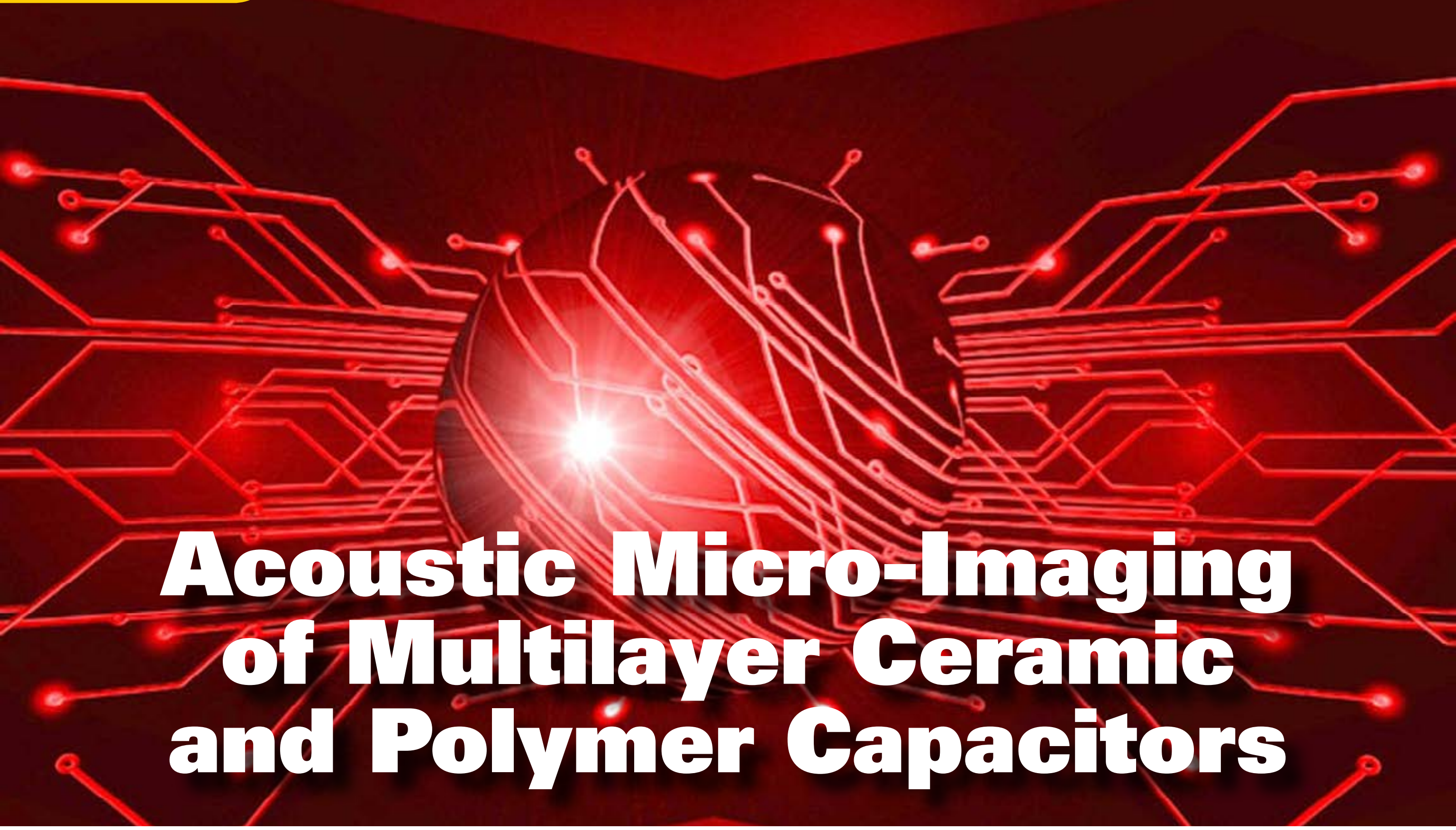

Acoustic Micro-Imaging of Multilayer Ceramic and Polymer Capacitors

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***SUMMARY:** They are inexpensive and relatively simple in design, but multilayer ceramic capacitors (MLCCs) are nevertheless capable of causing unanticipated field failures whose severity may range from very minor to catastrophic.*

The root cause of multilayer ceramic capacitor (MLCC) failures is very often some type of internal structural defect such as a crack, delamination or voids. These types of defects typically create an open circuit or leakage paths between electrodes that can disrupt the capacitor's functioning and impact the performance of the system.

