ANALYSIS OF BGA AND OTHER AREA ARRAY PACKAGING USING ACOUSTIC MICRO IMAGING

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Abstract

Long term reliability is of concern with regard to Ball Grid Array (BGA) packages. The unique construction of these devices can present a challenge to inspectability. Clearly, it is a benefit for both process development and quality control to have a method of evaluating these devices for internal physical anomalies which are related to premature failure. Acoustic Micro Imaging (AMI) has demonstrated utility for the nondestructive analysis of plastic BGA packages. In general, acoustic microscopes use high frequency ultrasound (5 to 500 MHz) to image the internal features in materials or components. The ultrasound is sensitive to variations in the elastic properties of materials and is particularly sensitive to locating air gaps (delamination or void). It is routinely used to locate delamination and popcorn cracking in BGAs. There are other potential applications for acoustic microscopy in the evaluation of BGAs, such as evaluation of the die attach or evaluation of the solder joints. However, it is necessary to understand the capabilities and limitations of acoustic methods relative to the construction of these devices in order to determine which applications are viable. For example, it is better to evaluate the condition of the die attach through the top (encapsulant) side of the package providing there are no large defects in the molding compound or delamination at the encapsulant/die interface. Evaluation of the die attach through the back side of the part would not be possible if the BGA is bonded to a PC board. If the part was not already bonded to a substrate the influence of the solder balls could complicate the information at the die attach when the die attach is evaluated from the bottom side of the BGA.

Two types of acoustic microscopes were used in this study: the Scanning Laser Acoustic Microscope (SLAM), which operates in the through transmission mode, and the C-Mode Scanning Acoustic Microscope (C-SAM), which is a reflection mode instrument. The work in this study concentrated on determining the optimum techniques, frequencies and other inspection considerations for a number of applications in BGA packages. A survey of appropriate applications is presented. This study also addresses the reasons that some applications are not possible using ultrasonic methods. During the course of this investigation other types of area array packages were also investigated. Examples of applications on flip chip devices will be included. Although many applications are possible with other area array packages such as microBGA, CGA and TGA, these applications will be presented at a later time.

Keywords: BGA, Area Array Packages, Acoustic Microscopy, Acoustic Micro Imaging, AMI

Background - Acoustic Micro Imaging (AMI)

There are two types of acoustic microscopes which can be used to study and evaluate Area Array Packages. The Scanning Laser Acoustic Microscope (SLAM) and the C-Mode Scanning Acoustic Microscope (C-SAM). Both instruments utilize high frequency ultrasound to detect internal discontinuities in materials and components.

The SLAM is a through transmission technique (Figure 1) operating at frequencies between 10 and 500 MHz. SLAM utilizes a scanning laser detector of the ultrasound to obtain real time (1/30 second per image) ultrasound images of the internal features of a material. The ultrasound travels through the entire volume of the material, and the scanning laser detects the variations in the transmitted ultrasound.

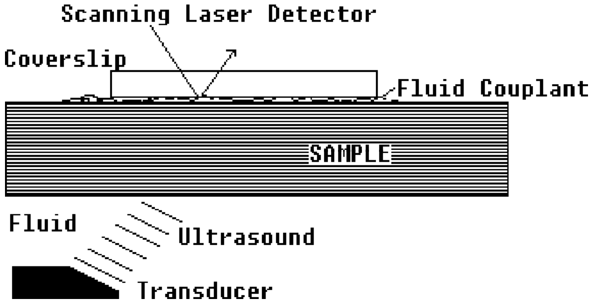

Figure 1: Block Diagram of a Scanning Laser Acoustic Microscope (SLAM)

In SLAM analysis, a continuous plane wave of ultrasound penetrates the entire thickness of the sample. The pattern of transmitted ultrasound is then detected by a rapidly scanning, finely focused laser beam which acts like an ultra sensitive point-by-point "microphone". The transmission of ultrasound is affected by internal features and defects, discontinuities and material properties. Images, which are produced in real time (1/30 of a second), simultaneously reveal bond integrity of all interfaces throughout the entire sample thickness.

