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High Acoustic Frequency Imaging

Tiny ceramic chip capacitors can be screened for defects using high acoustic frequency imaging.

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An internal structural defect in a ceramic chip capacitor becomes activated when it expands to create an electrical leakage path between two adjacent electrode layers. Expansion is usually the result of thermal cycling in service, and may be assisted by the presence of moisture.

Voids, delaminations and cracks are typical structural defects that can cause electrical leakage. Delaminations and cracks are the most likely to expand; voids tend not to grow, although they may still create a leakage path. A void is considered more dangerous if its diameter exceeds one-half the diameter of the dielectric in which it resides. Mechanically, the void reduces the strength of the dielectric and makes it easier for stresses to create a crack. Electrically, the void reduces the barrier between two electrodes and makes arc-over more likely.

Identifying a given defect specifically as one of these three types is not always easy, however. No sharp distinction exists between, for example, a void and a delamination of the same size. The more critical a particular application is, the more important it becomes to screen ceramic chip capacitors for structural defects before assembly. By using only defect-free capacitors, the risk of capacitor failure by this route can be reduced dramatically.

Screening for Defects
Non-destructive screening of ceramic chip capacitors is performed by acoustic microscopes. Typically, the microscope’s transducer raster-scans a tray of capacitors, pulsing ultrasound into the capacitors and receiving the return echoes from several thousand x-y locations per second. Ultrasound pulsed into a homogeneous solid material produces no echoes, but the interface between two dissimilar solid materials
reflects a portion of the ultrasound (see Figure 1).

The percent reflected, and thus the amplitude of the return echo signal, can be calculated from the density and acoustic velocity of the two materials. The boundary between a solid material and a delamination or other gap-type defect is the most highly reflective internal feature and reflects virtually 100% of the ultrasound. Voids, delaminations and cracks therefore appear bright white in the acoustic image.

Ceramic chip capacitors with very small x-y dimensions are common. However, the thickness of such a tiny capacitor may have actually increased in order to achieve higher capacitance. In some capacitors, the use of new dielectric materials may have made thinner dielectric layers possible. At the same time, the ultrasonic frequencies used in acoustic microscopes have gone up. Higher ultrasonic frequencies have better spatial resolution (a sharper image), but less penetration into materials.

Conventionally, ceramic chip capacitors have been imaged at frequencies of 30, 50 and 100 MHz, although some of the largest ones, measuring about 1 x 2 in. and about a quarter of an inch thick, have been imaged at 10 MHz. But in smaller ceramic chip capacitors, critical defects are also smaller and thus can be more effectively imaged at higher acoustic frequencies.

Using Higher Acoustic Frequencies

Engineers have recently demonstrated the use of the ultra-high frequency of 230 MHz on 0603 (0.06 x 0.03 in.) and 0402 (0.04 x 0.02 in.) ceramic chip capacitors. The advantage of the high frequency is that otherwise ambiguous features can be more certainly identified as defects or as harmless anomalies. The 230 MHz frequency is, generally speaking, the highest practicable frequency that can be used on a relatively wide range of samples.

Some acoustic microscope systems include 300 MHz transducer models and 400 MHz transducer models, but these frequencies have limited penetration and increasingly shallow fields of view (although the image resolution

![Figure 1. Ultrasound pulsed by scanning transducer is reflected moderately by solid-to-solid interfaces, but almost totally by solid-to-gap interfaces such as voids, cracks and delaminations.](image)

![Figure 2. Acoustic image of a group of 0603 ceramic chip capacitors. The enlarged capacitor has a defect in the electrode region; approximately 10 others have similar defects.](image)

![Figure 3. Acoustic image of a group of 0402 ceramic chip capacitors. The enlarged capacitor has a defect in the electrode region; no others have defects.](image)

for samples on which they can be used is superb). For example, the 400 MHz transducer has been used to image the bonding of solder bumps beneath a silicon chip. Silicon absorbs very little of the ultrasonic pulse passing through it and is often described as being “acoustically transparent.” Ceramic chip capacitors don’t have the transmission properties of silicon, so the 230 MHz transducer was a logical choice for small capacitors because this transducer combines very high spatial resolution with sufficient penetration into materials.

A ceramic chip capacitor is constructed in layers and has many internal material boundaries. If each boundary reflected ultrasound strongly, imaging might be difficult. But the dielectric and electrode materials are thin and quite similar in their densities and acoustic velocities. To a pulse of ultrasound, the defect-free areas of the capacitor are only moderately reflective. Any gap-type defect such as a delamination, though, is a near-100% reflector.

Figure 2 is the 230 MHz acoustic image of a group of 27 size 0603 ceramic chip capacitors. One capacitor (red arrow) has been enlarged to show detail, and the frame of the figure has been extended slightly to accommodate it. The electrode stack at the center of the package is mostly represented by a medium-to-dark gray tone, showing that the approximately 30 material interfaces collectively reflected a significant portion of each ultrasonic pulse.

The white spot in the upper half of the enlarged capacitor in Figure 2 is a void and therefore a threat to long-term reliability. In military and aerospace applications, a void will cause a capacitor to be rejected if the void extends through half or more of the thickness of one dielectric layer. This definition is a bit outdated, however: in the effort to pack more capacitance into each component, the number of layers has increased greatly in recent years, and the thickness of each layer has accordingly diminished. Reflection-mode acoustic imaging displays the x-y dimensions of a void or other gap-type defect, but not the thickness of the gap. In fact, the reflection of ultrasound at the solid-to-air interface at the top of a gap is nearly 100%—even if the whole gap is only 0.01 micron thick.

At least 10 of the capacitors in Figure 2 have small bright white defects. The precise location of a defect can
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make the difference between accept and reject: the void in the enlarged capacitor—and those in several other capacitors—are clearly among the electrodes. But in critical applications, a defect’s location may not matter because a void or other defect anywhere in the capacitor is cause for rejection.

Figure 3 (p. 15) is the acoustic image of a group of 32 ceramic chip capacitors measuring 0.04 x 0.02 in. Like the 0603s in Figure 2, these 0402s were imaged with a 230-MHz transducer. The only anomaly is a small defect in the capacitor shown at the upper left. The capacitor is enlarged at the top of the figure. The defect, although small (probably about 0.002 in. in diameter), is within the electrode portion of the package.

Both the 0603s and the 0402s shown here are square in end view; they are as thick as they are wide. Using an optical microscope, a group of such unmarked capacitors is first arranged on a tray. Each capacitor must be positioned so that the electrode plates are horizontal. Even though there are no markings, the external contour of each capacitor identifies the ones that need to be turned 90° in order to provide a horizontal layered structure for the ultrasound to propagate through. The capacitors are then imaged acoustically.

The higher 300 and 400 MHz frequencies mentioned earlier could be used to image very small capacitors, but because of the structure of capacitors and their size, the advantage would be slight. Even smaller capacitors such as 0201s and 01005s can be imaged acoustically at 230 MHz, but these tiny parts are seen only occasionally. The chief difficulty is not the process of imaging, but the time required for the handling of such minuscule samples. When these truly minuscule capacitors are needed for critical applications, however, their exceedingly tiny anomalies and defects can be imaged acoustically.

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