Focus on Power: Advancements in Ceramic Capacitors

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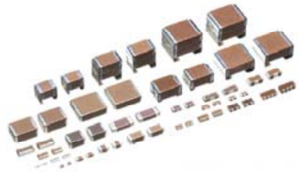
APEC 2011: Ceramic Capacitor Update

Topics

1. Materials
2. Construction
3. Applications



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Recent advances in material technology and design have allowed multilayer ceramic capacitors (MLCCs) to extend beyond replacing electrolytic capacitors in output filtering applications. While still offering the attributes of ultra low ESR and high ripple current capability, MLCCs with higher effective capacitance, thermal/mechanical robustness, and stability have been developed. These constructions offer many advantages to power applications.

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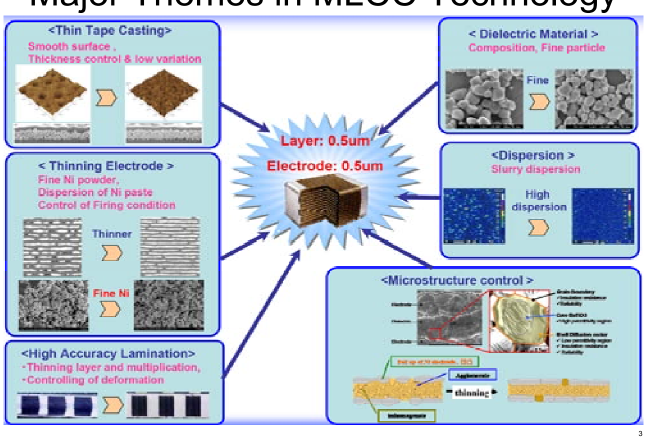
Major Themes in MLCC Technology



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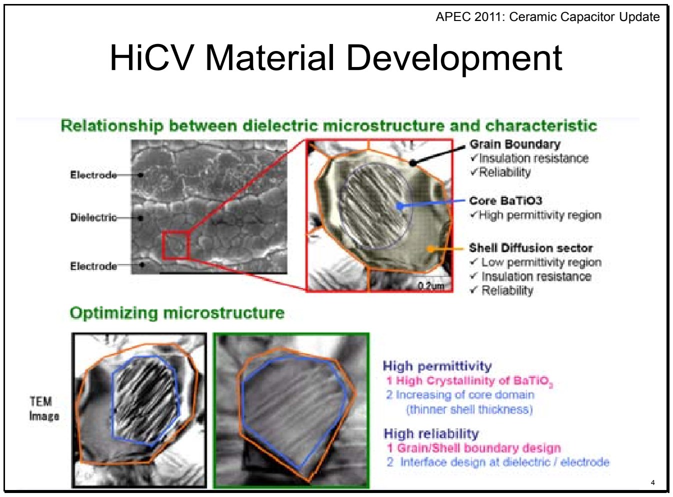
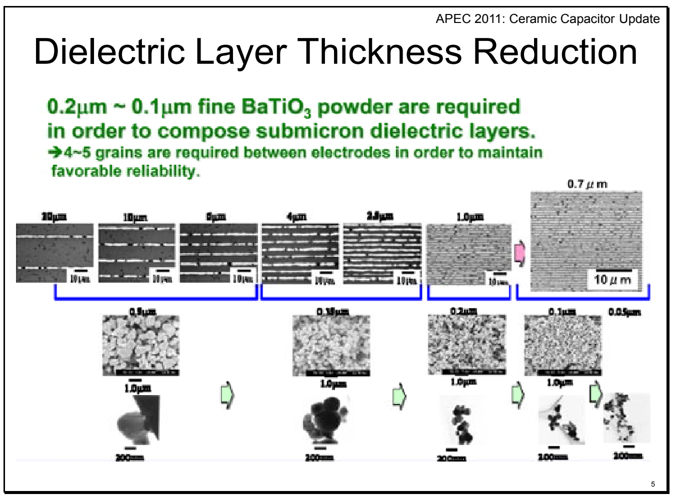
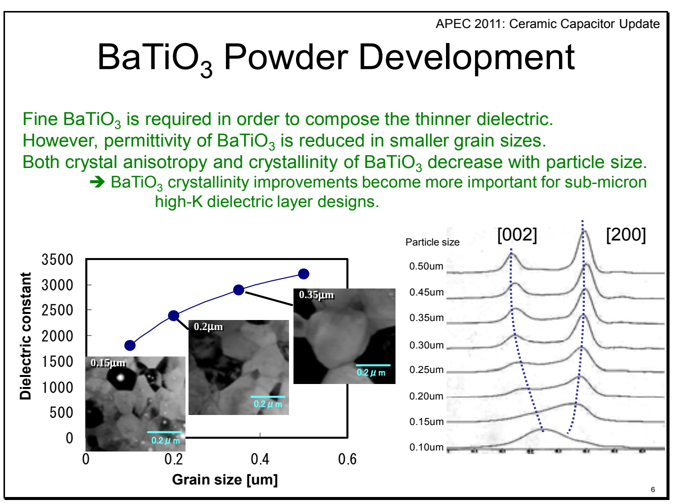
The technology themes for MLCC capacitors are strongly tied to material developments and construction techniques. Continued refinements of dielectric powders and internal electrode materials are required for increasing layer counts in these capacitors. Through microstructure control of the functional dielectric phase, improved dispersion of additives, and accurate lamination of smooth layers, the volumetric efficiency of the MLCC capacitor is greatly improved.



