void in an electronic part or component is like an air bubble that appears by various means during raw materials processing that is later cured or hardened. Although it is simplest to think of a void as a trapped air bubble, many voids—depending on the host material and processes—are not formed by entrapment and do not contain air.

Whatever their etiology, voids are significant because they can cause electronic failures. They occur in polymers such as molding compounds and flip chip underfills, in metals such as solder, and in ceramics such as those in ceramic chip capacitors. Often the void that causes an electronic failure is very small and operates as a slow-motion failure mechanism that can lead to unanticipated field failure.

In terms of inspection, voids are very susceptible to imaging by acoustic microscopes because they all contain a solid-to-gas interface. The acoustic properties of any solid-to-gas interface are profoundly different from the properties of solid-to-solid interfaces. A void’s solid-to-gas interface reflects virtually 100% of the ultrasound pulsed into the material; the very high amplitude signal sent back to the acoustic microscope’s transducer can become a very bright pixel in the acoustic image. As the transducer scans over the surface of the part and sends pulses of ultrasound into the part, internal voids show up as white (or pseudocolor) features. The acoustic images shown in this article were made in Sonoscan’s various Sonolab offices.

**Voids in encapsulants**

To encapsulate a lead frame-mounted integrated circuit (IC), a gate in the mold machine is opened and the fluid mold compound flows into the cavity around the lead frame and IC. The pressure applied to the fluid mold compound, the speed with which it flows, and the mold compound temperature are all critical to void-free encapsulation.

During transfer molding, the most widely used method, several process changes can create voids in the encapsulant:

- Excessive moisture in the molding compound – Atmospheric moisture can find its way into a molding compound if the compound is exposed to air when being warmed. Moisture expands during transfer molding and forms voids.
- Low viscosity – A fluid mold compound having too low a viscosity may flow into the cavity in an uncontrolled fashion and trap air and volatiles.
- Excessive transfer speed – If the fluid mold compound enters the cavity too quickly, it tends to spray rather than flow. Exit vents may be blocked by the spray before all air and volatiles are expelled.

Figure 1 shows the C-SAM acoustic microscope image of one portion of a plastic-encapsulated microcircuit (PEM) package. The rows of diagonal lines are wire loops extending from the die. This image was gated to include only the depth from the top of the die (the base of the wires) up to the mid-point of the wires. Gating means that only acoustic echoes from this depth range were used to make the image. Echoes from other depths were ignored.

Mixed in among the wires are small bright white features that indicate voids. One concentration of voids is marked by the red oval. The shallow depth encompassed in this image illus-
trates that the voids are close to the wires in all three dimensions. A void positioned between two wires can result in a leakage path for current between the two wires, threatening reliability. Over time, voids may absorb moisture and contaminants from the environment, leading to wire corrosion and electrical shorting failure modes. Worse yet, if voids impinge on a wire, electrical failure is likely.

The mottled pattern of the molding compound in Fig. 1 is related to, but does not directly represent, filler particles and epoxy. Very tiny features that are bright white may well be tiny voids.

Voids can cause failures in plastic-encapsulated devices in other ways as well. Examples include connecting two lead fingers and causing them to short; by appearing in the die attach beneath the die and blocking heat dissipation; and by lodging on top of the die at a wire bond (although delaminations are more common here) and causing the bond to break.

Various types of underfill processes used to protect the solder connections beneath flip chips (and, more recently, silicon interposers) are also subject to voiding, and resulting failures. Underfill voids can block heat dissipation from the flip chip—because the solid-to-gas interface at the top of a void that reflects ultrasound so well is also a good reflector of heat. These voids can also create electrical failures by causing solder bumps to collapse and break contact.

Figure 2 shows the acoustic image of a flip chip section. The image is gated on the solder bumps (small circles) and the underfill surrounding them. At center, the large bright feature is a void that makes contact with at least eight of the solder bumps. The pattern and color of each of the small circles connected to the void is uniform, and more importantly is the same as the pattern and color of those bumps away from the void. This means that no bump has yet become detached. But the functioning of those bumps partly or wholly unsupported by underfill is likely to be brief.

