

# **Shorting Failure In High Voltage Ceramic Capacitor With Floating Internal Electrode Structure**

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## **Abstract**

Based on the open failure mode consideration and the non-linear relationship of dielectric thickness and voltage<sup>[1]</sup>, high voltage multi-layer ceramic capacitors (>500V) are often using the floating internal electrode structure. MLCC with such floating electrode configuration is regarded as reliable, because it equivalent to two or more capacitors in series, which can effectively avoid the shorting failure mode of the board-flexure-related cracking. This paper describes a shorting failure of the high voltage ceramic capacitor with floating electrode. Through the analysis we believe that the failure is related with the high voltage screen test which induces an electrical crack horizontal propagating from one electrode to the spaced electrode.

## **Introduction**

We have received the failure feedback of filtered connectors in succession. A filtered connector is the combination of filter elements in a connector. Here three high voltage MLCC (10nF/1kV, X7R, 1206) are mounted inside the connector between each of the contacts and the connector ground shell. These connectors have been launched into market for about one year. By analyzing the returned parts, it can be judged that these connectors are seriously damaged due to the shorting failure of the capacitors. It is difficult to find out the root cause as the capacitors have been burned seriously.

The failures were not batch related. In addition, it is proved that the failures are not related with the quality and design of the capacitor by comparing with another vendor's capacitor (with size of 1210) through DPA and reliability assessment. Owing to the floating internal electrodes structure, it is unlikely that the shorting failures of the capacitor are caused by thermal and mechanical stress.

We reviewed the internal manufacturing process and design of the filtered connector, and found that the dielectric withstand voltage (DWV) of the filtered connector (1.5kV) is higher than DWV of the capacitor (1.2kV) mounted. And the creep distance of the capacitor were reduced because of the internal design of connector, thus the breakdown voltage of capacitor was decreased. Moreover, we conducted the 1.5kV DWV test for individual capacitor and the capacitor mounted in connector. And then we had the life test of capacitor and humidity loading life test for connector. The experiments show that the capacitors experienced 1.5kVdc DWV test have failures during the test.

However, in the process of DWV test of connector, the only influence factor on failure of capacitor is that the internal design of connector decreases the breakdown voltage (arc-over). Based on simulation test and the literature discussions, we think that the single arc-over

thermal stress almost cannot result in short failure unless the capacitor has subtle defect like microdelamination. While in case of such 1kV rated voltage, the 1.5kV high voltage stress also cannot result in the short of capacitor directly. So is the short of capacitor resulted in by thermal stress during arc-over or 1.5kV high voltage stress, or by microdelamination? It is difficult to confirm the accurate and critical factor if no returned failure parts which have not been damaged seriously can be analyzed.

### **Failure Analysis**

Before going to the detail analysis, we first look at the list of potential cause and failure mechanism as the following:<sup>[8]</sup>

- ◆ Visible Intrinsic Defects
  - Knit Lines / Delamination
  - Firing Cracks
  - Voiding
- ◆ Thermal Stress
  - Thermal shock
- ◆ Mechanical Stress
  - Placement/handling cracking
  - Flex cracking
- ◆ Chemical
  - Dendritic growth
- ◆ Electrical Stress
  - Dielectric breakdown
  - Electro-thermal breakdown
  - Resonance or Electro-mechanical breakdown

It is obvious that to make a MLCC with floating internal electrode structure short should have a shorting path which crosses the floating electrode.

#### Visible Intrinsic Defects

Some intrinsic defects in MLCC, such as knit lines /delamination and voiding, can develop to a crack that run parallel to the electrodes, thus forming a conducting path which crosses the floating electrode.<sup>[8]</sup> Although the failures were not batch related, we have doubt about the quality of the capacitor selected by connector vendor. Will it have some minor intrinsic defects which are not detected? We compared the basic electrical performance and internal structure of the capacitor with another vendor's capacitor (with same specification but the size is 1210). Both samples of these two manufactures are in normal properties of appearance, size, capacitance, dissipation factor, IR and withstand voltage. The average breakdown voltage is 4kV.