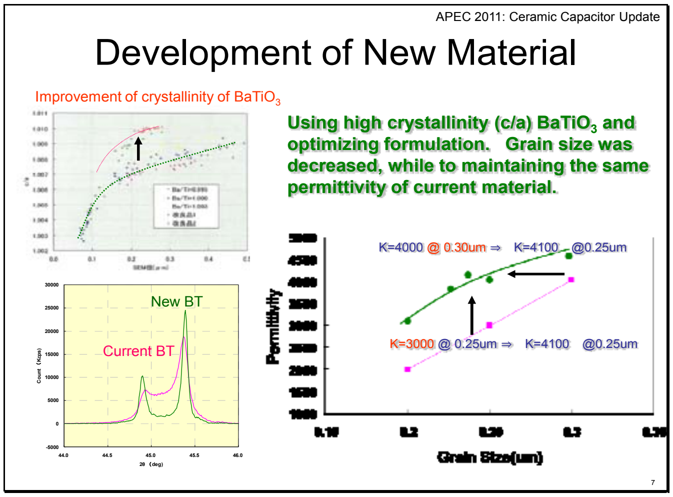
Dielectric grain size reduction typically leads to the shell having an increased role. Increasing the core volume in the grain structure slows dielectric constant reduction with smaller grain size.



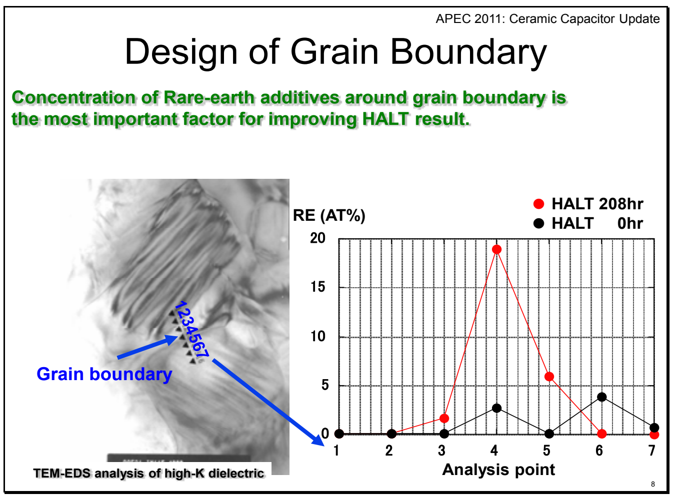
Beyond merely extending the CV product in the MLCC, reliability is also improved through these technology themes. Albeit with thin dielectric layers, reliability is preserved/improved, by maintaining/increasing the number of grains per dielectric layer.