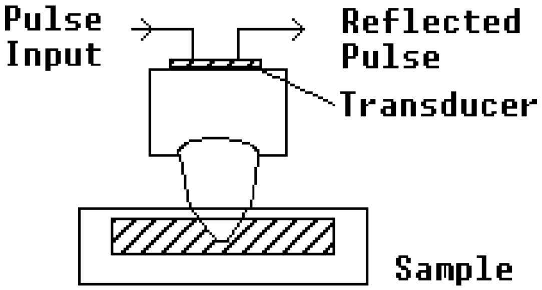

Figure 2: Block Diagram of a C-Mode Scanning Acoustic Microscope (C-SAM)

The C-SAM operates in the pulse-echo mode, typically over a range from 5 to 200 MHz, to produce level specific images of a sample (Figure 2). A focused ultrasonic transducer works alternately to send and receive reflected signals within the sample. An electronic gate is used to select a specific depth, or, interface. A very high speed mechanical scanner is used to index the transducer across the sample and produce images in tens of seconds.

Operating frequencies ranging from 15 to 180 MHz were used for the data in this study. In general the higher the frequency the higher the resolution in the acoustic images. Lower frequencies, however, provide more transmission through materials. A frequency which provides the best compromise of resolution and penetration can be found to suit most applications.

There are several different imaging modes of Acoustic Microscopes. A discussion of the modes which will be referred to in the text of this paper follows.

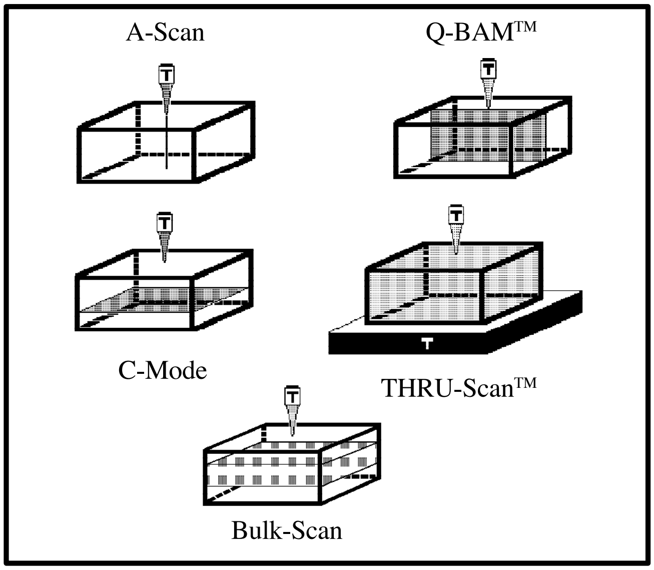

Figure 3: Various modes of C-SAM system used for BGA and Flip Chip analysis.

Experimental Methods and Discussion

Through Transmission Mode

Through transmission imaging modes rely on sending the acoustic signal through the entire thickness and/or multiple layers of a sample and detecting the transmitted signal using a separate receiver. Defects, if present, block the ultrasound from the detector, appearing as dark shadows in the acoustic image. The SLAM uses a scanning laser as the detection method, as shown in Figure 1. The C-SAM's Thru-Scan™ mode uses a second transducer as the detector, as seen in Figure 3.

A-Scan

Reflection mode acoustic microscopes can acquire information in several different ways (one of which, the Thru-Scan™, is mentioned above). The fundamental information, using the reflection mode, is contained in the A-Scan. The A-Scan displays the depth information in the sample at one X,Y coordinate. Echoes displayed in the A-Scan correspond to different interfaces in the device being examined. The distance between the echoes relates to their depth in the device. The following formula can be used to calculate the exact depth within the sample:

$$D=vt/2$$

Where, D = distance, v = velocity of sound & t = time

The amplitude and phase information of the echoes is used to characterize the condition at the interface. The equation which describes the interaction between materials at an interface is as follows:

$$R = \frac{Z_2 - Z_1}{Z_2 - Z_1}$$

Where, R = Reflection Coefficient, Z_1 & Z_2 = Acoustic Impedance of Materials 1 & 2, respectively.

