Eliminating electronic failures is about the little things

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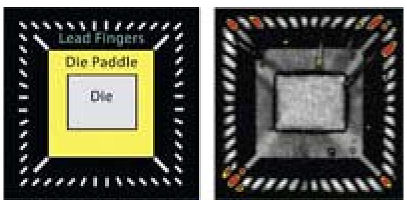

Figure 1. Lead fingers in this PEM (plastic-encapsulated microcircuit) design are very short. Wires are therefore close to the package exterior and susceptible to delamination-caused corrosion.
Select figure to enlarge.

Field failures in medical electronics systems often originate in structural anomalies in the plastic-encapsulated microcircuit, or PEM. The structural anomalies may be very small, but over time thermal stresses and exposure to moisture and contaminants can cause them to grow until they cause an electrical failure. The types of stress depend on environment. That is, an implanted device sees essentially no thermal stress, but may be susceptible to residual stresses originating in its construction. These field failures may be avoided by eliminating the structural anomalies from production.

Most of these anomalies consist of cracks, delaminations, or voids. An unresolved residual stress is not visible acoustically, unlike a crack resulting from residual stress. The various anomalies may be formed during construction and encapsulation of the PEM, or during assembly processes. Voids may form during application of die attach material and the die, or during injection-molding of the mold-compound. Delaminations are non-bonded regions between two materials such as the mold compound and the die face, or the mold compound and the lead fingers. Cracks are nearly always popcorn cracks, which occur much less frequently than a decade ago.

Because delaminations, cracks, and voids are gaps in solid materials, they can be imaged by acoustic micro imaging systems. The transducer of an acoustic micro imaging system scans the PEM while pulsing VHF or UHF ultrasound into it and receiving the return echoes. The echoes are returned only by material interfaces within the PEM, and not by the bulk of homogeneous materials. An acoustic image will display, for example, the bonded interface between the mold compound and the die face, but the strongest echoes come from gaps - meaning delaminations, cracks, and voids. For example, if a portion of the top surface of a die is bonded to the mold compound above it, and an adjacent region is disbonded, both regions will be imaged, but the disbonded region will return much higher amplitude signals to the transducer and will appear much brighter in the acoustic image.

The acoustic images illustrating this article were made by the SonoLab division of Sonoscan, Inc. One of the main functions of the laboratory is to screen PEMs for internal anomalies before the PEMs are used in the production of medical systems. Medical equipment manufacturers may also screen their own PEMs with in-house C-SAM acoustic microscopes. How rigorous the component screening may be depends on the extent to which system failure threatens the life of the patient. A pacemaker or diabetic pump is more critical than a system that does not directly impact patient survival, or whose impact on the patient is gradual rather than immediate.

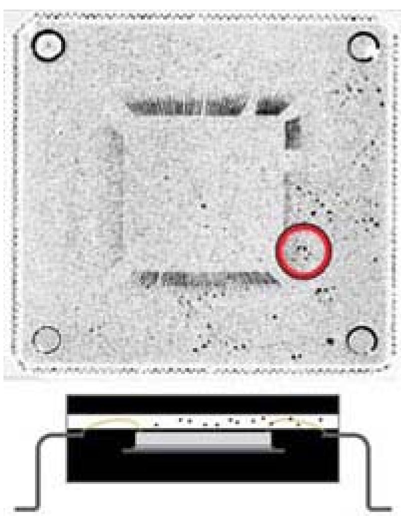

Figure 2. Black dots (circled) in the acoustic image of this PEM are voids in the mold compound among the wire loops. Diagram shows side view.

Acoustic imaging is a direct and nondestructive way of weeding out anomalies, but in some cases anomalies, and the resulting field failures, can be avoided by careful design. For example, a lead frame that incorporates very short lead fingers and that creates a situation in which the outer wire bond is close to the exterior of the package. If a delamination occurs along the short lead finger, moisture and contamination can easily corrode the wire bond and break its connection. Not all packages having short lead fingers experience this type of failure; many operate for years without a problem. However, selecting an equivalent device with longer lead fingers when designing a medical electronics system may prevent this type of failure.

The diagrammatic view and the acoust ic image of a PEM having short lead fingers are shown in **Figure 1**. The red areas in the acoustic image are delaminations along several of the lead fingers. What the acoustic image actually displays is the interfaces between materials (the mold compound and the die; the mold compound and the die paddle, etc.). In this image the defect-free interfaces are gray. Red in this image is used to display the delaminations, which have the highest-amplitude reflections.

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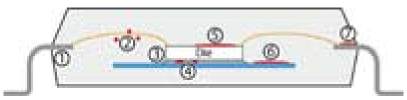

Figure 3. Side view diagram shows some of the design concerns and structural anomalies that can lead to field failures. 1: very short lead finger. 2: voids in mold compound. 3: small die on large die paddle. 4: voids in die attach material. 5: delamination between die and mold compound. 6: delamination between die paddle and mold compound. 7: delamination on lead finger.
Select figure to enlarge.