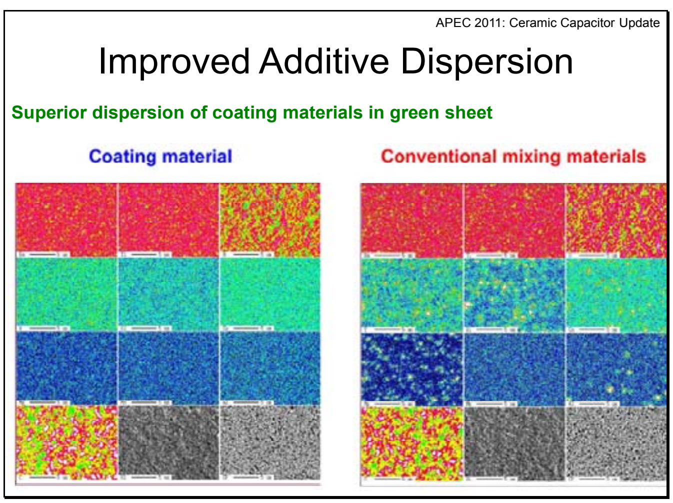
Within a material set, as barium titanate grain sizes decrease, crystallinity decreases leading to the dielectric constant being lower. The amount of capacitance per MLCC layer is reduced.



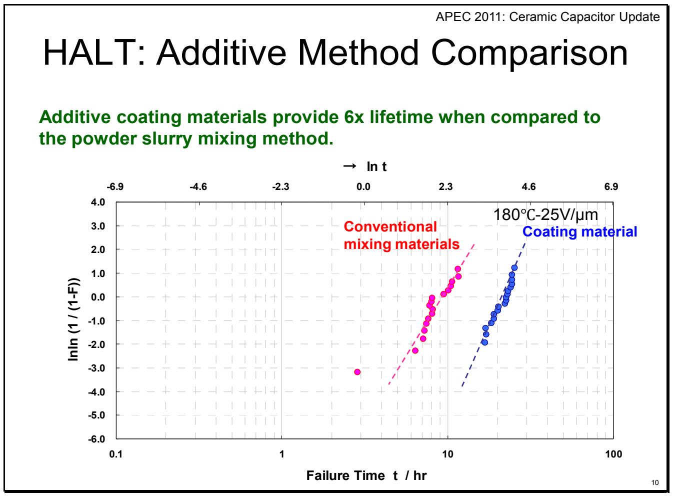
To overcome the drop in capacitance per layer, barium titanate grains with larger core volume (optimized microstructure) is used.



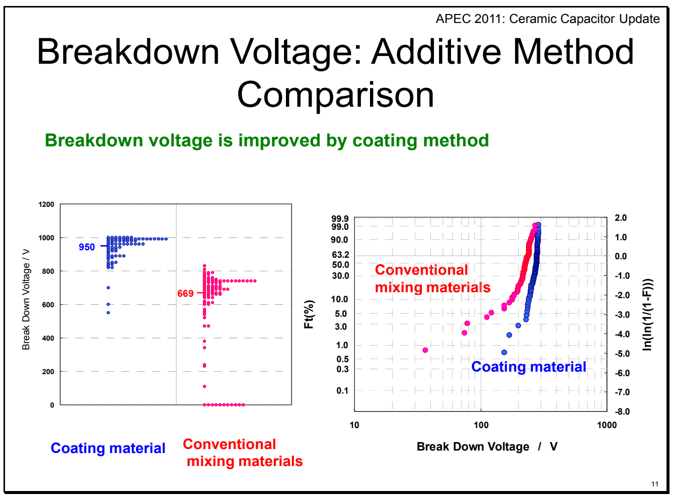
Reliability is directly related to the integrity of the grain boundaries in the ceramic layers.



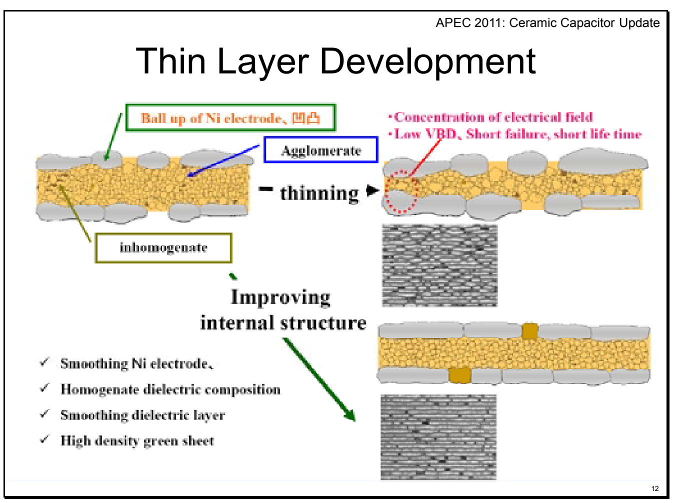
The traditional method of mixing dielectric and additive powders together has limited effectiveness. Coating the dielectric with the additives, on a liquid scale, prevents low insulation resistance regions caused by agglomeration of the additives. Coating processes provide even coverage on the grain surface.



