Acoustic Imaging and Screening of Ceramic Chip Capacitors

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On any printed circuit board, the number of surface-mounted ceramic chip capacitors is likely to be large and may even be greater than the number of any other component. And while these passive components lack the technical complexity of plastic-packaged ICs and other active components, they are very capable of causing the system to malfunction or even fail entirely.

Ceramic chip capacitor failures are sometimes caused because the formulation of the dielectric is not within specifications. Such a dielectric may form a leakage current at operating temperatures. Burn-in is very successful in identifying capacitors in this category and is usually carried out for 168 hours at twice the rated voltage at a temperature ranging from 85°C to 125°C.

But electrical burn-in cannot screen out all potential failures, many of which occur for a quite different reason—internal structural defects. In ceramic chip capacitors, these internal anomalies are, in order of frequency, voids, delaminations, and cracks. Some of these anomalies, of course, cause the outright failure of the capacitor, and such failed capacitors are easily found by electrical testing. More serious are the internal anomalies that give no initial electrical signature but that grow or change in service until they cause a failure.

Ceramic chip capacitors that have survived burn-in may also be screened by a nondestructive technique known as acoustic micro imaging, which is sensitive to voids, delaminations, and cracks—the structural defects that may eventually cause electrical failure. Capacitors that have successfully passed both burn-in and acoustic screening have a very high degree of reliability and are widely used in many types of critical applications. Sonoscan, the developer and maker of acoustic micro imaging systems, maintains an applications laboratory that has acoustically imaged millions of ceramic chip capacitors. Many of these had already passed electrical tests and were destined for automotive or consumer applications. Others had already passed through burn-in and were destined for aerospace or military applications. With the July 1998 revision of MIL STD C-123 (now MIL PERF 123-B), acoustic micro imaging became a required inspection method for ceramic chip capacitors in many high-reliability applications.

Voids, Delaminations, and Cracks

A void is basically a tiny pocket of air or another gas that is trapped during manufacture of the capacitor. Most voids are probably somewhat flattened bubbles. They may exist between layers of metal and dielectric or within a single dielectric layer.

A void can cause a failure in one of two ways. First, it can respond to normal thermal cycling by expanding as a crack; this crack can lead to a short between metal layers. For small voids, this type of growth is unlikely. What is much more likely, especially if the void is within a dielectric layer, is that metal will slowly migrate onto the inner surface of the void. Eventually, the void accumulates enough metal so that it becomes a leakage pathway between two electrodes and a short occurs. The problem from a reliability perspective is that the timetable is impossible to predict.

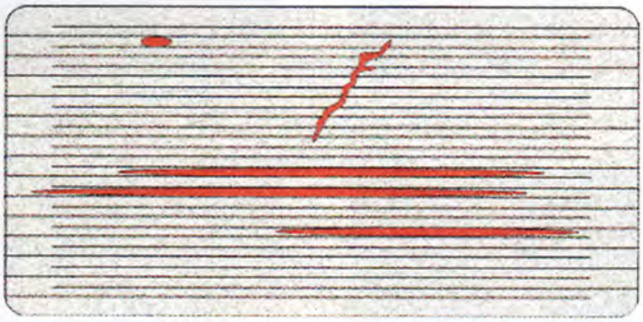

Figure 1: Diagram of a cross-sectioned ceramic chip capacitor shows the most frequent internal structural defects that can lead to electrical failure: voids, cracks, and delaminations.

Delaminations (which are often simply very large voids) and cracks may follow somewhat different routes, but, like voids, may eventually cause a short. Cracks typically extend vertically through several layers. Delaminations are horizontal, and a given delami-

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nation may be limited to a single interface. If any delaminations are present in a capacitor, it is not unusual for several delaminations to occur at multiple depths. These conditions are shown diagrammatically in Figure 1.

Finding these electrically invisible anomalies before assembly is relatively important in low-cost consumer products because the defects can degrade the mechanical integrity of the capacitor, causing it to crack or fall apart during soldering. Finding these anomalies is extremely important in military and aerospace products.