Because the defects are gaps in solid materials, they are easily imaged by the ultrasound pulsed into MLCCs by acoustic microscopes. SonoLab has been imaging MLCCs for three decades. Typically, the screening involves a range of small to large lots of loose capacitors, with the purpose of identifying and removing capacitors that meet the user's definition of reject before assembly begins.

Screening Acoustically for Defects

In a typical screening operation, up to several thousand MLCCs are arranged on a tray for imaging. During imaging, the transducer of a microscope such as a Sonoscan C-SAM scans over the tray, pulsing ultrasound into the MLCC and receiving the return echoes several thousand times a second. Data in the return echoes make up the acoustic image.

Even though it consists of two different layered materials (electrode and dielectric), the bulk of a capacitor acts much like a homogeneous material and sends back few significant echo signals to the transducer. But where the pulse of ultrasound strikes a crack, delamination or void, the great difference in acoustic properties between the air in the gap and the solid material just above it reflects virtually 100% of the ultrasound. This very high amplitude reflection means that gap-type defects will show up as very bright features in the acoustic image.

Individual capacitors with significant internal defects are removed from the lot. The remaining capacitors are known, at this time, to be free of internal defects that could lead to functional failures. Most MLCCs go into high-reliability military, aerospace or medical appli-

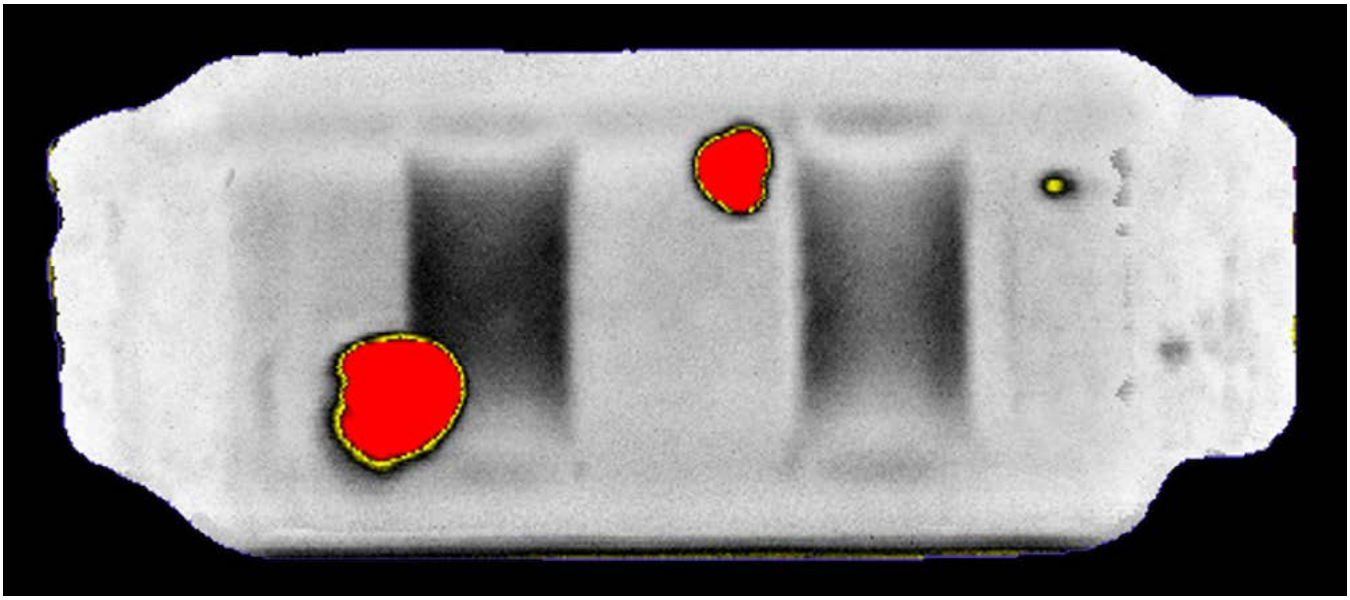

Figure 1: Bulk acoustic image of a typical ceramic chip capacitor. Electrode plates are gray; delaminations are red; void is yellow.

cations. Some are used in high-reliability commercial applications such as high-end electronics. In other cases screening is performed on a sampling basis for the purpose of lot qualification.