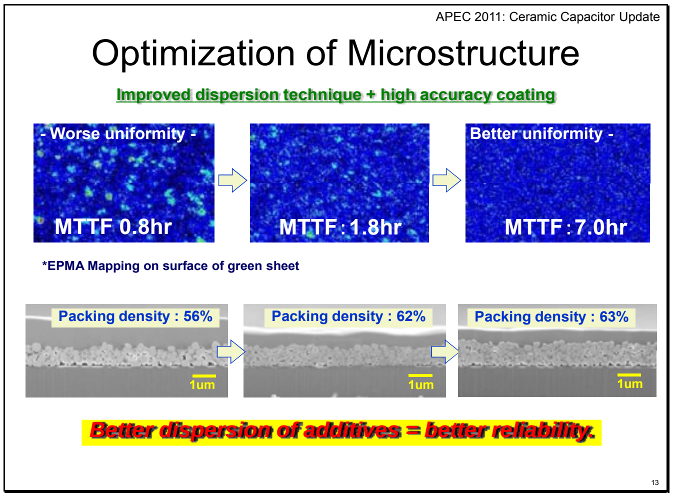
The improvement in HALT results indicates that the improved dispersion and even coating of additives on the dielectric grains is very effective. These failures are based on 10x increase in leakage current.



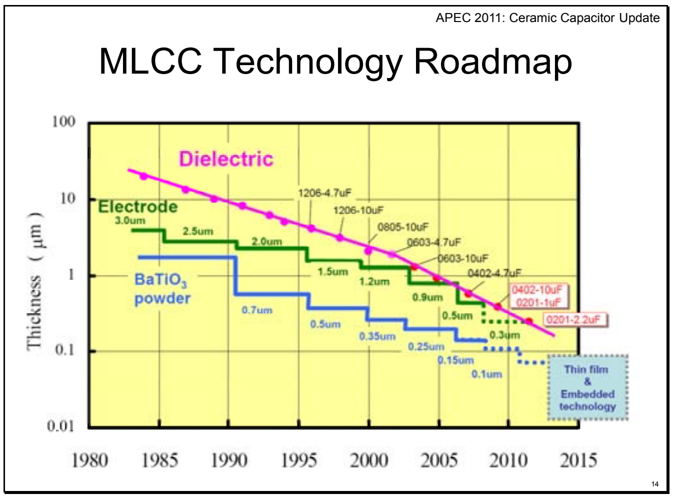
Breakdown voltage level and variation are improved. Failures here are based on true rupture of the dielectric (100V/sec)…usually audible cracking.



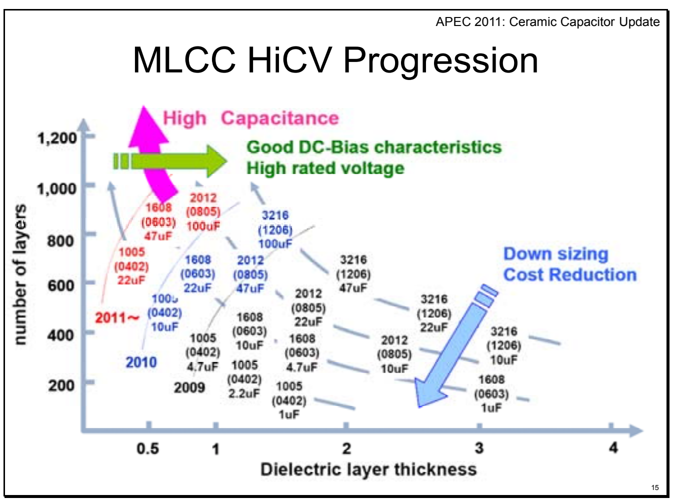
The MLCC construction quality is also dependent upon the electrode characteristics. Closely matching the firing profile performance of the electrode and the dielectric creates fewer gaps. Ceramic particle loading of the electrode paste improves the mechanical strength of the fired body.



