Longevity Qualification and Stability Test Workshop

Capacitor Robustness in LAr

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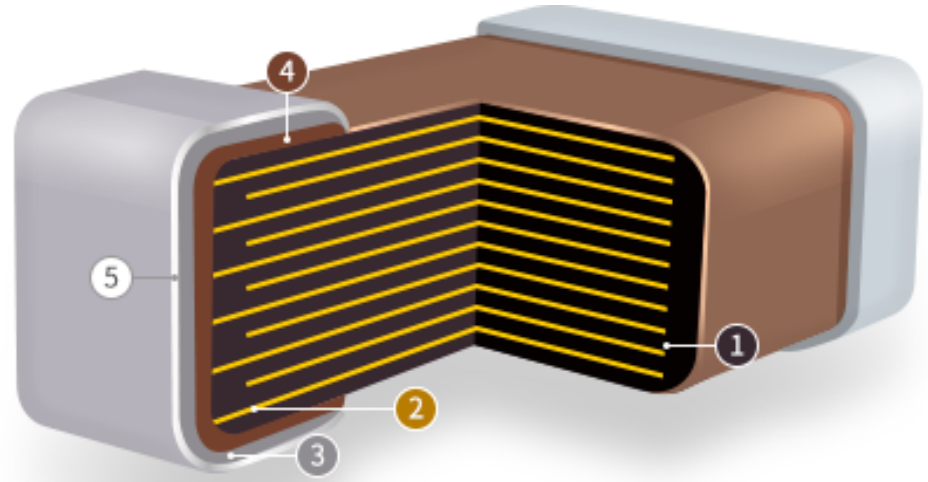
LBNL

Typical MLCC Capacitor Structure



1 Ceramic body 2 Electrode(Ni/Cu*) 3 Plating(Ni)
4 Termination(Cu or Cu+Metal Epoxy) 5 Plating(Sn)

* Internal Cu electrode is only applied to limited products.

*Samsung Electro-Mechanics

- Termination: Palladium Silver, Solder Plated Over Nickel, Tin over Nickel Plated, and Gold over Nickel Plated

Typical MLCC capacitors used in cold electronics :

A) High dielectric constant type (Ba_2TiO_3) (Class 2) : Eg. XR7

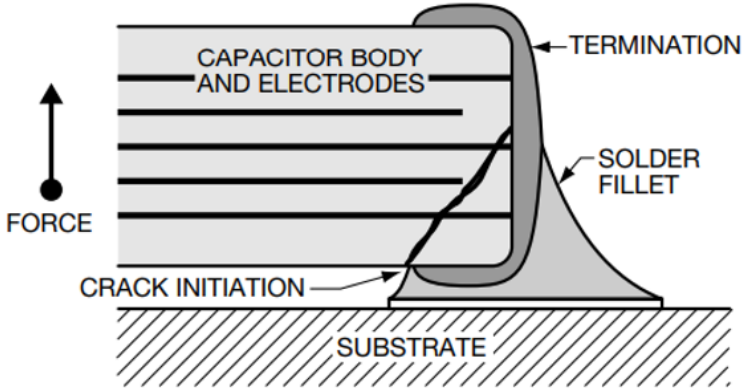
- Can work at cryogenic temperatures
- Best suited for coupling (DC blocking) and power supply bypassing
- Temperature drift
- These capacitors age because the crystal structure they have when they are made slowly changes to another, lower K form, over time

B) Temperature compensating type ($CaZrO_3$) (Class1) : Eg. C0G

- One of the most stable capacitor dielectrics available
- Capacitance change with temperature is 0 ±30ppm/°C
- Typical capacitance change with life is less than ±0.1% for C0G

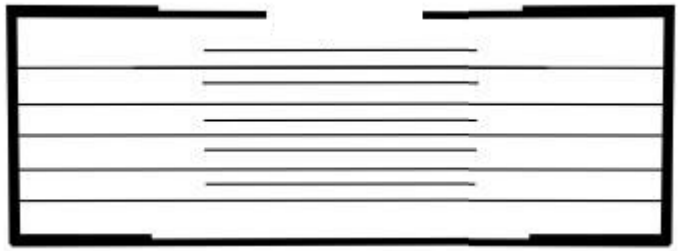
Typical Degradation Mechanisms

Board Warpage [1]