Interface Scan Technique (C-Mode)

The basic imaging method commonly used to evaluate devices for delaminations and voids is the interface scan. This method involves gating the specific echo for the interface to be investigated. The focus of the acoustic beam is optimized for the interface as well. Figure 3 describes the interface scan technique called C-Mode. The acoustic image of the interface displays both the amplitude and phase (polarity) of the gated echoes via the AIPD (Acoustic Impedance Polarity Detector).

Bulk Scan Technique

This technique is used to image the acoustic appearance of the “bulk” of a material as opposed to a specific interface. A diagram of the “Bulk Scan” technique appears in Figure 3. The gating of the acoustic signal within the material begins immediately after an interface echo and includes all of the area up to the next internal interface echo. The focus is at a level within the thickness of material. If the material is entirely homogeneous, there will be little or no signal to be displayed in the image. Voids or other discontinuities will cause signal reflections which appear as bright areas in the image. This imaging mode is typically used in material characterization applications, such as molding compound analysis. However, it also has utility in applications where the exact level of a defect can vary slightly. An example of this situation is locating voids within the thickness of the solder volume of BGA or Flip Chip attachments.

Q-BAM™ (Quantitative B-Scan Analysis Mode)

Q-BAM™ is an imaging mode that provides a nondestructive cross-sectional view of the sample along a designated line through the device, as seen in Figure 3. Each pixel of the cross section is in the correct focus for that depth in the sample. The distances between the internal depth levels is related to the sonic velocity within the material.

BGA Analyses

Plastic Ball Grid Arrays (PBGA) have the potential to become the most prevalent package type. The detection of “popcorn” cracks and related delaminations have been a concern. Due to the design of the PBGA a single interface scan of the device is not sufficient to detect the full extent of damage in these devices. Where possible, the through transmission techniques provide the best overall map of the flaws present within the entire device. This method is recommended for inspection of individual devices prior to mounting on the substrate. Figures 4A & 4B compare through transmission images for a “good” BGA package (4A) and a device showing a popcorn crack (4B). The images were made at an operating frequency of 15 MHz to provide optimum penetration through the volume of the part. In the image of the good device the package is transmissive to the ultrasound. Details of the internal structure are visible such as the outline of the die and the shape of the die pad metallization. Some black areas are seen within the outline of the die which are most likely voids in the die attach. The part exhibiting the popcorn effect shows a large dark area at the center of the device in the image which corresponds to the laminar crack(s).

