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The Effects of Different Temperatures and Temperature Cycling On Breakdown Voltages of Tantalum Capacitors

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Abstract : This study focuses on the effects of different temperatures and temperature cycling on breakdown voltages of tantalum capacitors. High and low temperature tests and temperature cycling tests were done. In all tests the used temperatures were inside component's operating temperature limits. After the tests, capacitors were tested for their breakdown voltage. According to results of this research, high or low temperature testing inside component's operating temperature limits does not have an effect on the breakdown voltage of tantalum capacitors. However, temperature cycling inside component's operating temperature limits can lower the breakdown voltage of tantalum capacitors.

Keywords: accelerated testing, reliability, tantalum capacitors, temperature, temperature cycling

I. INTRODUCTION

In today's competitive market, it is important for a company to know the reliability of its products and to be able to control it for continued production at optimum reliability. Sometimes there is a need to examine the performance of a specific electronic component: it may be radically redesigned, or there may be an individual reliability specification for that component. That is why reliability testing of components has become a concern for electronics manufacturers. Also, in many cases, component-level reliability testing is undertaken to begin characterizing a product's reliability when full system-level test units are unavailable.

Electronic components are often stored and used at high or low temperatures, and sometimes temperature can change radically during component's lifetime. Temperature and temperature changes can have various, often unpredictable effects on components. Reliability tests seek to simulate the component's use environment in order to find the effects of environmental stresses. Because such testing is very time-consuming, accelerated testing becomes necessary. Accelerated testing is a procedure in which conditions are intensified to cut down the time required to obtain a weakening effect similar to one encountered in normal service conditions [1].

High Temperature Storage Life (HTSL), JESD22-A103C, and Low Temperature Storage Life (LTSL), JESD22-A119, tests "are applicable for evaluation, screening, monitoring, and/or qualification of all solid state devices and typically used to determine the effect of time and temperature, under storage conditions, for thermally activated failure mechanisms of solid state electronic devices [2, 3]." The standard HTSL test is run for 1000 hours (42 days) and the standard LTSL test for 168 hours (7 days) [2, 3]. During the tests, increased/reduced temperatures (test conditions) are used without electrical stress.

Temperature cycling, according to the standard JESD22-A104D, "is conducted to determine the ability of components and solder interconnects to withstand mechanical stresses induced by alternating high- and low-temperature extremes. Permanent changes in electrical and/or physical characteristics can result from these mechanical stresses [4]." This standard test includes numerous temperature cycling conditions. The test usually lasts 500 or 1000 cycles.

These standard accelerated tests are commonly used for testing reliability of electronics and were used in this research. The object of this research was to test the effects of low temperature, high temperature, and the effects of temperature cycling on tantalum capacitors.

II. TANTALUM CAPACITORS

Surface mount solid tantalum capacitors (henceforth referred to as "tantalum capacitors", shown in Fig. 1) of a maximum voltage of 50V, a capacitance of 10µF, and an operating and non-operating temperature of -55˚C to 125˚C were used in this research. The structure of these capacitors is presented more detailed in Fig 2.

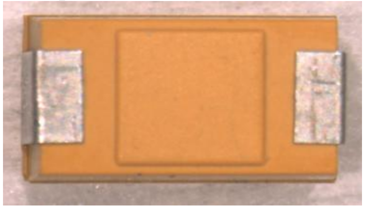

Figure 1. Bottom side of a surface mount tantalum capacitor used in this research.

A. Structure of tantalum capacitors

A tantalum capacitor (structure shown in Fig. 2) consists of three main elements: anode, cathode, and a dielectric layer of tantalum pentoxide that separates them. The capacitor contains an embedded tantalum pellet (anode), surrounded by a tantalum pentoxide, amorphous dielectric layer. The cathode is a semiconductor, manganese dioxide. This pellet is coated with carbon and then with silver to provide the final connecting layer to the cathode terminal. The tantalum wire passes through these layers and connects the positive termination to the tantalum pellet. The negative termination of the capacitor is attached with a silver adhesive to the silver paint layer. Next sections focus on possible failure mechanisms caused by temperature and changes in it.