Imaging Internal Features

Acoustic micro imaging—the process of pulsing ultrasound into a sample and using the return echoes to create a high-resolution image—is by far the best method of finding internal anomalies in ceramic chip capacitors. It is much more efficient than, for example, neutron radiography, which is sensitive to relatively large defects where a significant mass of material is missing—something not generally true of the gap-type defects in ceramic chip capacitors.

The ultrasound pulsed into capacitors by acoustic micro imaging systems usually has a frequency between 10 MHz and 300 MHz. Lower frequencies penetrate deeper into materials, and higher frequencies can produce images with higher spatial resolution. This range of frequencies corresponds rather nicely to the imaging needs of ceramic chip capacitors. A relatively large, high-voltage capacitor within a plastic encapsulant might be imaged acoustically at a low frequency, such as 10 MHz or 15 MHz; the tiniest 0201 capacitor might be imaged at 100 MHz or higher.

In both cases, the ultrasound is pulsed into the capacitor (or into a tray of capacitors if the process involves mass screening) by the scanning transducer. Ultrasound travels downward into the capacitor until it encounters a material interface. At the interface, some portion of the ultrasound is reflected back to the transducer, where it will be collected. (In a truly homogeneous sample, such as a block of ceramic, there is no echo except from the top and bottom surfaces.)

How much of the ultrasound is reflected depends on the differences between the two materials—more specifically, on the differences between their densities and their acoustic velocities. When the ultrasound encounters an interface between an electrode and the dielectric in a capacitor, the differences are modest and only moderate reflection takes place. But any gap-type defect—a delamination, void, or crack—includes air or another gas. Therefore, ultrasound pulsed down onto a delamination encounters an interface between ceramic and air or between metal and air. Air is so much less dense than other materials with an acoustic velocity—so much lower that nearly all of the ultrasound is reflected back to the transducer. In the acoustic image, this very high degree of reflection gives delaminations, cracks, and voids very high visual contrast.

What the Acoustic Image Means

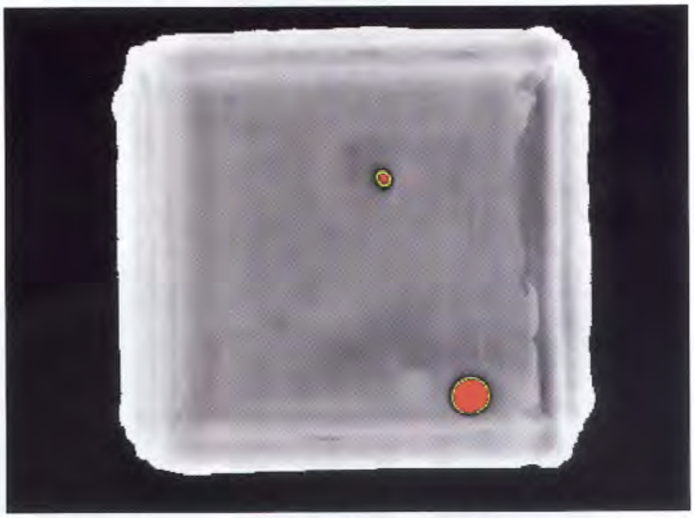

Figure 2: Internal voids (red) are often small and more or less circular. This acoustic image also shows the active area (gray) within the capacitor.

Figure 2 is the acoustic image of the internal features of a ceramic chip capacitor having relatively small internal defects. At the edges of this ceramic chip capacitor, where the ultrasound travels only through ceramic and not through any ceramic-metal interfaces, the acoustic image is white. Over most of the capacitor, where a very slight reflection of ultrasound has occurred at each of many ceramic-metal interfaces (slight, because the layers are very thin and because the differences in acoustic properties are small), the accumulated reflections give the image a gray color. Gray in this case represents a higher intensity of reflection than white.

But this capacitor also contains two small, roughly circular voids. The voids, because of the very sharp change in density and in acoustic velocity at the interface, are bright red; the slightly thinner edges of the voids are yellow. Red in this instance (the choice of color is arbitrary) indicates the highest degree of reflection.