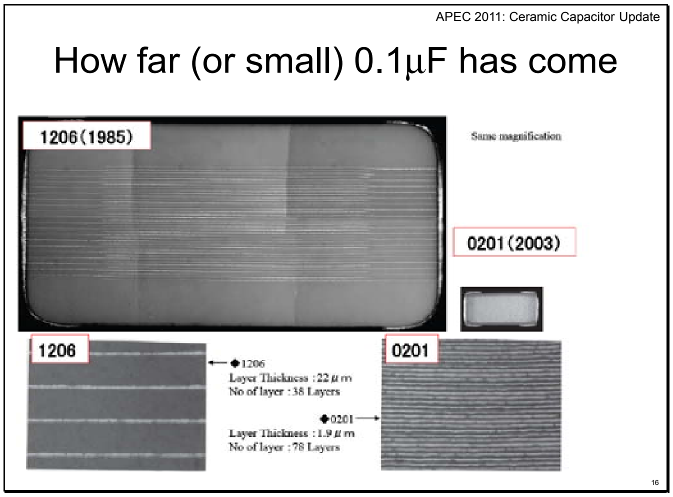
Dispersion of additives and consistent layer thicknesses eliminates electric field concentrations, improving long-term reliability and dielectric strength. The MLCC's volumetric efficiency gains through the improved packing density.



In particular, high CV MLCC capacitors have undergone remarkable case size reductions. Additionally, lower circuit voltages have allowed for lower rated voltage capacitors. The combined effect is great board space savings and improved cost-effectiveness.



The market is driven to provide high effective capacitance in small case sizes.



Getting more into finished MLCCs, let's take a look at a very common value. In 1985, a 1206 body size was needed to achieve 0.1uF, at 25V. Eighteen years later, this value was available in an 0201, at 6.3V. The reduction of IC operating voltages has enabled this volumetric downsizing.

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HiCV Benchmark Developments

Reference	Traditional solution	Currently	(near term)
50V, 1000pF	0805 NP0	0402 NP0	
50V, 0.1µF	0805 X7R	0402 X7R 0805 NP0	
100V, 1µF	1812 X7R	1206 X7R 0805 X7S	(0805 X7R, CY2012)
6.3V, 10µF	1206 X5R	0402 X5R	
6.3V, 22µF	1210 Y5V	0603 X5R	(0402 X5R, CY2013)

Key points -typical ref. K values: Y5V ~ 3.5 times X5R/X7R ~ 3500 times NP0

-space savings:

0805 => 0402	80% less board space!
1812 => 0805	>80% less board space!
1206 => 0402	~90% less board space!
1210 => 0603	85% less board space!

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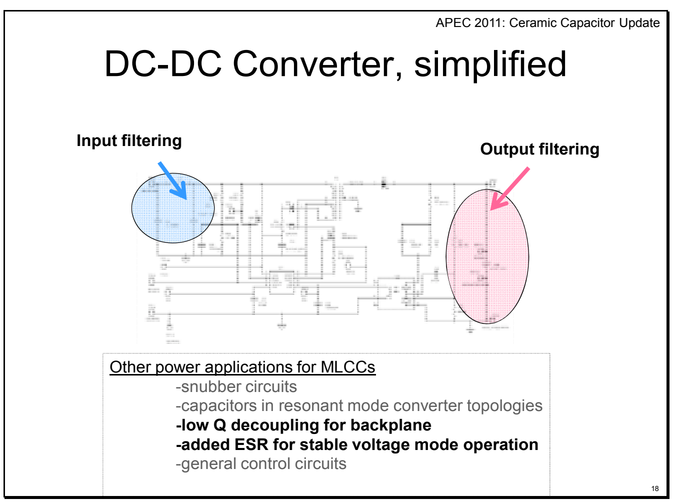
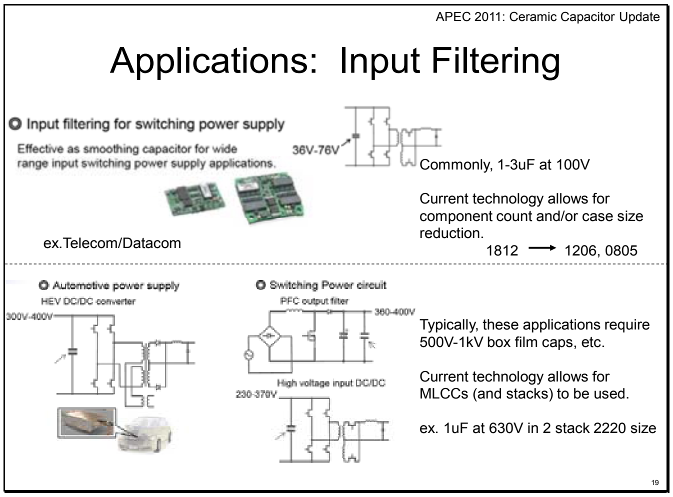
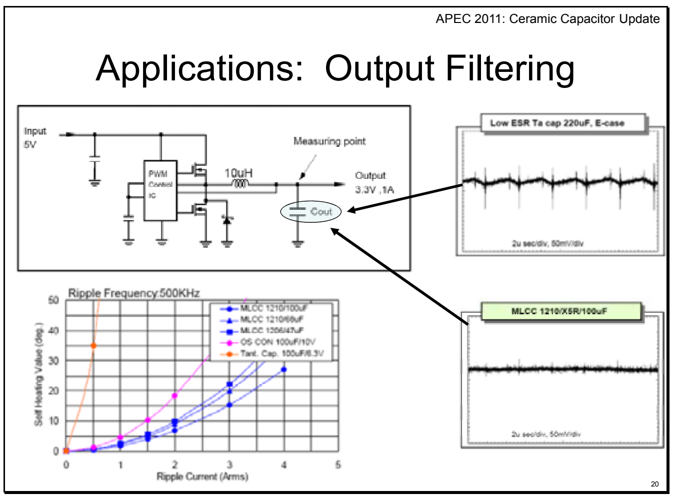
In many cases, yesterday's 0805 can be replaced with an 0402, for a 80% board space and 92% volume savings.



