Ultrasound’s sensitivity to material interfaces makes it useful in screening plastic-encapsulated microcircuits (PEMs) and other components used in the assembly of medical electronics products. The purpose of screening is to identify and remove from production individual components that contain internal structural defects that could cause electrical failure of the component and compromise the functioning of the product.

Acoustic microscopes are used to carry out this screening because the high frequency and ultrahigh frequency ultrasound they employ does not damage or alter the components. The acoustic images that are produced by the microscopes depend on the fact that ultrasound is reflected by the interfaces between materials. When the scanning transducer of an acoustic microscope sends a pulse of ultrasound into a sample, there are three possible outcomes:

- If the sample is homogeneous (a defect-free block of ceramic, for example) no ultrasound will be reflected from the sample’s interior because there are no material interfaces.
- If the pulse strikes the bonded interface between two solid materials (a polymer and a metal in a PEM, for example), a portion of the pulse will be reflected to the transducer for imaging, and a portion will be transmitted across the bonded interface and will travel deeper until it reaches the next material.
- If the pulse strikes a delaminated or non-bonded interface between two solid materials, it is actually encountering the interface between the first solid material and a gas such as air. More than 99.99% of the pulse will be reflected, even if the delamination or nonbond is as thin as 0.01 μ. The high amplitude negative echo is caused solely by the solid-to-gas interface and is typical of gap-type structural defects such as nonbonds, delaminations, and voids—all of which are of interest because they are capable of causing the eventual electrical failure of the component.

Using an acoustic microscope to scan trays of PEMs increases the long-term reliability of the product by removing questionable components. The reliability requirements of medical products are often similar to those of military and aerospace products. In these industries, some applications permit internal anomalies that appear harmless, while others permit no internal anomalies at all. Manufacturers of medical electronics systems may also use IPC/JEDEC, JEDEC, NASA or Mil STDS standards that place limits on the types, locations, and number of defects in a PEM based on reliability concerns.

Acoustic scanning of PEM lots is often performed by a laboratory acoustic microscope. Laboratory C-SAM systems are basically analytical tools rather than production tools, but they are capable of handling the typically small lot sizes involved in medical electronics production. The PEMs are generally manually loaded into a suitable tray and scanned; a high throughput rate is not as important as identification and removal of defective components.

Acoustic screening can also be important for FDA approval of a medical product. When a product is being redesigned, acoustic screening may be necessary to justify the use of a new or different PEM. In practice, a lot of PEMs may be scanned twice. During the initial scan the transducer pulses ultrasound into the PEM, but signals are collected only by a sensor below the PEM.

Figure 1. Red areas in this acoustic image show a lack of bonding between the mold compound and the lead fingers and die paddle before (left) and after thermal cycling (right).
Delaminations and other gaps reflect ultrasound upward, with the result that what arrives at the sensor below is a dark acoustic shadow of the defect. These transmission-mode images give no depth information about the feature creating the shadow, but they are a fast way to find most gap-type defects.

Reflection-mode imaging is used next. The transducer pulses ultrasound into the sample but in this case receives the echoes from solid-to-solid and solid-to-air interfaces a few millionths of a second later. The echoes are gated on (encompass) the bulk of the PEM body, which is typically thin enough for the ultrasound to be in focus over the entire vertical extent of the PEM with a properly selected transducer.

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How likely a given anomaly is to cause an eventual electrical open or short depends on which type of anomaly it is and its location. In general, unless reliability studies have been performed, it is often difficult to accurately predict the future behavior of an anomaly. During their service life, Delaminations, nonbonds, and voids often expand, which is a typical cause of broken connections and overheated die. They are also points where moisture and contaminants that penetrate the mold compound collect and form tiny electrolytic cells that initiate corrosion.

Figure 1 shows the reflection-mode acoustic image of a PEM in its original state (left) and after 1000 thermal test cycles (right). The red areas are high-amplitude reflections from delaminations or other gap-type defects. Testing, which was designed to produce the effects of normal thermal cycling in an accelerated format, has caused the original defects to grow and has created new defects. Most of
the defects on the left side are delaminations along the top surface of lead fingers. Because no defect extends the full length of the lead finger, allowing ingression, these would meet the standards of J-STD-020, an IPC/JEDEC joint standard.