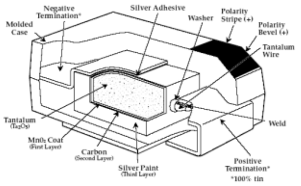

Figure 2. Structure of a tantalum capacitor [5].

B. Effects of temperature and temperature cycling on tantalum capacitors

Temperature, whether generated externally or internally, degrades the performance and reliability of tantalum capacitors. The use of tantalum capacitors at high temperatures has been studied, and manufacturing tantalum capacitors for high-temperature applications is found to be challenging [6, 7]. Mechanical stresses related to the temperature changes during reflow-manufacturing and use of surface mount tantalum capacitors at high temperatures affect their performance and reliability and can account for their breakdowns. Due to mismatch of the coefficients of thermal expansion between the constituent materials, significant mechanical stresses develop in the bulk of materials and at the interfaces. During heating, shear forces are exerted on the anode wire. The molded case pushes on the lead frame in one direction and the pellet in another, generating forces that pull the wire away from the anode structure. Once the device has passed though high temperatures and its elements are shrinking while cooling, they may not fit together as they did before the expansion. Compressive forces may appear on the pellet structure and produce fractures. In addition, these stresses may cause cracking in the tantalum pentoxide dielectric and/or delaminations at the interfaces, resulting in different failure modes of the components. A crack in the dielectric at a corner or edge, when exposed to high stress, may lead to failure [9-11]. The cracking increases leakage current, decreases breakdown voltage, and may cause short-circuits. On the other hand, delaminations can raise the effective series resistance and thus increase power dissipation and temperature of the capacitor, which can decrease its reliability. Severe delaminations may result in intermittent contacts and open-circuit failures of the components [11].

Temperature has also a specific effect inside a tantalum capacitor, known as crystal growth [12-14]. The tantalum pentoxide dielectric is considered an amorphous material. An amorphous state tends to order and crystallize to reduce its internal energy. Surface impurities can induce direct growth of tantalum pentoxide crystals and any imperfection in the dielectric structure is a potential site for crystals to grow. Once the dielectric crystallizes, conductivity and leakage current increase. The presence of impurities is not the only mechanism that may lead to a growth of crystals; Crystal growth can also be initiated in small areas of crystalline order in the dielectric. The conductivity of the crystallized structure has been reported to be higher than that of a dielectric in an amorphous state [14]. However, the latest findings suggest that the crystals themselves are good insulators with very limited conductivity [12, 13]. The exact conductivity mechanism related to the crystal phase is not yet fully understood. The increase in leakage current may still be caused by other mechanisms accelerated by the crystal growth. However, studies show that field crystallization may have only a limited impact on the end use of tantalum capacitors [12].

The temperature cycling of tantalum capacitors has been studied before [11, 15] with capacitors subjected to temperature cycling in a range from -40°C to 85°C [15], -65°C to 125°C, and -65°C to 150°C [11]. Results indicate that tantalum capacitors are capable of withstanding up to 500 cycles of temperature ranging from -65°C to 150°C. However, different lots show different robustness under cycling conditions, and though parts may not fail formally by exceeding specified limits, a significant degradation in the leakage current and breakdown voltages indicates an increased propensity of some lots to failure after temperature cycling. Cracking in the tantalum pentoxide dielectric, which develops during temperature cycling, results not only in increased leakage current, but also increases the probability of scintillation breakdowns [11]. The results suggested that a harmful temperature cycling effect can be achieved in a much shorter time than in 500 cycles [15].

III. RELIABILITY TESTING

Testing was divided into five tests, hereafter called Tests A, B, C, D, and E. Test A was a low temperature test in -40°C temperature and lasted for 168h. Tests B and C were high temperature tests, Test B was done in 85°C and Test C was done in 125°C. Both tests lasted for 1000h. Tests D and E were temperature cycling tests. Both tests lasted for 500 cycles and one cycle lasted for 0.5h. In test D, the temperature changed between -40°C and 85°C and in Test E, temperature changed between -40°C and 125°C. In all tests, 18 capacitors were tested. Because the capacitors were rated for an operating and non-operating temperature of -55˚C to 125˚C, they were tested here within their operating limits. This was done in order to get information on their usability in such field conditions and to compare the effects of different temperatures and temperature cycling. All tests and their conditions can be seen in Table 1.