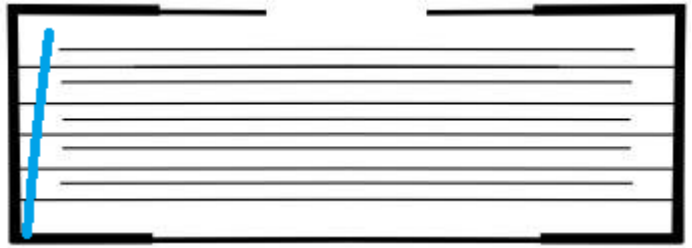
Cryogenic liquid fills the crack, further damaging it during thermal cycling

HV Capacitor

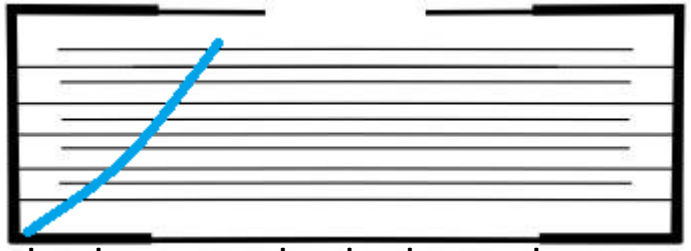


HV Capacitor are less likely to short due to cracks

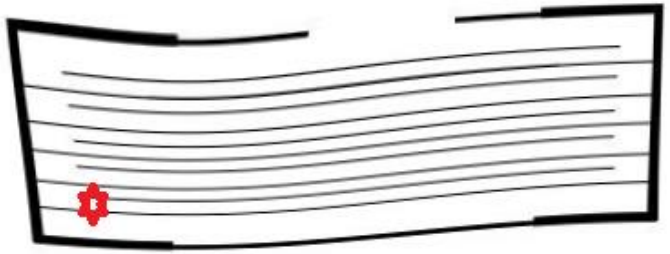
- Lower coefficient of thermal expansion
- Thinner geometrics are desirable



Most cracks happen close to the contacts resulting in capacitance change and noise



Cracks that cross both electrodes can short the capacitor



If warping happens while the component is active it can short it as it decreases its dielectric strength

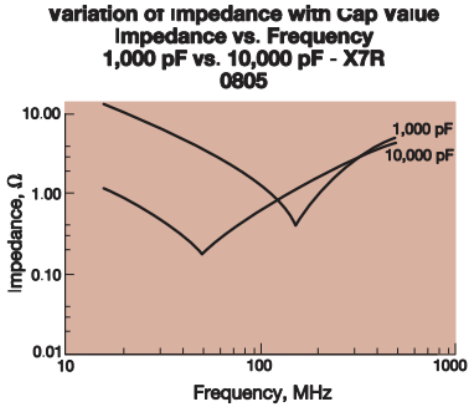
Typical Degradation Mechanisms

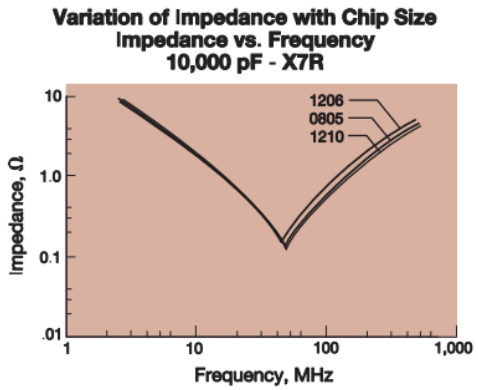
Type 2 capacitors

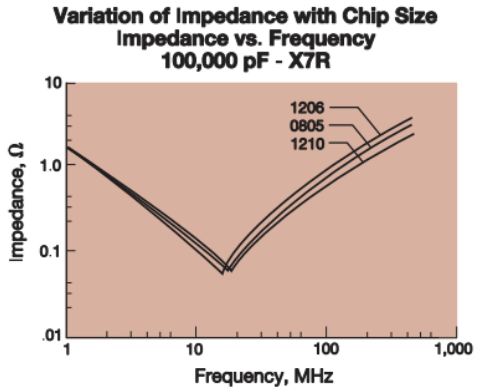
- Extreme increase of ESR capacitors can lead to failure due to heating caused by current or voltage spikes
- Current spikes with a duration of less than 1 μs might cause rather significant increase in the temperature of small elements due to adiabatic conditions of heating, at which all energy generated in the element goes to increase its temperature proportional to the square of the current amplitude [7].