Figure 1 depicts a typical acoustic image of an MLCC. Echoes from the various depths in the capacitor arrive at the transducer at different times. A method called bulk scan imaging is generally used with capacitors; this method accepts for imaging all echoes from all interior depths of the capacitor. The ultrasound is said to be gated on the entire thickness of the capacitor.

In Figure 1, the two red features are delaminations, while the smaller feature at upper right is probably a void. In the color map used here, red indicates the highest echo amplitude. The top view of the electrode plates is visible—the plates are gray, indicating a material interface giving an echo of much lower amplitude. This MLCC would be rejected from any high-reliability application because the defects make it likely to fail.

Gate-by-Gate Imaging

In the past few years capacitors themselves have changed, in part by becoming smaller, but also by the use of new materials, particularly polymers, to replace the ceramic dielectric materials. The technology for viewing MLCCs acoustically has also advanced. Sonoscan has introduced an automated gate-setting system that lets the acoustic microscope operator set the locations and thicknesses of a number of individual gates.

Each individual gate represents a thin horizontal "slice" of the capacitor and produces its own acoustic image of that slice. The gates are usually set up to be adjacent to each other and all of the same thickness, but other arrangements are possible—overlapping gates, separated gates, and gates of different sizes. The maximum number of gates is 100 (or 200 with a dual-channel machine). The acoustic image of a single internal slice of an MLCC can be a useful diagnostic tool when it is necessary to understand the details and structure of internal anomalies without physically destroying the sample.

Figure 2 shows the images from three individual gates in a single MLCC. This was a high-voltage capacitor measuring 10.1 mm x 10.1 mm x 2.98 mm. The microscope operator chose to set a sequence of 50 equal gates encompassing the entire thickness of the MLCC; thus,

