ENCAPSULANTS FOR HIGH-RELIABILITY MICROELECTRONICS

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Rajeev Kulkarni
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BGAs offer the twin advantages of high lead counts and freedom from external leads. Like other plastic-packaged ICs, they can fail because of internal structural flaws—delaminations, voids and the like. And like other plastic-packaged ICs, they can be imaged and analyzed by acoustic micro imaging tools, although their internal structure demands somewhat different imaging techniques.

Small and large lots of plastic BGAs are screened by an acoustic micro imaging tool before assembly in order to remove defective parts, or after failure to diagnose the cause of failure. In the commonly used amplitude mode, acoustic micro imaging typically pulses ultrasound into a component package and uses the amplitude of the return echoes to make acoustic images. Plastic BGA packages differ in some significant ways from other plastic package types. The lack of a lead frame and the presence of an interposer/substrate are major structural differences. Plastic BGAs are typically relatively thin and wide, characteristics which make them prone to warping. Warping is important because it creates internal stresses that can break loose the solder bonds that hold the solder bumps beneath the BGA to its substrate. The normal thermal cycles encountered in service can cause repeated flexing and unflexing of the BGA package, with unpredictable results.

An acoustic micro imaging tool such as a Sonoscan C-SAM® system is most often used to collect amplitude data to image and analyze internal defects such as delaminations. But the tool has numerous other modes, one of which pulses ultrasound into a package, then ignores the amplitude of the return echoes and records only the arrival time of the echoes from the package's top surface. By collecting the distance from the transducer to the BGA package surface at each of the thousands or millions of x-y coordinates it pulses ultrasound into, Sonoscan's Acoustic Surface Flatness mode uses color to show that this plastic BGA package is warped.
BGAs imaged and analyzed acoustically

Mode maps the contours of the package surface. It is a fast way to check the flatness of a BGA package. Amplitude mode and Acoustic Surface Flatness mode can be used simultaneously, during the same scan, so that surface flatness and internal features, including defects, can be both be imaged at once.

Figure 1 is the acoustic flatness image of a warped plastic BGA where the highest elevations are blue and magenta, and the lowest elevations are red. The warpage in this BGA package is more or less symmetrical. The four corners are raised significantly above the lowest points, which are at the center.

Warpage in plastic BGA packages is common, and worrisome because the highest stresses tend to be at the corners of the package. The solder bumps near the corners are pulled upward and are therefore more susceptible to being broken. Another concern: BGA packages that are warped do not always behave the same way when heated and cooled; i.e., stresses might unexpectedly become greater in some parts of the package.

Figure 2 is a three-dimensional representation of the same BGA surface, but here the vertical distances have been greatly exaggerated to make them more obvious. As the scale shows, the low point near the center has a value less than 0.1mm, while the highest edge at upper left has a value of about 0.5mm. The total vertical warpage is thus greater than 0.4mm.

The most interesting depths in the acoustic search for structural defects in BGA packages are the die and substrate surface, and depths below them. The mold compound above the die is not often the site for a significant structural anomaly. But imaging the BGA package in several sequential thin gates starting at the top surface can reveal surprising details. Software developed by Sonoscan lets the operator create up to 200 gates, which may be of the same or different vertical dimensions, and which may be adjacent to each other, overlapping or separated.

Figure 3 shows gates 2 through 5 of the 20 sequential gates, each 50 microns wide, used to image a plastic BGA package. Gate 1 (not shown here) displayed chiefly the grey-black pattern created by, but not directly representative of, the filler particles; gates 2 through 5 are shown here.

The red features in gate 2 (and in the remaining gates) are the very high intensity reflections from air bubbles in the mold compound. Air bubbles at these depths in a BGA package are very unlikely to cause
Each delamination is essentially a thin flat bubble of air or another gas. Even if it is as thin as 100Å, it will reflect essentially all of the ultrasound that strikes the solid-to-gas interface. In this image, the ultrasound reflected from the interface travels upward and encounters numerous traces and other features above. These block the returning ultrasound, so those traces and features are displayed acoustic acoustic shadows. The same features outside of the delaminations are displayed directly in reflection mode.

The structural defects that most frequently cause failures in plastic BGAs are at the depths of the die and substrate surface or lower. Figure 4 was gated to include the face of the die in a different BGA package. Most of the die face—the two red areas—are delaminated from the mold compound above. The gap between the mold compound and the die face reflects >99.99% of the ultrasound and thus has the highest signal amplitude. But the region of the die face that is still bonded to the mold compound reflects ultrasound more modestly and is displayed as the gray region. The wires leading from the die are yellow in this color map. The stresses placed on wires by the delamination in the red areas, though, may have already broken connections.

Figure 5 in the acoustic image of a BGA where there are two delaminations (arrows) within the layers of the substrate. Each delamination is essentially a thin flat bubble of air or another gas. Even if it is as thin as 100Å, it will reflect essentially all of the ultrasound that strikes the solid-to-gas interface. In this image, the ultrasound reflected from the interface travels upward and encounters numerous traces and other features above. These block the returning ultrasound, so those traces and features are displayed acoustic acoustic shadows. The same features outside of the delaminations are displayed directly in reflection mode.

Gap-type defects deeper in the interposer may be imaged in reflection mode, but problems are likely to be encountered in imaging them for two reasons: 1) the weave of the fiberglass tends to scatter ultrasound strongly; and 2) if the resin did not thoroughly wet the fiberglass during fabrication, there are likely to be numerous air bubbles. Imaging a delamination that is relatively far down in the interposer requires the initial ultrasonic pulse to travel through such obstacles, and also requires the return echoes to travel through the same obstacles. On some plastic BGA packages, such imaging can be done; on others, it cannot.

Beneath the interposer lies a feature that is of great interest but hard to reach acoustically: the bond of the solder balls to their pads. If the ultrasonic pulse can reach this interface, it will send back medium-amplitude echoes that will be displayed in gray—meaning a good bond and no defects. If the bond of a particular solder ball is white, then it is disbonded. The problem, though, is that the ability of the interposer to scatter ultrasound often means that the condition of the BGA solder ball attach cannot be determined by reflection-mode imaging.

Reflection-mode imaging itself has recently added a new mode that will be helpful in imaging BGAs and other package types. In conventional reflection mode imaging, a pulse is sent into the package at each of thousands or millions of x-y coordinate positions. If the pulse strikes a material interface within the gated depth, numerous echoes are returned at various frequencies, but reflection-mode software uses only the single echo having the highest frequency to determine the pixel color.

The new integral mode uses all of the echoes from the interface at that x-y location to determine the pixel color. Since faint echoes are included along with strong echoes, integral mode can do a better job of displaying subtle differences. One example: a material interface between two solids where the quality of the bond varies, even though there are no actual disbonds. Integral mode will show local variations more clearly.