In most cases, there is probably little qualitative difference between voids and delaminations. Both are nonbonding gaps in the capacitor; delaminations are different from voids chiefly in the area they cover. A capacitor may contain multiple large delaminations without suffering an immediate electrical failure. In one early study (circa 1985), every one of a group of ceramic chip capacitors that had passed initial electrical tests was found to contain huge multiple internal delaminations. Although those capacitors performed electrically at the

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moment, their life expectancy was very limited.

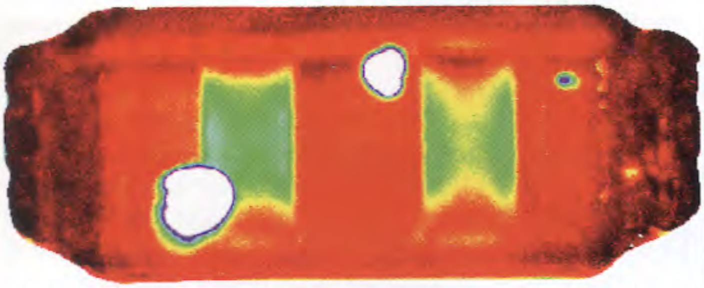

Figure 3: Internal delaminations may be large and occur at different depths within the capacitor. In this acoustic image, delaminations are white. Green areas are part of the internal structure of the capacitor.

Multiple Delaminations

The capacitor shown in Figure 3 has two large delaminations—the white regions indicating a high degree of acoustic reflection—in addition to a smaller void at upper right. The green areas are not defects, but are part of the internal structure of the capacitor.

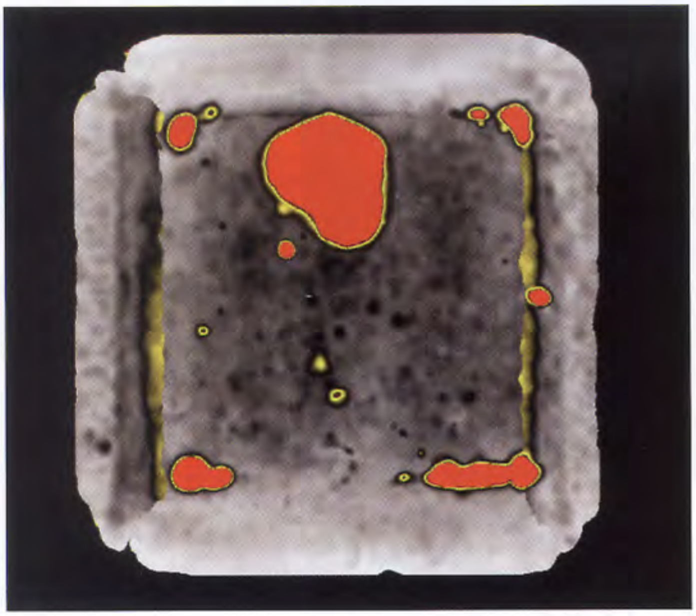

Figure 4: This capacitor has a large red delamination, smaller red and yellow delaminations and voids, and even smaller voids (dark gray, black) grading down to variable porosity within the dielectric.

The capacitor imaged acoustically in Figure 4 has several internal features of interest. The most prominent are several red defects. The largest defect is a delamination, while the smallest red features may be classified as voids because of their small size. But there are even smaller black and yellow features that are clearly anomalies. These are voids as well; they are yellow or black rather than red because of their small area. The smallest of these might be described as porosity within the dielectric. The numerous anomalies nearly obscure the fact that the electrode stack is visible as a darker gray rectangular feature.

Low-Volume and High-Volume Screening

Acoustic imaging of ceramic chip capacitors is typically done to qualify a new lot of capacitors or to screen marginal or defective capacitors from a lot. Conventionally, most screening has been performed manually, imaging a single capacitor at a time or imaging large groups. The area scanned by the ultrasonic transducer can hold dozens or hundreds of all but the largest high-voltage capacitors.

Very recently, automated acoustic imaging of ceramic chip capacitors has been carried out, using a high-throughput system that loads, inspects, and unloads trays of parts automatically. This system was primarily designed to perform automated imaging of plastic-packaged integrated circuits before surface mounting (the value being that it can remove from the production stream any IC package having a gap-type internal defect) and is well suited for imaging ceramic chip capacitors. ❑