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Finding Singulation-Caused Cracks in MLCCs

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Singulation-caused cracks in multi-layer ceramic chip capacitors (MLCCs) are a wonderful demonstration of that fact that a relatively simple failure mechanism may have far-reaching and expensive consequences. What matters for contract manufacturers is knowing how to deal with these defects. Singulation cracks typically are formed when panels are snapped apart into separate PC boards.

During the separation process, the individual boards may be slightly twisted. The stress caused by twisting must be relieved somewhere, and the point of relief may turn out to be surface-mounted multi-layer ceramic chip capacitors.

Cracks caused by singulation, or by other handling steps, are typically vertical and are near the end of the capacitor.

The capacitors are firmly attached to the board, and they are more brittle than many of the other components on the board. When tin-lead solders were almost universally used, the much less rigid tin-lead solder could take up some of the stress and perhaps prevent a capacitor from being cracked. But lead-free solders are much more rigid and, at least in theory, are much more likely to deliver stress right to the capacitor.

Sonoscan's new D-9500 "Gold Standard" C-SAM acoustic microscope system.

The cracks caused by singulation, or by other handling steps, are typically vertical or nearly vertical and are located near the end of the capacitor, usually very close to the termination. At least initially, the extent of a crack is usually limited. The small initial size has two very significant consequences: first, the cracks are very unlikely to reach the surface of the capacitor, where they might be identified visually; and second, they are less likely to cause significant electrical problems during testing. Over the long term, as a result of thermal cycling, the crack is likely to expand and break through more and more electrode plates. Eventually one or more capacitors on a board may become electrically degraded to the point where they affect overall system performance or cause a system failure. If a manufacturer ships a large number of boards or systems that have initially small singulation cracks, the potential exists for a large number of product field failures to occur over an unknown stretch of time.

Internal Gap Features

It would be useful to be able to spot singulation cracks in capacitors early, and to be able to identify and modify the processes that are causing the cracks. A good tool for investigating ceramic chip capacitors is acoustic micro imaging, which is very sensitive to internal gaps in materials. An internal gap in a solid material reflects virtually all of the ultrasound that reaches it. Acoustic micro imaging systems use a laterally scanning transducer that, as it moves, pulses ultrasound into the sample and picks up the return echoes several thousand times a second. The transducer is able to operate rapidly because the velocity of sound in production materials is typically very high. The round-trip from transducer to gap and back to the transducer is usually a matter of a few nanoseconds.

For high-reliability applications, ceramic chip capacitors may be imaged acoustically before they are mounted to screen out those that already have defects.

To visualize this action, think of each location where the trans-

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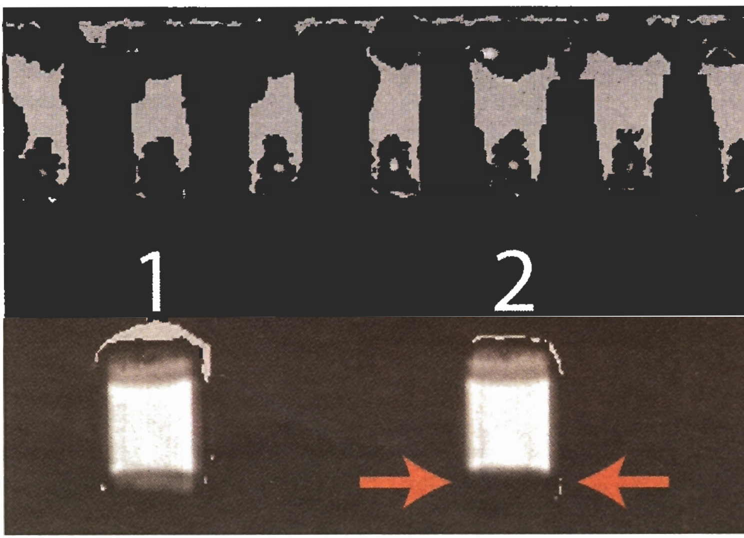
ducer sends a pulse and receives an echo as one x-y coordinate in the acoustic image that is assembled from the return echoes. A location where the ultrasound encounters a gap will have a very strong return echo that will become a very bright pixel in the acoustic image. A location where there is no internal gap, and no internal material boundary, will have no return echo and will create a black pixel. The image of a ceramic chip capacitor without internal defects usually is more or less gray because of the very slightly reflective, but numerous internal interfaces between the electrode plates and the dielectric ceramic.