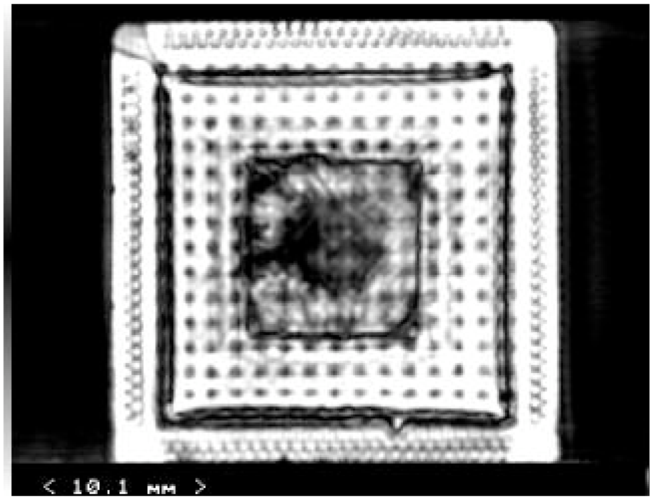

Figure 4A: Through transmission image of a "good" BGA

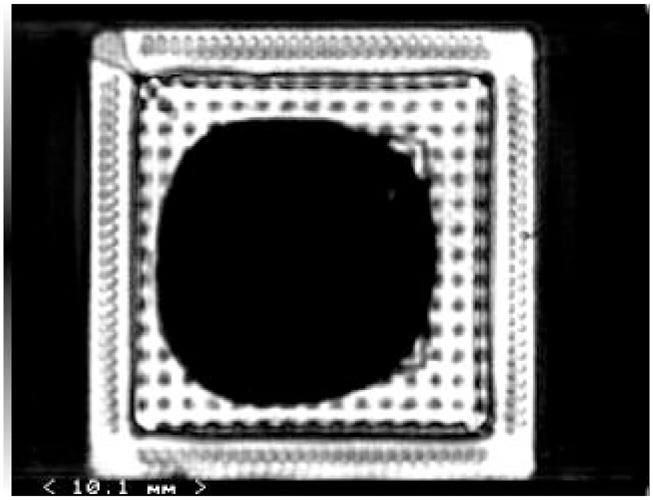

Figure 4B: Through transmission image of a BGA with a popcorn crack.

Once the device is mounted to the substrate, however, the through transmission technique, which requires unobstructed access to both sides of the unit, is not appropriate. A method can be employed to provide a through transmission type picture on the mounted BGAs. This technique looks at the reflection at the bottom side of the substrate through the entire device thickness. Similar to through transmission, any defects within the device block the signal from the interface resulting in a black shadow.

To make a more detailed assessment of the defects present in a device interface scans are used to investigate specific layers within the device such as the mold compound/die, die attach or mold compound/substrate interfaces. Figure 5 shows the mold compound/die interface and the gate includes the mold compound/substrate level. The levels were accessed through the top of the device at a frequency of 15 MHz. Only cracks or voids in the mold compound will interfere with this technique. This sample was examined as mounted to a PC board which would make imaging through the back of the part impossible. The die surface was bonded to the molding compound in this sample except for one small corner (circled area), however, large delamination (popcorn effect) is seen surrounding the die at the mold compound/substrate interface.

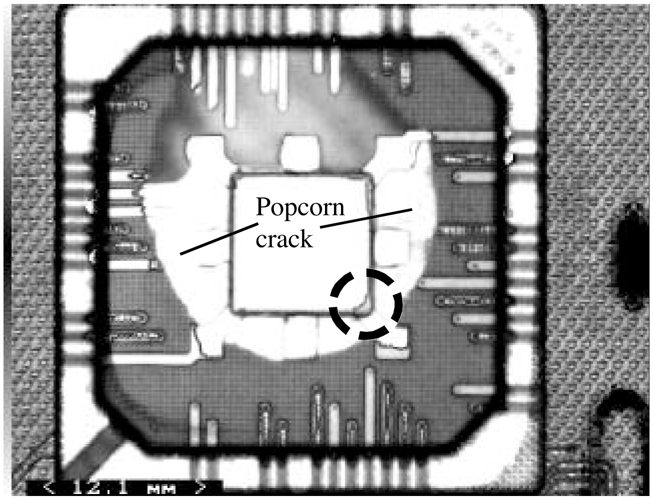

Figure 5: C-Mode image of a popcorn cracked BGA at the molding compound/substrate interface.

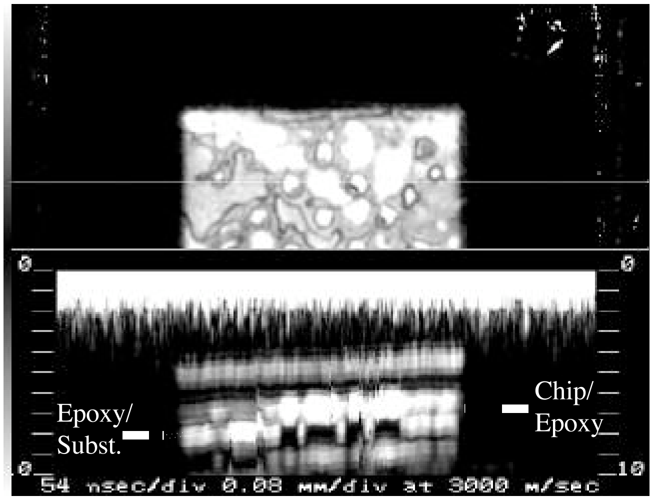

Figure 6: Q-BAM™ image of BGA with voids at both interfaces within the die attach.