Capacitance and ESR measurements at 300 K, 77 K and 4 K normalized to 100 nF at 300 K

Capacitor type	Measured capacitance (100 nF at 300 K)		f \ T	Measured ESR		
	77 K	4 K		300 K	77 K	4 K
X7R ceramic	21.3 nF	3.4 nF	1 kHz	76 Ω	574 Ω	5.6 MΩ
			10 kHz	1.5 Ω	64 Ω	400 kΩ
			100 kHz	0.3 Ω	7.6 Ω	62 kΩ
NPO ceramic (NPO/COG/COH)	100.2 nF	99.7 nF	1 kHz	2.1 Ω	2 Ω	3 Ω
			10 kHz	0.3 Ω	0.4 Ω	0.1 Ω
			100 kHz	0.2 Ω	0.02 Ω	0.05 Ω

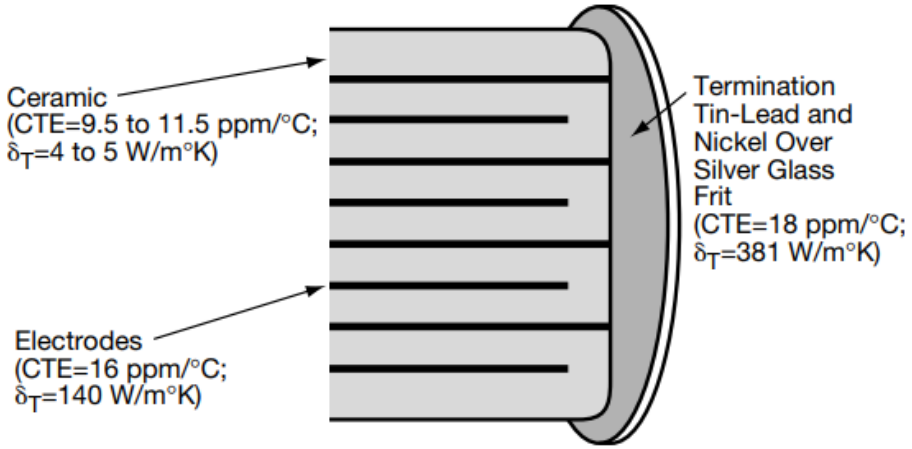


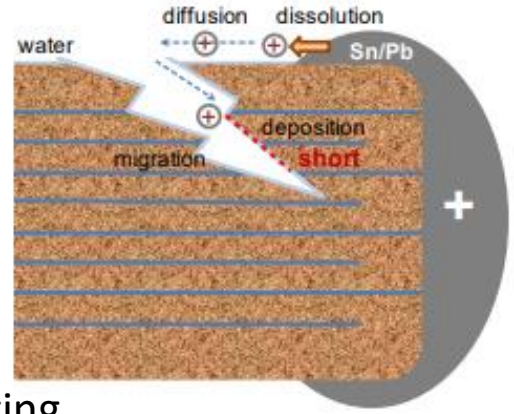




Typical Degradation Causes

MLC Structure with CTE and dT Listed

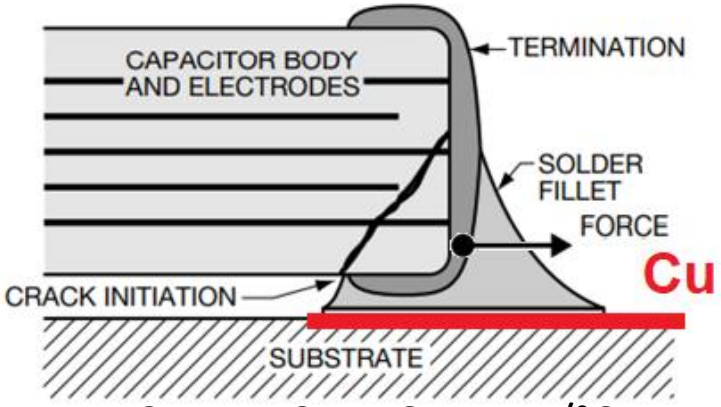




Use conformal coating

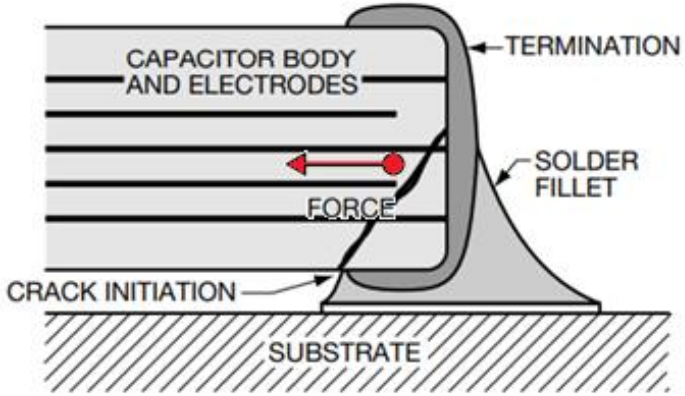
Schematic of failures in MLCCs with cracks caused by migration of ions that are anodically dissolved from terminations.

CTE mismatch



Copper CTE 16.7 ppm/°C