Table 1. All tests and their test conditions.

Test	**A**	**B**	**C**	**D**	**E**
Stresses	-40°C	85°C	125°C	-40°C 85°C	-40°C 125°C
Time	168h	1000h	1000h	500 * 0,5h	500* 0,5h

After all temperature tests, capacitors were tested for their breakdown voltage. The capacitors were tested for voltage that was slowly increased (rate of voltage increase: 1V per second) from 0V to 93V provided no failure occurred. The voltage range was chosen because of equipment limitations. The accuracy of measurement was 1V

IV. RESULTS AND DISCUSSION

Table 2 shows breakdown voltages for capacitors without testing and in Tests A-E. Accordingly, capacitors not submitted to any kind of temperature testing did not fail at voltages below 93V. This means that the capacitors can be expected to withstand voltages of over 93V.

Table 2. Failure voltages for capacitors without testing and in Tests A-E.

No Test	Test A	Test B	Test C	Test D	Test E
>93	>93	>93	86	50	57
>93	>93	>93	>93	79	63
>93	>93	>93	>93	81	72
>93	>93	>93	>93	84	72
>93	>93	>93	>93	91	89
>93	>93	>93	>93	>93	>93

>93	>93	>93	>93	>93	>93
>93	>93	>93	>93	>93	>93
>93	>93	>93	>93	>93	>93
>93	>93	>93	>93	>93	>93
>93	>93	>93	>93	>93	>93
>93	>93	>93	>93	>93	>93
>93	>93	>93	>93	>93	>93
>93	>93	>93	>93	>93	>93
>93	>93	>93	>93	>93	>93
>93	>93	>93	>93	>93	>93
>93	>93	>93	>93	>93	>93
>93	>93	>93	>93	>93	>93

There were no failures in Tests A and B and there was only one failure in Test C. This means that such low temperature and high temperature did not have a significant effect on breakdown voltage of these capacitors and such conditions should be no problem. Tests with higher temperatures (e.g. 150˚C) and lower temperatures (e.g. -55˚C) could be tried.

There were 5 failures after both tests D and E. This means that temperature cycling inside operating temperature limits has an effect on breakdown voltage of these tantalum capacitors. This should be taken into account is these capacitors need to be stored or used in such conditions. However, none of the failures in any tests occurred at voltages under 50V, which is capacitor´s maximum operating voltage. In addition, there are a lot of non-failed components, so there is a lot of uncertainty that should be taken into account. Tests with larger amount of components should be done. Also, a test with more radical temperature cycling (e.g. -55˚C / +150˚C) could be tried.

Failed components were further examined. They were cross-sectioned and analyzed for failure by optical microscopy (shown in Fig. 3). Cross-sectioning of all the failed tantalum capacitors showed redness in corners where overheating had burned the capacitors’ internal materials and molding.

Faults may occur in the oxide from stress imposed by changes in temperature. The oxide may have cracked with a slight shear. In addition, even if the pellet has not fractured, it may have sustained enough compressive pressure for a fault site in the dielectric to grow or extend further into the dielectric and develop into a breakdown at these lower voltages. Field crystallization is one possible failure mechanism but it may have only a limited impact in the temperature cycling test and its effects on breakdown voltages.

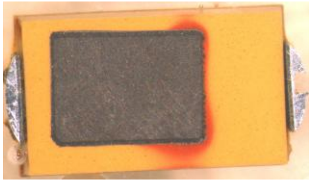

Figure 3. An example of a cross-section of a failed capacitor.

V. CONCLUSION

A tantalum capacitor can be used in various different temperatures. Also radical temperature changes occur commonly in the field. In this paper, the effects of high and low temperature, and the effects of temperature changes on breakdown voltage of tantalum capacitors were tested. Low temperature and high temperature tests inside component´s operating temperature limits were not found to have an effect on breakdown voltages of these capacitors. However, a temperature cycling test inside component´s operating temperature limits affects tantalum capacitors in that it weakens their characteristics and lowers their breakdown voltages. More testing work needs be done in order to collect statistical data for conclusions. Such results would be useful in addition to these results, where conclusions are mostly done based on literature review.

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