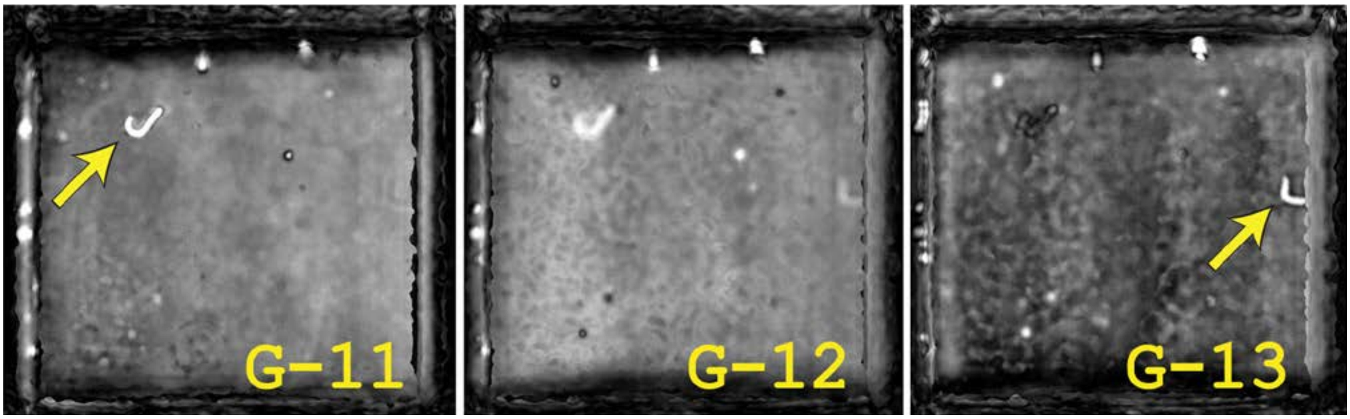

Figure 2: Acoustic images of three consecutive PolyGates in a ceramic chip capacitor. Each gate is approximately 60 microns thick. Arrows show defects that change with depth.

each gate has a thickness of approximately 60 microns. Destructive analysis after imaging showed that the MLCC had a total of 42 electrode layers, so each gate covers somewhat less than one layer.

Gate 11 shows the expected medium-gray field in defect-free areas of this slice, as well as a somewhat elongated, curved defect at upper left (arrow). From its shape, this defect is likely the void left by an airborne fiber particle that was incinerated during firing of the ceramic.

Some 60 microns deeper into the part, in Gate 12, the J-shape defect is beginning to fade, probably because only the lower portion of the void is actually within Gate 12.

But in Gate 13 a new defect appears (arrow) —a defect that appears to be another elongated void, perhaps also left by an incinerated fiber particle. This defect is faintly visible in the Gate 12 image. If we look at the location of the similar void seen in Gate 11, it is actually visible in Gate 13, but as a dark feature. The reason: This void now lies completely above the depth from which ultrasound is being reflected, and the air in the void blocks the return path of echoes from Gate 13. The void is therefore seen as an acoustic shadow.

MLCCs Keep On Shrinking

The strong demand for ways to save space and weight in cell phones and other systems has led to the design of truly tiny MLCCs. What matters is the total capacitance of a capacitor, which is in part determined by the total x-y area of the electrode plates. An MLCC that places many very thin electrode plates, separated from each other by very thin dielectrics, into a tiny x-y area gives a manufacturer a significant advantage.

Some 16,000 of the tiny capacitors measuring 0.020 in. x 0.010 in. can be placed on a single tray and imaged simultaneously, but this is a fairly rare occurrence. More often, full trays of 0.040 in. x 0.020 in. and of 0.060 in. x 0.030 in. MLCCs are scanned.

The ultrasonic frequency used for a given lot of MLCCs depends on the thickness of the capacitors, rather than on their x-y dimensions. 50 MHz is generally the starting point, and probably the most frequently used frequency. Thinner parts may be imaged using 75 MHz or 100 MHz transducers (higher frequencies give better spatial resolution). Very thin capacitors might be imaged at 230 MHz, although this is a bit unusual and gain may be limited. Thicker MLCCs—usually high-voltage types—may be imaged at 30 MHz. When a relatively thick MLCC is destined for a particularly critical application, each face of the capacitor may be imaged at 50 MHz (higher resolution), after which a single face may be imaged at 30 MHz (better penetration).

One challenge encountered when imaging very tiny MLCCs has to do with accept/reject standards rather than the capacitors themselves. The military standard is that a void in the dielectric of an MLCC is cause for rejection if the thickness of the void exceeds one-half of the dielectric thickness. The reasoning is that a void of this size or larger may turn into a leakage path between two electrodes.

But MLCCs are now shrinking down to only 0.03 in. (0.762 mm) thick, with up to 240 electrode layers, for a total of 480 layers. Each layer is thus about 0.000625 in. (0.0016 mm) thick, or 1.6 microns. A void half this size would be less than 1 micron in diameter—undetectable by the highest frequencies available because it is smaller than the spot size of the transducer. Larger and presumably more dangerous anomalies such as delaminations and multilayer voids can be imaged in these capacitors, but not the smallest anomalies permitted by current military standards.