Thermal Shock



Pd/Ag termination and plated terminations show large differences in thermal shock due to the rate at which the heat transfer occurs across the termination.

Recommended Components

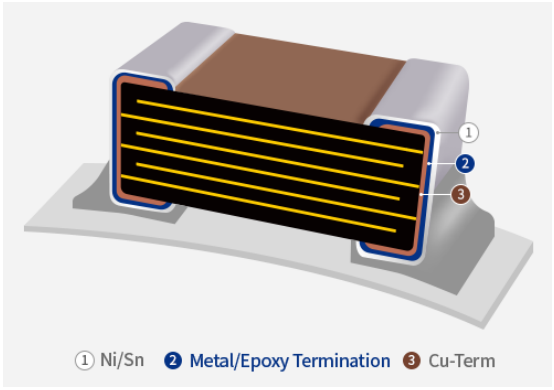
- Temperature compensating type (class 1); C0G/NP0

PCB Material

Dielectric Material	Thermal Conductivity (W/m·K)	CTE (ppm/°C)
FR-E/E-glass	0.3 to 0.4	XY: 16/20 Z:60
Polyimide	0.2 to 0.4	XY: 15/19 Z:55
PTFE Ceramic (RO3000)	0.5 to 0.66	XY: 17 Z:25
Non-PTFE Ceramic (RO3000)	0.6 to 0.65	XY: 12/16 Z:50

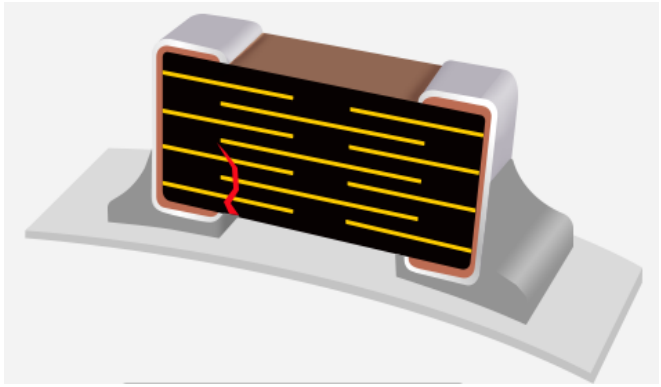
*A maximum of 0.1mm deflection for each cm of board segment may be allowed.

High Bending Strength(Automotive)



The thermal/mechanical stress on the chip can be reduced by the ductile properties of Soft Termination.
It is also resistant to stress caused by board bending.