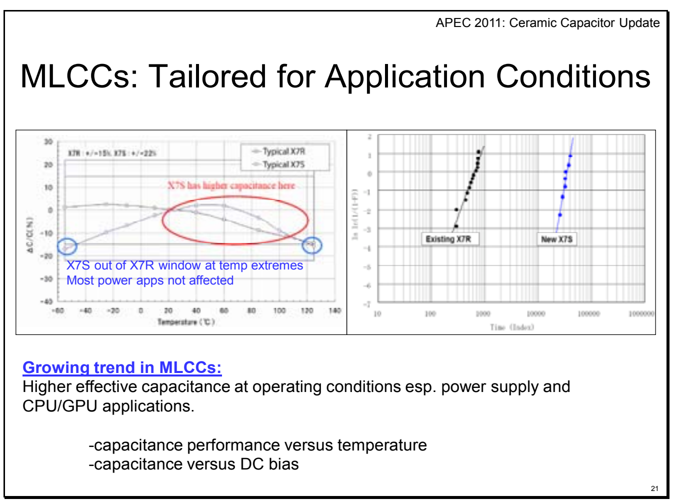
In response to power design challenges, MLCC development trends have resulted in a variety of new series of application solutions such as X7S, Soft Term, and Mega-Cap. These offer small size, Pb-free soldering process compatibility, wide operating temperature/voltage range for applications such as input filtering, resonant circuits and low Q decoupling. Portions of various power topologies will be used to illustrate the use of MLCCs in power design.



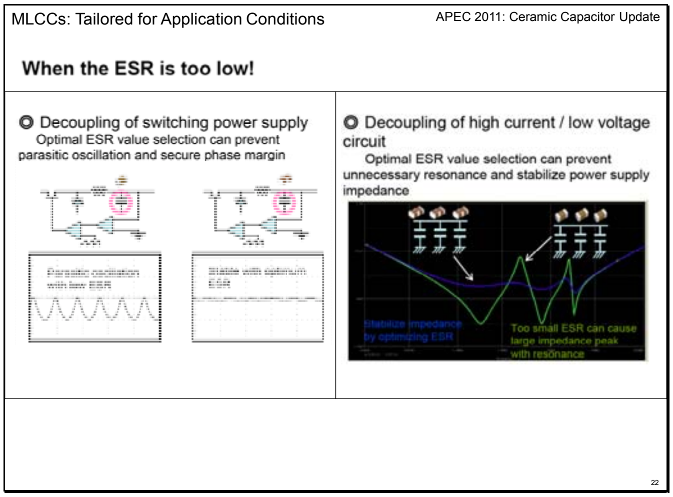
For input filtering already using MLCC solutions, technology improvements allow for 2-3 case size reductions. In higher power/voltage applications, it is possible to switch to MLCCs.



