layer of carbon from a graphite dispersion is placed on the MnO_2 layer and onto this is applied a metallic conductive coating. For simplicity's sake, it will be assumed that these layers constitute the cathode side where the external connection can be attached.

DC leakage current is present in all tantalum capacitors. This leakage level is low and stable and should not compromise circuit performance. In timing circuits, the charging current should be at least 10 times the DC leakage current of the capacitor. For example, a 5 V volt timing circuit with a 100 KΩ series resistor and a 47 µF capacitor requires a capacitor with a maximum 5 µA leakage current over the operating temperature range.

Breakdown of a capacitor is characterized by a sudden increase of the leakage current. The dielectric, tantalum oxide, is ruptured. The mechanism of breakdown is rather well-known (1 and 2). The oxide dielectric which was originally amorphous, has now become crystalline in certain areas, the size and number of which will vary. These crystallized spots of tantalum oxide emerge within the amorphous oxide layer causing a fracture to occur in the oxide surface through which electric current can flow. The capacitor is no longer efficient as a current barrier. Recognition of this inherent property for any solid tantalum capacitor is vital in the design of the circuits using these devices. If this breakdown occurs in an operation with high levels of applied voltage and elevated temperature, the reaction can accelerate and rapidly spread through the metal/oxide. The high energy electron penetration through the oxide is described as the "avalanche effect" (1). 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 of key importance to reduce or eliminate the potential for this effect.

Contrary to this, if the oxide defect is not too large, a "healing effect" can occur (3). In this case,the current passing through the defect generates a localized high temperature such that the MnO_2 is thermally reduced to a lower oxide of manganese. The reduction series that can occur is:

MnO_2----------MnO_2O_3----------MnO_3O_4----------MnO

The level of heat attained determines the oxide form that results. The initial reduction occurs at about 530 °C and the final step at about 1000 °C. All of these lower oxides are less conductive than the MnO_2 (much higher resistance) by orders of magnitude. The high resistance oxide then electrically isolates the defect.

Obviously, leakage current failure is manifested by a leakage current increase. The degree of damage, as mentioned, can vary from a catastrophically destroyed unit to microscopically small sites. In general, the degree of failure is dependent on the degree of protection offered by user circuit design and process controls during both the manufacture of the capacitors and during their attachment to the circuit board. Those failures which have generated a lot of heat are readily observable by the user, the others are not. In order to understand the origin of such a defect and implement the right corrective action in the process to improve the design of the capacitor, failure analysis of defective units is conducted, where possible.

This analysis consists of disassembling the package and then systematically stripping the different layers by appropriate methods. A microscopic examination (if needed) of the tantalum oxide may reveal the spots that are the breakdown sites, depending on the size and the location of the defect on the tantalum pellet. These sites can also be revealed by electrochemical plating with copper using a copper salt solution, in which the copper plates selectively onto the defects. It is not always possible to pinpoint the breakdown sites, and while this is not the best situation in terms of formal failure analysis, it is unfortunately a fact that must be acknowledged.

Origin of Breakdown

There are several possible origins of breakdown which are mainly:
Mechanical dielectric defect.
Impurities included in the dielectric.
Oxide crystal spots already included in the dielectric.
Mechanical defects can be of at least two types. The simplest type is caused by damage occurring to the oxide after it has been completely grown on the metal surface. This can happen by striking the oxidized pellet on a hard surface, thereby physically breaking the oxide. Obviously this would occur on the external pellet surface. Damage to the oxide can also occur during deposition of the MnO_2 coating. During this operation the capacitor is heated to high temperatures, typically 300 °C to 400 °C, several times to convert the manganese salt solution to the MnO_2. The decomposition reaction is rather violent, generating steam and gases and depositing the hard MnO_2 thickness builds within the very small pores of the pellet creating pressure on the oxide. The combination of the thermal shock and thermal-chemical reaction damages the tantalum oxide layer.
Defects associated with impurities can arise from segregated impurities present in the tantalum at the surface of the metal. Such impurities could be carbon or various metals, e.g., iron or calcium. Under normal conditions the thickness of the tantalum oxide is uniform; however, if the surface of the tantalum contains a metal segregate, the oxide growth at this site will be restricted. Oxide from surrounding pure metal tends to partially grow over the site but a defect in the oxide remains. (4.5)

Defective oxide can also result from impurities present in the electrolyte, either from the chemicals used, or the water. As a result, special attention is paid to the purity of these materials. (6,7,8)

The third cause of breakdown sites is the presence of crystallized oxide included in the oxide layer (9). This can occur through the use of improper electrolyte material, improper concentrations of electrolyte, or inadequate temperature control. Oxide crystallites can also be present on the metal due to excess oxygen concentration of the tantalum powder (10). It is known that it is important to control the oxygen concentration of the powder since oxygen levels that exceed certain concentration will generally precipitate as pyramid-shaped nodules on the surface of the metal. These cause defects in the oxide similar to the effect described due to metal impurities. For this reason, tantalum powder manufacturers expend a lot of effort and expense to control the oxygen levels in the powder, before the the powder is shipped to the capacitor manufacturer

To further control the condition of the tantalum metal, the sintering process - which is done at high temperature and high vacuum - must be carefully controlled, and assurances made that the conditions chosen match powder type used. In addition to the sintering process, Vishay has a unique process to control oxygen levels in the pellet even further.

Process Controls

Related to the nature of these potential defects and their origin, several controls are implemented along the process.

First, the material itself is checked at incoming inspection. The tantalum powder must be a high purity material. A complete chemical analysis of impurities is performed for each powder lot, and capacitors are made to confirm this analysis by electrical measurements.

Another control point is the sintering vacuum. In order to maintain the high vacuum required, sintering furnaces are carefully controlled and periodically cleaned.

Pressing and sintering operations are checked by controlling tantalum pellets formed under the appropriate conditions as capacitors. The electrical and physical characteristics of these capacitors are measured by Statistical Process Control (SPC).

The electrochemical oxidation of the tantalum pellet that builds the oxide layer is also carefully controlled prior to running the operation, and afterwards through the monitoring of the electrolyte resistivity, temperature, and electrical parameters.

When all the layers are built up (tantalum oxide, manganese dioxide, carbon and silver paint) capacitors are again measured and these measurements are analyzed to detect trends by SPC methods.

The capacitors are submitted to stress during an opening called ageing. The operation is performed to eliminate failures, which correspond to infant mortality, and to heal minor defect.

After this operation, the leakage is reduced on most of the parts and/or definitely increased to high values. These last units with high leakage are sorted from production during redundant testing operations.

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