The mechanism by which voids destroy solder bumps is shown in the diagram in Fig. 3. The void, at right, creates an empty space in place of cured underfill supporting and encasing the bump. With repeated thermal cycling, the solder begins to move. Pb-solder is most likely to creep into the void, while the more rigid Pb-free solder will probably fracture. In either case, the bump may eventually slump to such a degree that it will become detached from the bond pad on the flip chip above. Lead-free solders tend to deform more slowly than solders containing lead, but both types are susceptible to this failure mechanism. This type of defect is a key reason why such large numbers of flip chips and silicon interposers—the former from both development and production, the latter chiefly from development—are imaged in Sonoscan’s laboratories.

Voids in solder

Solder joints connecting the external leads of a component to a printed circuit board are not imageable by ultrasound because they present no flat surface; ultrasound merely scatters in many directions from their rounded and unpredictable shapes.

But solder is often used to attach a heat sink to a single component such as a flip chip, or to an assembly such as a printed circuit board or an isolated-gate bipolar transistor (IGBT). In these applications, the integrity of the solder is important, primarily to ensure that voids do not prevent heat dissipation and thereby cause chips to overheat.

Figure 4 shows the acoustic image of a metal heat sink portion that was soldered to one side of a printed circuit board. The weave of the board and a few other features can be discerned in the background. The red-yellow features are ultrasonically highly reflective voids in the solder. These may simply be pockets of air trapped when the solder was applied; one of
the large voids seem to have taken on the shape of a printed circuit board depression that matches a component on the other side of the board. Collectively the large and small voids cover a large enough percentage of the heat sink to make overheating a concern. To some degree, they also weaken the attachment of the heat sink to the board.

More critical voids occur in the solder that bonds heat sinks to IGBT modules. These power devices typically generate high heat levels, and do not tolerate high levels of voids in the heat sink solder. Acoustic imaging through the heat sink not only finds voids, but also can map solder thickness at the same time. Irregular thickness often means that ceramic plates under the solder are tilted.

Voids in ceramics

Many of the voids imaged by acoustic microscopes reside in multilayer ceramic chip capacitors. A void in a ceramic capacitor is confined to a single layer of dielectric material. Such voids are formed during fabrication. Cracks and delaminations are probably both more frequent causes of electronic failure in ceramic capacitors than are voids, but voids could serve as crack initiators. After failure occurs, the void site that caused the failure may, either optically or acoustically, resemble a crack. Voids can also occur in electrode layers, where they pose little danger to reliability.

Military inspection standards define any ceramic chip capacitor in which there is a void whose diameter is more than half the thickness of the dielectric as a reject. A void with a diameter greater than this may be susceptible to a leakage current. This current may be small initially, but it may eventually degrade the dielectric until there is a leakage path between the two adjacent electrodes. In a low-power environment, a void of this type may show no symptoms for a relatively long time; in a high-power environment, failure is likely to occur more quickly.

Figure 5 shows the acoustic image of a multilayer ceramic chip capacitor containing an unusual type of void. The long, straight white feature is a void created not by air, moisture, or volatiles, but by a single fiber dust particle that found its way

![Acoustic image of a multilayer ceramic chip capacitor](image)

**Fig. 5** — Acoustic image of a multilayer ceramic chip capacitor shows many tiny voids (bright spots) and a single relatively huge void that once held an airborne fiber that was incinerated during firing.

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into the layers of the capacitor. When the capacitor was fired, the fiber vanished, leaving the void. The dozens of much smaller bright pinpoint features are tiny voids in the various layers of dielectric in the capacitor.

Much larger voids sometimes appear in monolithic ceramic parts in electronic assemblies, where there is no layered structure. Depending on the application in which the part is used, large voids may result in structural weakness or an imbalance caused by the irregular distribution of weight in the part.

A flat, perforated ceramic disk is shown in Fig. 6. To make this image, a 3-D acoustic method developed by Sonoscan for its C-SAM systems was used. The method allows the operator to remove echoes pertaining to specific material interfaces from the acoustic image. The side walls and bottom surface were removed. The bulk of the ceramic is not imaged because, being monolithic, it had no interfaces to reflect ultrasound. The top surface was retained to indicate the shape of the sample and the much brighter images of internal voids. The bottom surface of the disk was just below the large void group; note a few smaller voids in other locations. Being able to see the 3-D structure of the disk and the complex anomalies within the disk can simplify the process of learning how voids formed.

Voids occur in many other electronic parts. One example is direct bonded wafers, where a void between the two wafers can cause silicon to fly loose as one wafer is thinned. Many failures are not so immediate, and a small molding compound void that is not near another surface may pose no risk at all. It is the potential for voids to generate unanticipated field failures that makes them such frequent subjects for acoustic micro imaging.

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