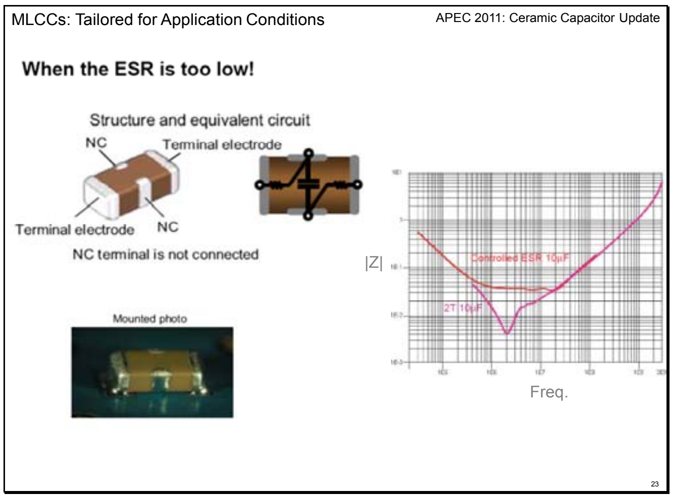
It is widely known that MLCCs offer ultra low ESR/high ripple capability and capacitance stability with frequency. For high frequency converters (>100kHz or so), MLCCs can offer greater noise reduction and ripple suppression while using fewer capacitors.



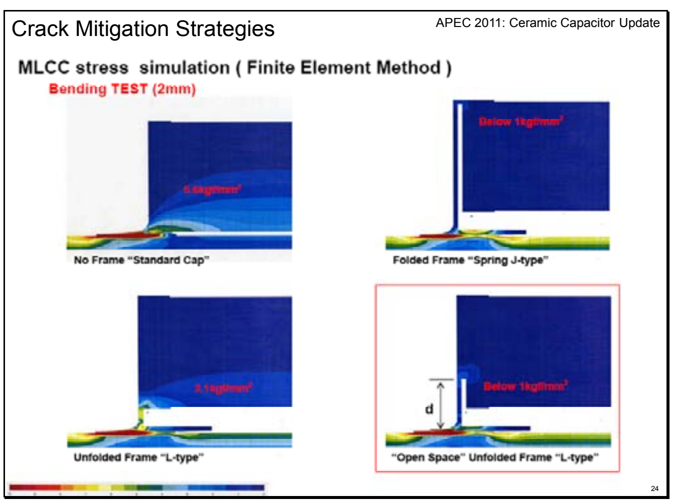
In general, capacitors are rated at room temperature, low voltage, and low frequency. At the actual operating conditions, capacitor performance is much different. For the power and CPU/GPU markets, MLCC manufacturers are responding with higher performance capacitors. X7S is one example.



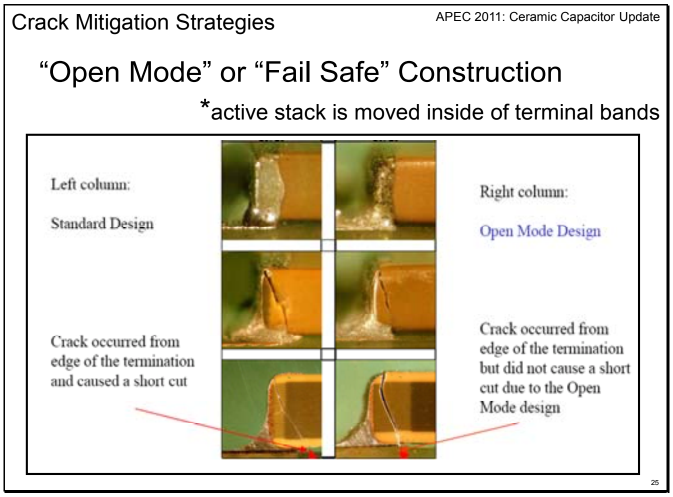
In most cases, having an ESR value in the single digit milliohm range is accepted as an attribute. However, in some power conversion applications, the ESR can be too low. Instability and unwanted oscillation can occur if sufficient ESR (damping resistance) is not present. Power backplane applications, that may use hundreds of MLCCs in parallel, may have stability issues. Adding ESR provides a level load line.