The square feature at the center of each image is the die. On the left, there is a faint yellow line where the die meets the die paddle. Although innocent in appearance—it might just mark the boundary of two materials—this yellow feature probably represents the early stages of the red area surrounding the die in the image to the right. This red area shows that the mold compound has separated from the die paddle. The risk is that this delamination will extend under the die into the die attach, where a delamination can cause the die to overheat and fail. In addition, any wire bonds to the paddle will be subjected to stresses that may lead to a break in the wire interconnect.

In some medical products, some anomalies may be acceptable. Figure 2 is a simplified side-view diagram of a plastic-packaged BGA. Anomaly 1 is an isolated void in the mold compound, not adjacent to wires, leads, or other important elements. Its future behavior depends on the type of mold compound, the environment in which it is used, and other factors, but, in general, such a void is very unlikely to cause a failure.

Anomaly 2 is a delamination or nonbond between the die face and the mold compound. The die face is one of the worst possible locations for an anomaly because it is very likely to expand and break nearby wire bonds. The die face also acts as a reservoir for contaminants that can corrode the metallization on the surface of the die. Anomaly 3, a delamination or nonbond in the die attach material, prevents the removal of heat from the die. Anomaly 4 is a delamination within the interposer/substrate, which can also prevent heat transfer or cause an interconnect failure. Although ultrasound must pass through multiple materials to reach this depth and be reflected, such anomalies—which are dangerous—can usually be imaged. Anomaly 5 is a delamination/nobond between the mold compound and the leads, but is near a wire bond and therefore a reliability threat. If this package were a flip chip BGA, a defect like Anomaly 5 might be acceptable.

Of these five anomalies, Anomaly 1 would probably be acceptable in many applications but perhaps not in implantable devices. Anomalies 2, 3, 4, and 5 would almost certainly be cause for rejection.

Simply identifying these defects is acoustic screening; determining what process deviations caused them to be there is analytical work. There are many acoustic techniques for analyzing features in samples.
The high-throughput production system mentioned earlier has a software tool that permits making successive images at specific thin-slice depths moving downward through the PEM. Just as the return echo signals can be gated on the whole thickness of a PEM in order to find anomalies and defects at any depth, echoes can be gated by this tool on very thin depths. The number of depths can be as many as 200 (probably too many for analyzing a PEM), meaning that a single gated depth can be a small fraction of a millimeter in thickness. Typically, the gates are all of the same thickness and are adjacent to each other, but many other arrangements can be selected.

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Figure 3 shows two of the 50 thin slices into which one PEM was divided. Counting from the top surface of the PEM, these two images show depths 24 and 25. Each gate is 36 \( \mu \) thick. To image each thin slice of the BGA, only the echoes that arrive at the transducer in a time frame (measured in nanoseconds) that matches the gate are used. (The 23 gates above this chiefly show the mold compound and, nearer to the die, the tops of the wire loops.)

Gate 24 is on the left and shows some red areas (arrow) that might be of concern. There are also red areas around the wire bonds at the inner ends of the leads.

Gate 25 brings the lead fingers into focus and reveals numerous red delaminations (arrows) that are long enough to be worrisome. The wire bond areas also look delaminated in this image, as does part of the die face. Careful acoustic imaging of this PEM has revealed several problematic features and their precise depths.

This approach is useful, for example, when initial reflection-mode imaging, which includes most or all of the PEM’s thickness in a single gate, spots a void in
Testing the same x-y location as lead fingers. A void that is in contact with or between lead fingers is likely to initiate corrosion that will eventually create a short between the lead fingers. Thin-slice imaging can show the real depth of the void in relation to the lead fingers. It may reveal that the void is well above the lead fingers and relatively harmless.

There are numerous other specific techniques (such as measuring the flatness of a BGA package, or the thickness of a material layer) that can be used to solve particular problems. Acoustic screening and subsequent analysis are useful tools in achieving overall reliability in medical electronics.

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