The New Breed of Polymer Capacitors

Lots consisting of new types of capacitors that use polymers have begun to show up at Sonoscan. In these capacitors, the dielectric material is a polymer rather than a ceramic. One obvious physical advantage is better resistance to cracking. One of the most frequent causes of cracks in MLCCs is the singulation of panels by snapping the boards apart. The stresses involved may create more or less vertical or diagonal cracks, typically near the terminations. Polymer capacitors are presumably more forgiving of these stresses.

The polymer caps are not quite as easy to image as MLCCs, however. Ceramic is a good transmitter of ultrasound, while polymers tend to absorb ultrasound. A ceramic capacitor of a given size might be imaged at 50 MHz, while a polymer capacitor of the same dimensions might be imaged at 30 MHz in order to gain penetration, while giving up a little resolution.

Figure 3 is the side view diagram of a very thin (0.040 in.) organic polymer surface mount capacitor, one of several new types of capacitor to use a polymer. The pellet is a block of porous tantalum or another metal that has been immersed in an electrolyte to form an oxide lay-

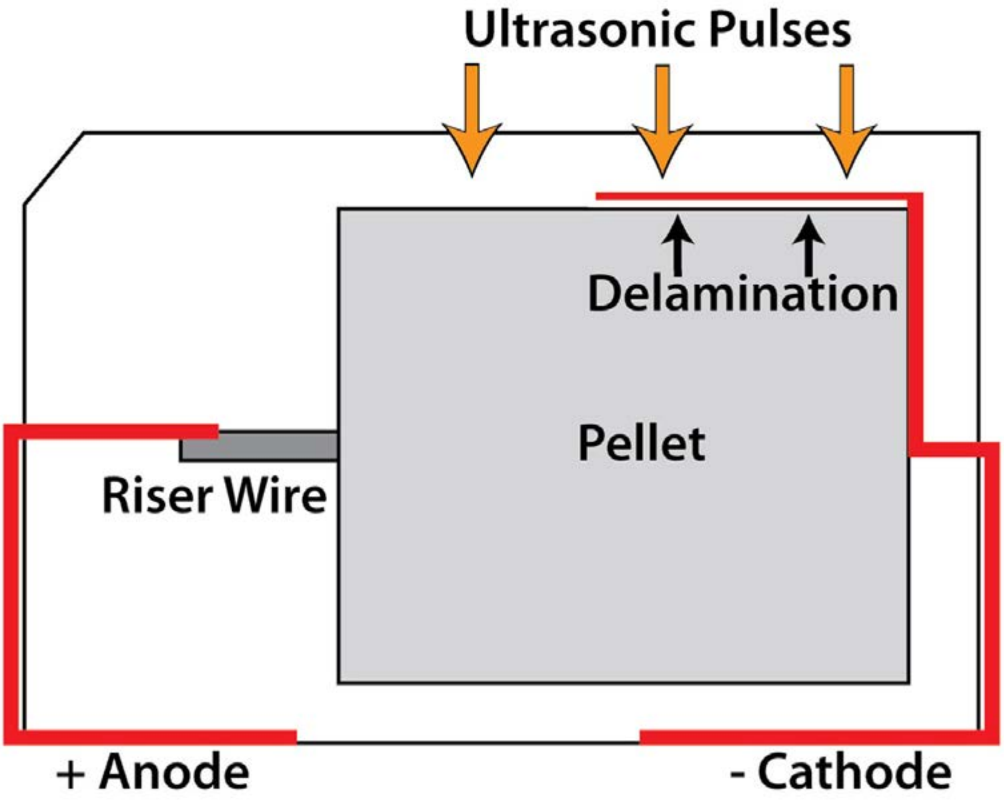

Figure 3: Side view of an organic polymer surface mount capacitor.

er on the pores. Its interconnects are the wide anode and cathode, both of which, in the top view, are as wide as the pellet. The anode is connected to the pellet by a riser wire, while the cathode is connected by a conductive polymer.