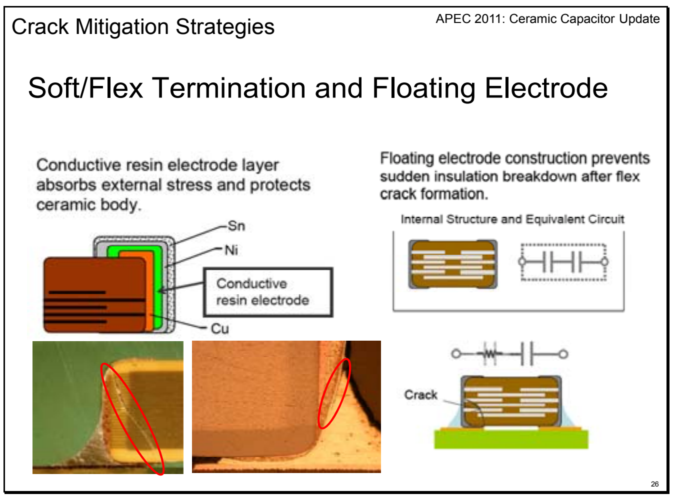
Adding ESR turns the MLCC into an "anti-resonant cap" suitable for low Q decoupling.



Post-solder handling of circuit boards (bending, torsion) continues to be the main cause for cracking of SMT components. Strategy one is to use the smallest possible component. This provides the shortest span between solder pads (bending moment) and the best aspect ratio (thickness:length) to resist cracking. Strategy two is to add a lead frame to the component. Three different styles provide varying stress relief to the component body.

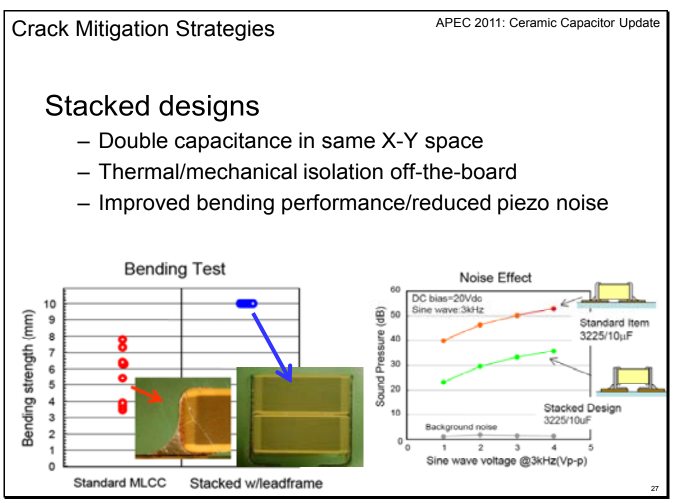


Typically, in MLCCs, the flexure crack propagation path is from the bottom termination edge toward the side edge of the termination. Moving the overlapping portion (active stack) inside of the bottom termination edges, the path is through common electrodes. This preserves insulation resistance.



Two other additional countermeasures are soft termination and floating electrode. Soft term adds a polymeric resin material to the termination layering. This provides significant drop test improvements and 5-10 times board bending versus standard constructions.

Floating electrode is constructed as two series-connected capacitors per layer. Similar to the "open mode" design, the insulation resistance is maintained.



Another MLCC cracking countermeasure involves use of a lead frame. MLCCs are attached to a lead frame. Paying special attention to the position of the MLCC on the lead frame is required to minimize thermal and mechanical stresses. Reduced piezo noise is an additional benefit of the proper use of the lead frame construction.

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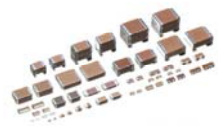
MLCC Summary

1. Through material advancements, volumetric efficiency (CV product), reliability and stability at actual operating conditions continue significant improvements.

2. Developments in construction have allowed for greater thermal/mechanical robustness and board space savings.

3. MLCCs offer small size, high temp solder/environmental compatibility, and broad temperature/voltage ranges. Principal targets are high power density, high efficiency, and high reliability power applications.



Use of MLCCs with high effective capacitance (at real operating conditions), and high reliability continues to expand in power applications. This is especially so for those applications that require small size, high efficiency/power density, and maintenance-free reliability.