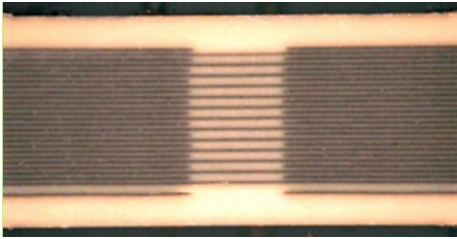


Figure 1. The internal structure of capacitor from Vendor A

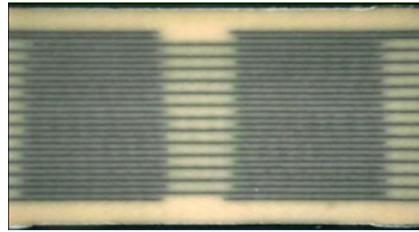


Figure 2 The internal structure of capacitor from Vendor B

From the DPA, these capacitors are floating internal electrode construction, and the thickness of dielectric layer is 30um for A and 40um for B (as in Figure 1&2). It may be seen that the dielectric layer of vendor A is thinner than vendor B due to the difference of size. Figure 3&4 show the fracture surface of the capacitor by SEM. No obvious defect found according to the DPA standard EIA/E CA-469-D.

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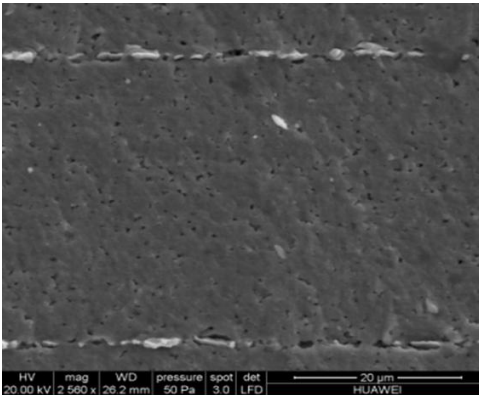


Figure 3 Vendor A MLCC SEM Fracture surface 2560×

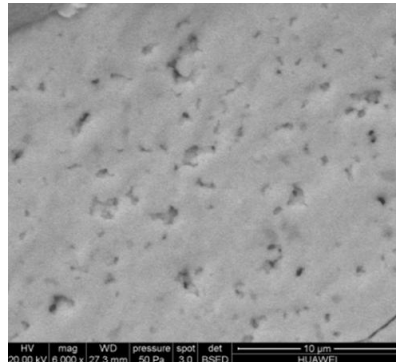


Figure 4 Vendor B MLCC SEM Fracture surface 6000×

### Thermal Stress Factor

As the capacitors are mounted inside the connector by spring clip, it is a mechanical contact, no soldering process involved, and the defect induced by thermal shock is usually 45-degree microcrack emanating from the termination of the end cap, thus the thermal shock can be neglected.

In addition, Reference [8] also pointed out another case of thermal shock which can induce a horizontal crack. That is when invisible intrinsic defects, such as microdelaminations, are present along the electrode/dielectric interface; the location of the thermal shock crack would shift away from the termination to the defect sites.

### Chemical /Mechanical Stress Factor

From the analysis of the good capacitor in the returned connector, no dendritic growth was found on the surface of the capacitor. Thus chemical factor can be excluded.

Generally, the high voltage capacitor with floating electrode structure has little possibility of short failure, because the floating structure may effectively avoid 45 degree crack or vertical electrode crack. The function of this structure is equal to two capacitors in series. Even though one capacitor is short because of the crack, the other capacitor still works, so the final short failure may be avoided. Therefore, the structure has high reliability.

Even so, in order to remove the mechanical stress factor, we also tested the internal spring stress of connector in extreme state, and reviewed the assembling process of connector. We did not find that any stress which exceeds the allowed was applied on the capacitor. In order to prove that the floating electrode structure may avoid short failure, we manually applied destructive stress on capacitor in different directions to verify the failure modes of capacitor, all these failures are open mode.

### Electrical Stress Factor

As the other factors have been eliminated from the analysis above, we put the focus on the electrical stress. There are three types of electrical breakdown mechanism in MLCC which are: dielectric breakdown by high field strengths, electro-thermal breakdown by high local temperatures and electro-mechanical breakdown by inverse piezoelectric effect. And high local temperatures can be caused by air discharges (corona) or power dissipation of AC load [2].