Singulation cracks are unusual in that they are vertical or nearly vertical. Most other defects in ceramic chip capacitors are horizontal or essentially horizontal — a delamination between the dielectric and an electrode plate, for example, or a void — which is a flattened air bubble. Because the



Acoustic image of a portion of a populated board. Singulation crack in capacitor #2 is a black acoustic shadow that covers part of the body of the capacitor as well as the termination.

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scanning ultrasonic transducer creates so many pixels, even a small horizontal gap-type defect creates a great many very bright pixels. For high-reliability applications, ceramic chip capacitors may be imaged acoustically before they are surface-mounted to screen out those that already have defects. But a manufacturer concerned with singulation-caused cracks is more interested in imaging the capacitors after they have been surface-mounted and reflowed and after the boards have been singulated.

Internal cracks caused by stresses on the board during singulation are usually very thin, vertical or nearly vertical, and close to the termination.

Finding Vertical Cracks

The difficulty posed by singulation cracks is that they are both vertical and very thin. Thinness doesn't matter much in horizontal cracks, because any gap more than 0.01 micron (0.0000004-in.) thick reflects virtually all of the ultrasound that strikes it. But a vertical crack is like a razor blade standing on edge: there is practically no surface area to reflect ultrasound. For finding horizontal defects, ceramic chip capacitors, whether loose or surface-mounted, are typically imaged acoustically by collecting all of the return echoes from all of the depths from just below the top surface of the capacitor to just above the bottom surface — in other words — the whole bulk of the capacitor, excluding the two surfaces that would give very large, but not very significant return echoes.

Developed at Sonoscan, the solution to the problem of imaging very thin vertical cracks is to change the depths from which echoes are received. Setting the depths that are imaged is called "gating". Normal capacitor gating — from just below the top surface to just above the bottom surface — will miss thin vertical cracks. To image thin vertical cracks, gating is altered so that the ultrasonic pulse travels past the crack to the back surface of the capacitor, where it is reflected back to the transducer. On the way to the transducer, the pulse encounters the vertical crack for the second time, and this double-pass technique creates a dark acoustic shadow much wider than the crack itself. Since singulation cracks are usually very close to the termination, it is not unusual for the acoustic shadow created by the crack to obscure the termination in the acoustic image.

In the photo, an acoustic image has been made using the double-pass technique, of a portion of a populated PC board. At the top of the image are the surface-mounted leads at one edge of a plastic-packaged IC. The two items of interest are the two ceramic chip capacitors.

In capacitor #1 the central body of the capacitor appears bright and featureless, a sign that it contains no defects. An ordinary horizontal defect such as a delamination would create an acoustic shadow that corresponds to the affected area of the capacitor. The terminations at either end of the capacitor are gray — no defects there. In addition, the acoustic image has captured some of the solder bonding the capacitor to the board, as seen in the bright area at the top of the capacitor.

Capacitor #2 is similar to #1 in most respects. The amount of solder visible at the top of the capacitor is smaller. But the most significant difference is that both the lower termination and part of the body of the capacitor are obscured by a dark acoustic shadow. This is the shadow that was created when the ultrasonic pulse encountered the very thin vertical singulation crack. This acoustic signature — a wide, dark acoustic shadow near the termination, and even obscuring the termination — tells engineers that they are dealing with a singulation crack.

Eliminating Singulation Cracks

When test results or field failures suggest that electrical anomalies may be the result of cracks in ceramic chip capacitors, the following steps are used to solve the problem:

- Capacitors on failed boards are imaged acoustically to find cracks.
- When it is known that singulation cracks are occurring, a new incoming lot of ceramic chip capacitors is imaged acoustically before surface mounting in order to remove any capacitors having pre-existing defects such as cracks, delaminations or voids.
- The good capacitors are then used in assembly. After reflow — but before singulation of the panels — the mounted capacitors are imaged acoustically to identify any cracks that may have formed during processing.
- The panels are then singulated, and the mounted capacitors on the individual boards are imaged once more. If cracks are found, they are evidence that the cracks are happening during singulation. If this is the case, the manufacturer can change the method used to separate the boards to reduce the stresses that were causing singulation cracks.

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