The growth of anomal ies, and their ability to cause electrical failures, can in part be explained by the ways in which PEMs respond to moisture and contaminants in the atmosphere. Moisture settles on the outer surface of the PEM, along with a variety of contaminants. Molecules of both moisture and contaminants gradually migrate into the mold compound. In the interior of the PEM, the molecules tend to settle on sur faces at material interfaces - meaning the lead fingers, the die paddle, and the die face. A layer of water and contaminants only several molecules thick can become an electrolytic cell, which begins corrosion of nearby materials. If there is an existing delamination on a lead finger, it may become an electrolytic cell, or the water and contaminants may form a delamination. Eventually the resulting corrosion may, for example, break a wire bond and cause an opening. Alternately, it may destroy the mold compound between two lead fingers and cause a short.

There are many other possible scenarios. **Figure 2** is the acoustic image of the wire loops in the mold compound, just above the top of the die. The groups of fine dark lines are the wire loops. At the same depth in the mold compound are small voids (one group is circled). The white area in the diagram highlights the critical depth in the component. Where a void is too close to the wires, the void may begin the corrosion process and ultimately break one or more wires.

Another potentially troublesome design is a PEM in which a relatively small die is mounted on a relatively large die paddle. Since moisture and contaminants tend to collect on surfaces, and since the die paddle is often the largest internal surface, this combination tends to result in disbonded die. Packaging reliability specialist Paul Melville at NXP Semiconductors, San Jose CA points out that a small die on a large paddle means that the wires will be very long, and therefore susceptible to wire sweep during molding.

An effective way to prevent field failures is to image PEMs acoustically before they are used in production in order to remove those having internal defects. PEMs having internal defects that move through production are likely to pass end-of-line electrical testing. Melville routinely images a great variety of PEMs to determine their moisture sensitivity level for IPC/JEDEC standards. He has often observed PEMs whose acoustic images reveal extensive internal damage, yet pass electrical tests because the cracks and other flaws have not yet broken a wire or, in extreme cases, cracked the die. Thermal stresses, moisture and corrosion will later cause a field failure. **Figure 3** shows some of the internal anomalies and design problems that can result in electrical field failures.

Figure 4 is the acoustic image of one-half of a PEM that has a frequently observed defect: the silver-plated inner ends of the lead fingers -- just where the wires from the chip are bonded -- are delaminated (red areas) from the mold compound. The absence of a bond between the mold compound and the lead finger in this area means that thermal changes can cause movement, and that moisture and contaminants can gather here. Either of these events can break wires. A likely cause of this defect is the choice of a mold compound that does not adhere well to silver. In a sense, this is a design problem, but the design and material choice are in the hands of the component manufacturer, and not the assembler of the medical system.

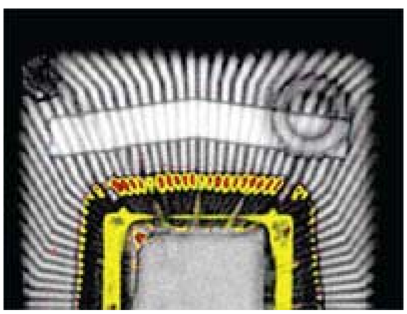

Figure 4. Delaminations (red features) at inner ends of lead fingers, perhaps caused by using a mold compound that does not adhere well to silver.

Since the delaminations are not likely to be immediately lethal, this is a type of defect that can slip through electrical inspection. Where high reliability is imperative, manual or automated acoustic imaging is used to screen PEMs before assembly. For large-volume automated imaging, PEMs are conveyed in JEDEC- style trays. Smaller lots can be placed on flat trays and imaged by laboratory-type acoustic micro-imaging systems. In both methods, software tools can identify and analyze specific features in specific locations in an acoustic image. The accept/reject criteria are determined by the user of the PEMs. The multiple delaminations in the PEM shown here are obviously in a critical location and would be a cause for rejection, but a single small delamination that is far from either end of a lead finger might be acceptable because it is not near wire bonds and because it would presumably take a very long time to expand to the point where it creates an open path to the exterior.

Once a lot of PEMs have been screened acoustically and moves into production, they may still be damaged by handling, reflow, or other processes. For this reason, mounted PEMs are sometimes imaged acoustically after reflow. Imaging at this point may be more difficult. For example, a tall component may have to be removed to provide access for the ultrasonic transducer.

Still, if a hard-to-pinpoint process flaw is suspected, acoustic imaging remains a nondestructive and fairly fast method of analysis. Even more important, the troubleshooting clues it gains during the production process could be the difference between life and death in the field.