We have readily excluded the possibility of electro-mechanical breakdown and thermal breakdown by power dissipation as these connectors are used mainly in the low voltage dc application (+/-5V,-48V). We notice that the 1.5kVdc DWV testing condition executed by the connector vendor is different from the DWV stated in the datasheet of capacitor. In case of 1kVdc rated voltage, generally the dielectric withstand voltage is  $1.2 \times V_r$ . May the 1.5kVdc applied in connector result in the capacitor failure? We apply 4kV high voltage to the filter connector resulting in the dielectric breakdown failure of the capacitor. It is found that the crack is horizontal and crosses the floating electrode from the cross-section of the failure capacitor, as shown in Figure 5.

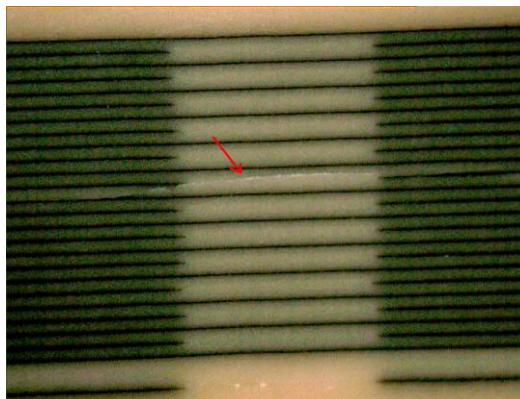


Figure 5: The horizontal crack propagating from one electrode to the spaced opposite electrode induced by high voltage field.

MLCC with such dielectric crack degrade slowly; remain undetected for a long time until it eventually fails in the field. The degrading process is the progress of Ag electromigration as stated in Reference [3]. Here the failure phenomenon of the problem is very similar to the dielectric breakdown failure by high field strength.

In addition, taking the 1.5kV DWV test again to the connectors from our stock, and finding there are one or two connectors will fail by surface arc-over, as shown in Figure 6. Further analysis proved that the internal structure of the connector have reduce the creep distance of the mounted capacitor, thus lower the breakdown voltage of the capacitor (Figure 7). Similar design problem have been described in Reference [4] and [5].



Figure 6. Arc-over on capacitor. The breakdown voltage of the capacitor decrease to 2.5kVdc~3kVdc after mounted inside the connector.

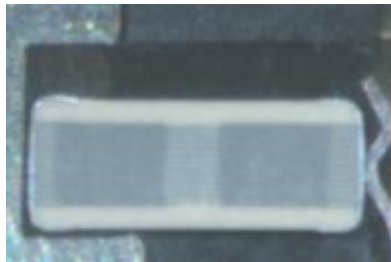


Figure 7 The creep distance of the mounted capacitor have been reduced by the internal structure of the connector.

Reference [2] pointed out the destructive mechanism of corona is by its local high temperature which can lead to thermal breakdown of the capacitor. As we review the connector DWV testing record, we found that the rate of failing to arc-over is as high as 1500ppm, which are not acceptable, as there is minor chance for passing the potential surface arc-over capacitor without detecting.

### Validation Experiments

In order to verify the influence of capacitor quality and 1.5kVdc DWV related testing condition on capacitor, we have conducted the following two experiments.

The test steps of experiment 1: (to capacitors individual)

- Capacitors of two vendors are each divided into two groups. (Total 4 groups, each group 64pcs)
- For both vendors, one group receives twice DWV test of 1.5kVdc, 2S
- For both vendors, the other group receives once DWV test of 1.15kVdc, 20s..
- Take 24pcs from each group, and conduct the thermal shock test of -55°C ~ +125 °C, 30min, 2min, 30min, 5cycle
- Take 40pcs left, and conduct the life test of 1.1kV, 125 °C, and 1000hr. (Measure at 500hr)

The result shows that 2pcs of 1.5kVdc DWV test samples of vender B fail in life test (1pcs is

broken down at 3min; 1pcs is electric degraded after 1000hr). It is obvious that the capacitors of vendor A have no any defect and maybe better than that of vendor B from this experiment. (The field failures are capacitor from vendor A)

The test steps of experiment 2: (capacitors are in the connector)

- Capacitors of two vendors are each divided into two groups, then mounted inside the connector (Total 4 groups)
- All the 4 groups receives once DWV test of 1.15kVdc, 20S
- For both vendors, one group (50pcs) receives once DWV test of 1.5kVdc, 2s again.
- All the 4 groups conduct the humidity loading life test of 5V, 40 °C, 90~95%RH, and 1000h. (100mA limited)

The result shows that for both vendors, the group of connectors which experience 1.5kVdc DWV test have 2~3pcs failures.

