Ceramic Capacitor Failures on the Rise

Since their introduction in the late 1990s, surface mount multilayer ceramic capacitors (MLCCs) gained rapid acceptance by the electronics industry and today are among the most common components on a circuit card assembly. The reliability of an MLCC can be extremely high, with an expected operating lifetime of decades. Problems occur when defects are introduced, either during manufacture or the assembly processes. Due to the large amount of energy stored by capacitors, internal shorts resulting from defects can cause explosions and dramatic temperature increases, which not only destroy the MLCC, and any evidence of root cause, but can also damage surrounding components, the printed board, adjacent circuit card assemblies, and may even lead to fires. Over the last eighteen months, CALCE laboratory services have assisted a number of companies in finding MLCC root cause failures.

Failure Analysis. When MLCC failure is catastrophic, the failure investigation starts by examining the MLCCs adjacent to the failure site and those in the same failure area on similar circuit card assemblies.

The first step in the failure analysis (FA) process is to confirm that electrochemical migration (ECM) underneath the capacitor was not the root-cause of failure. If samples of non-catastrophic failures exist, ECM can be investigated by washing the area around and underneath the capacitor and examining the solution for high levels of chlorides or bromides. Once ECM has been ruled out, the MLCCs are examined using scanning acoustic microscopy (SAM), with a 110 MHz transducer. This is very effective in locating voids, delaminations, and horizontal cracks, although it is not as successful in identifying flex cracks, thermal shock cracks, or other types of vertical cracks causing MLCC failures.

Flex cracks and extensive thermal shock cracks can be identified through methanol testing. Due to its polar nature, methanol is an electrically conductive liquid. Capillary action and methanol’s low viscosity allow methanol to become quickly absorbed by any surface cracks present in the capacitor. If the crack has propagated across opposing electrodes, the absorbed methanol will temporarily form a conductive film between the two electrodes, creating an observable rise in current leakage.

All suspect capacitors are eventually subjected to cross-sectioning. This is because some defects, such as small thermal shock cracks and vertical cracks caused by poor handling, are otherwise hard to detect. Cross-sectioning can be performed on capacitors attached to the board or on single capacitors. Sectioning of the board can create additional defects in the capacitor and confuse the FA process, so care must be taken. Air can also become trapped between the capacitor and the board during the potting process leading to damage during grinding and greater difficulty in getting an optimum image.

MLCCs can be removed from the board, preferably with a 150°C preheat and with hot air, to prevent the removal itself from introducing a defect and confusing the FA process. Next, the MLCCs are labeled so that top/bottom and left/right directions are identified, and then mounted in room-temperature cure epoxy for ease of handling and to minimize damage during cross-sectioning. For maximum efficiency and minimum damage, MLCCs are ground using 600-, 800-, and 1200-grit silicon carbide paper and periodically checked for anomalies. Beginning with a fine grit greatly reduces the amount of grinding-induced porosity that can mask intrinsic porosity, small cracks, and delaminations.

Thorough examination is conducted on at least four different internal planes—preferably where the end cap is ground off, at the start of the internal electrodes, and two other cross-sections. Optical examination is performed at magnifications between 50x and 200x. For maximum contrast, images are taken in bright and dark field modes. A particular emphasis is placed at the termination of the end caps, since this is where flex cracks and thermal shock cracks initiate.

Identification of Root Cause. Failures of MLCCs are often accelerated by defects introduced during the capacitor manufacturing process or by excessive stresses experienced at various stages of assembly. During manufacture, failure accelerators can arise from different root-causes. Contamination in the ceramic powder can lead to excessive porosity or voids. A void bridging electrodes can become a short leakage current path and a latent electrical defect. Non-optimized pressing or sintering can also lead to excessive porosity and voids, and to delamination (knife line cracks). Delaminations and single-layer voids do not cause failures directly but are very sensitive to mechanical stress that can rupture inter-electrode dielectric layers, which then become the latent leakage paths. Delamination can also extend from an electrode end to the opposite termination, again causing a latent leakage path. Rapid cooling can cause firing cracks, which often originate at an electrode edge, but not always. A firing-crack propagation path is perpendicular to the electrodes.

The danger of forming cracks, even microcracks, during the placement step is that the high temperatures during soldering will often induce internal cracks to grow across several electrodes. Cracking due to excessive placement force by a vacuum tweezer primarily consists of surface damage on the top of the MLCC with the potential for microcracking on the board side of the component.

Centering jaws can cause cracking due to excessive force or worn bits leading to stress concentrations. Both root-causes leave distinct crack signatures.

MLCCs are sensitive to thermal shock due to their construction and to differences in the CTEs of the materials used. Thermal shock cracks can occur during solder reflow, wave solder, cleaning and rework. Thermal shock cracks generally initiate on the bottom-side of the capacitor, at the termination of the end cap. They often propagate at a 45-degree angle and tend to range in size from 10 to 500 microns.

Capacitor failures that occur during connector insertion, depaneling, or bolting are often due to excessive flexure. Excessive flexure can cause flex cracks, which can emanate from the termination of the end cap and propagate at a 45-degree angle. This is similar behavior to a thermal shock crack. The primary difference is the size; flex cracks tend to be larger, propagating through the ceramic until the crack reaches the end cap.

For more information on ceramic capacitor failure identification and corrective actions, contact Dr. Craig Hillman of CALCE Laboratory Services at 301-405-4316 or email chillman@calce.umd.edu.