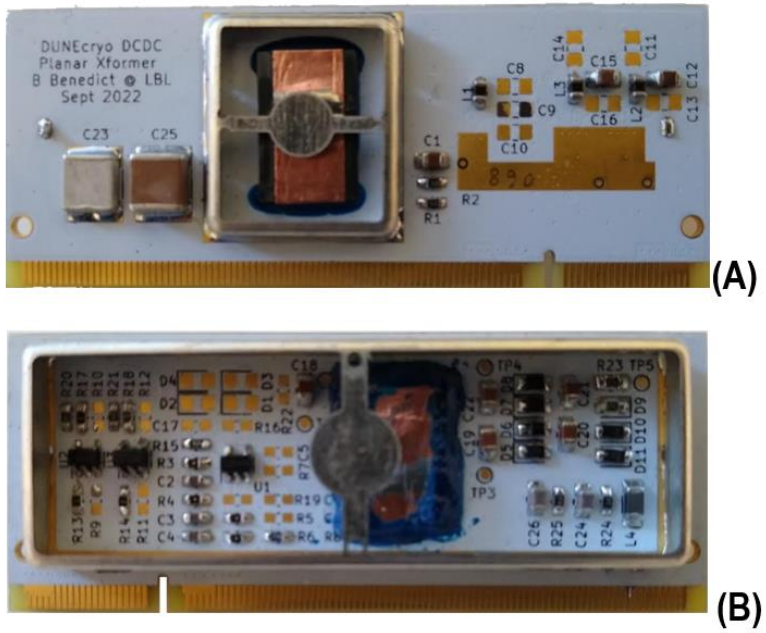
Fail Safe(Soft Termination 5mm)



Designed to prevent circuit malfunction in the case of an internal shunt caused by a crack occurs in an MLCC.

Recommended Components

List of resistors utilized, characteristics at 300K				
MFG	Value xF	Size (a)	% (b)	Technology
CGA4C2C0G2A102J060AA	1n	0805	±5	NP0/C0G, MLCC, 100V (1)
CGA4J3C0G2E103J125AA	10n	0805	±5	NP0/C0G, MLCC , 250V (2) (3) (4)
CGA4J1X7S1E106K125AC	10u	0805	±10	X7S, MLCC , 25V (3)
22201C106MAT2A	10u	2220	±10	X7R, MLCC , 100V (4)



(a) Top view of the board, and (b) bottom view of the same board.

- If class 2 is necessary due to capacitance value, voltage rating, or size add a class 1 in parallel
- Utilize small footprints when possible 0805 and smaller
- Voltage rating should be at least twice the operating voltage at LAr, ideally five times if possible
- Capacitors should be of the High Bending Strength type

Soldering Methods and Materials

Wave Soldering: Not recommended due to thermal shock very rapid rates of heat transfer from preheat to the actual solder bath. This soldering technique has therefore the largest temperature gradients and is the most difficult to process.

Infrared (IR) and Hot Plate : are recommend with pre-heating. For IR reflow, heat conducts from the substrate to component land patterns where the screened paste reflows to form the solder joints. The maximum rate of use or cool down of temperature in an IR or hot plate reflow profile should be 4°C/sec.

PbSn alloy: is able to operate at cryogenic temperatures and maintains its ductility if it has high Pb content. However, as Sn content increases up to more than 40%, the alloy becomes brittle at cryogenic temperatures. PbSn alloy containing Sb can mitigate this issue. Suggested alloys ($Pb_{90}Sn_{10}$),($Pb_{80}Sb_{15}Sn_5$), and ($Pb_{93.5}Sn_5Ag_{1.5}$).
Pure indium or indium alloys: Compared to standard PbSn alloy, have shown to be much better at cryogenic temperatures due to the greater ductility and longer lifetime. Suggested In99 (pure), and $In_{50}Sn_{50}$ (low melting point)

Testing and Capacitor Evaluation

- Testing can be performed in a specially design board containing up to 1000 parts
- Evaluation of parameters such as capacitance and ESR can be monitored continuously or before and after test while in LAr
- Slow charge and discharge of the capacitors should be performed at 10Hz cycles
- Fast transients should be evaluated with frequency components up to 100MHz
- Number of hours should be related to the frequency of transients and charge/discharge cycles of the capacitors

If nothing is neglect and the best arrangements are made boards operating in liquid Argon have been proven to perform reliably for 10 year +

REFERENCES

[1] Parameters Important For Surface Mount Applications Of Multilayer Ceramic Capacitors, Bharat S. Rawal Kumar Krishnamani John Maxwell, AVX Corporation.
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[6] R. W. Chang and F. P. McCluskey, “Reliability assessment of indium solder for low temperature electronic packaging,” Cryogenics, vol. 49, no. 11, pp. 630–634, 2009.
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