### Failure Mechanism Discussion

It is quite sure that the failures are related with the 1.5kVdc DWV test, but as the failure mechanism, we still not sure whether it is dielectric breakdown by high field strength, or thermal breakdown by corona.

After consulting the capacitor manufactory, they think that although 1.5kV slightly beyond the requirement, but the margin for the breakdown voltage is quite large, there isn't likely that 1.5kv voltage will lead to the dielectric breakdown. A 250 piece sample of capacitor was tested to DC breakdown with the distribution results shown in Figure 8. According to Reference [6]&[7], we can calculate that the breakdown possibility under 1.5kVdc would not larger than 10ppm from the process capability shown in Figure 8. Therefore, it is impossible that the breakdown of capacitor was caused by 1.5kVdc voltage.

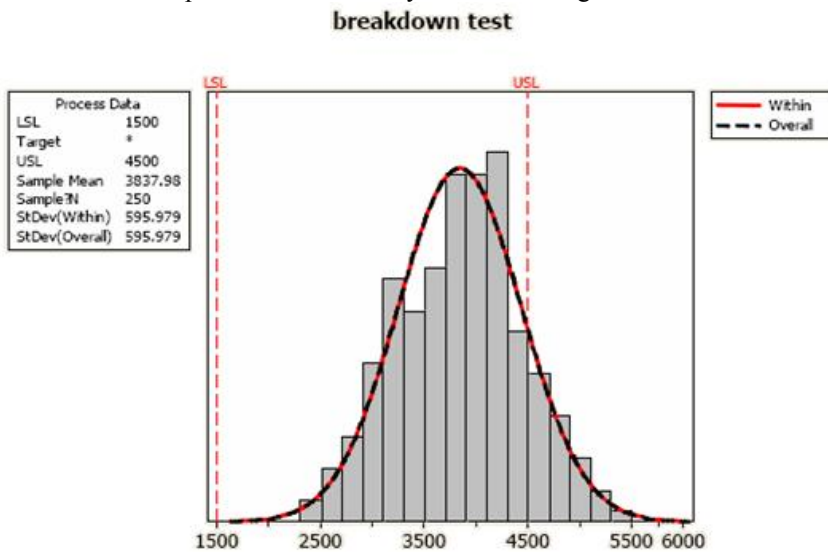


Figure 8 The breakdown voltage distribution of the capacitor (not inside the connector).

Although the heat generated by corona can lead to thermal breakdown, but there is no much description about the breakdown process, what is it look like after thermal breakdown; will it

form a horizontal crack parallel to electrode just like dielectric breakdown? What is more, will the high voltage contribute any effect during this breakdown process? Actually, Reference [9] has mentioned that too little heat is generated to thermally break down the insulation material, or to melt conductors in the corona process. Although he admitted that corona is destructive.

In order to verify this failure mechanism, we scratch the capacitor surface with a pencil, thus lower its breakdown voltage as there is carbon on the capacitor surface. After repetitious surface arc-over at lower voltage, no degradation and cracks are found in the capacitor by electrical test and cross-section. But as it is a PPM level failure that such a simple experiment might not show up the failure since the sample number is too small and to locate the defect is difficult through cross-section.

Another case is that if the capacitors have subtle intrinsic defects, such as microdelaminations, the local high temperature generated by corona might enlarge the delamination, forming a crack parallel to electrodes. For these capacitors, adding a thermal shock test might help to screen out the defect capacitors.

### **Conclusion**

To make a MLCC with floating internal electrode structure short should have a shorting path which cross the floating electrode, the shorting path could be the horizontal crack caused by high voltage field strength or microdelamination after thermal shock.

For a good design 1kV rated voltage capacitor, the 1.5kVdc DWV testing could not lead to the dielectric breakdown. But care should be taken to design the layout and position as not to reduce the creep distance of the capacitor, especial for 1206 or 1210 size. When these high voltage >1kV smaller capacitor are using, it is recommended to use insulating coating to prevent surface arcing.

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