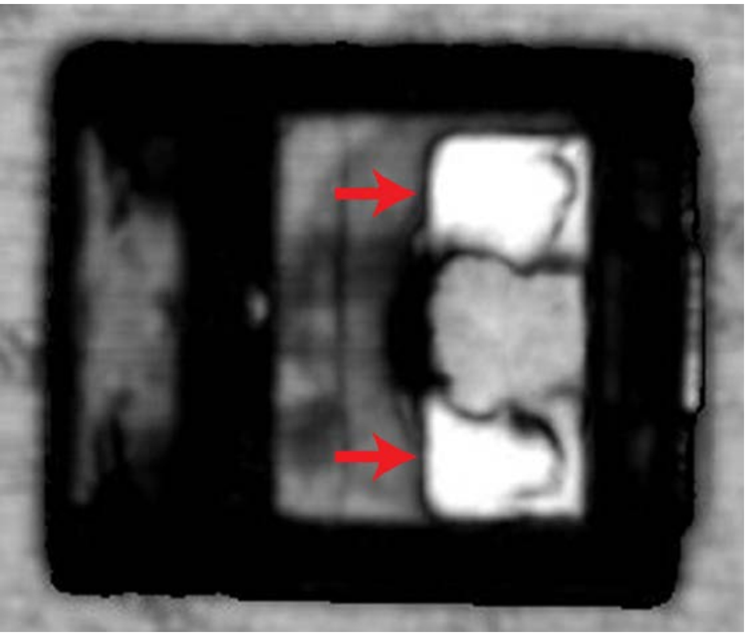

Figure 4: Acoustic image of an organic polymer surface mount capacitor. Arrows point out delaminations of the cathode from the pellet.

Because the top is thin, ultrasound can be pulsed into the top surface of the capacitor (as shown in the diagram) at a frequency of 50 MHz. The resulting acoustic image is shown in Figure 4. The two arrows point out bright white delaminated areas of the lead frame from the top of the pellet. The polarity of the echo (in this case, negative) demonstrates that the delamination is between the pellet and the lead frame, and not between the lead frame and the plastic package. The central part of the lead frame between the two delaminations is darker gray shows better bond quality. The left half of the pellet is gray, and is not covered by the lead frame.

Thanks to their low cost, utility and simplicity, ceramic and polymer capacitors are growing in popularity. Acoustic micro-imaging is a proven method for detecting failures such as cracks, delaminations, and voids. **SMT**

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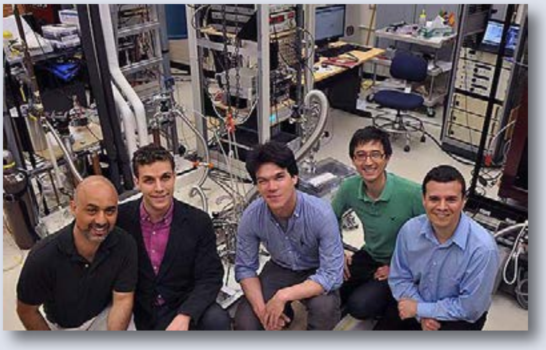
Graphene & Boron Nitride Combined to Create Semiconductor

Graphene has dazzled scientists since its discovery more than a decade ago with its unequalled electronic properties, strength, and light weight. But one long-sought goal has proved elusive: How to engineer into graphene a property called a band gap, which would be necessary to use the material to make transistors and other electronic devices.

Now, new findings by researchers at MIT are a major step toward making graphene with this coveted property. The work could also lead to revisions in theoretical predictions in graphene physics.



The new technique involves placing a sheet of graphene, a carbon-based material whose structure is just one atom thick, on top of hexagonal boron nitride, another one-atom-thick material with similar properties. The resulting material shares graphene's amazing ability to conduct electrons, while adding the band gap necessary to form transistors and other semiconductor devices.

The work is described in a paper in the journal Science co-authored by Pablo Jarillo-Herrero, the Mitsui Career Development Assistant Professor of Physics at MIT, Professor of Physics Ray Ashoori, and 10 others.