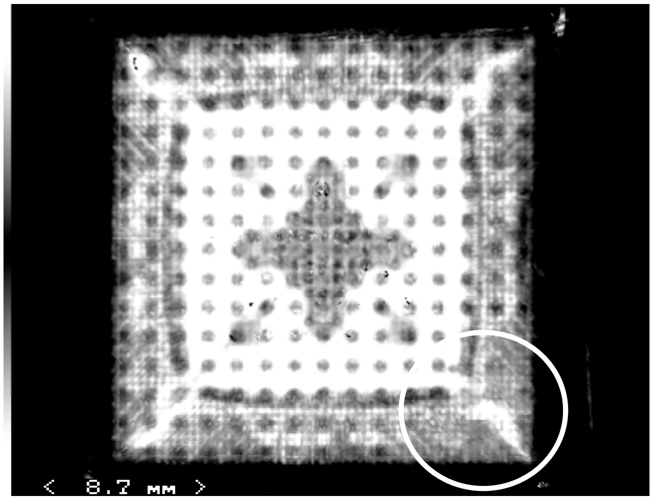

Figure 7: C-Mode image of a BGA soldered to a substrate. Notice the missing bump pattern (circled).

Figure 6 describes the die attach analysis of a PBGA. Again, the access was through the top of the device. Even though this was an unmounted unit it is advisable to access the interface through the least complex construction and fewest levels. In this case the frequency used was 75 MHz in order to provide better axial (Z axis) resolution. The imaging parameters include both the die/adhesive and adhesive/substrate levels. Voids are present in the die attach. The Q-BAM™ cross section through the die attach is shown in the lower half of the screen. In the cross sectional view the encapsulant/die surface interface is seen above the die attach levels, and delamination at the die/adhesive level can be distinguished from the adhesive/die pad interface.

Evaluation of the solder joints to the board is also of great interest. However, access to the substrate to bump level is difficult, if not impossible, through the PC board side of the assembly. The composite board material tends to be extremely attenuating to the ultrasound. Basically, the more composite and copper layers present, the greater the attenuation. Also, vias in the boards located in the proximity of the solder joints causes excessive scattering of the signal which interferes with the data. The best access to the solder joints is generally through the device itself providing no other defects exist in the device which will block the ultrasonic signal from that level.

Figure 7 shows a BGA with some solder joints to the substrate missing in one corner (circled area). A frequency of 15 MHz was used to penetrate through the thickness of the device. The influence of the metallization can be seen in the image. This device did not contain a die.

Figures 8A & 8B demonstrate that the solder joint level can not be accessed when a defect, such as a popcorn crack or delamination, is present within the sample. Figure 8A displays the substrate to bond pad level in one corner of this device. The edge of the popcorn crack is indicated by the arrows. The

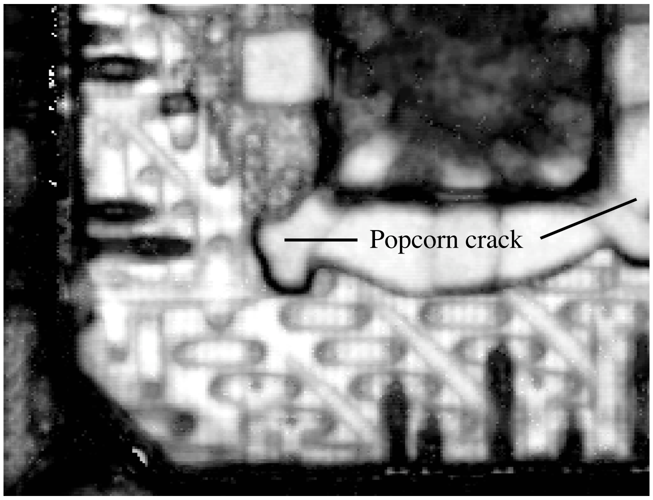

Figure 8A: C-Mode image of a popcorn cracked BGA at the substrate to bond pad interface.

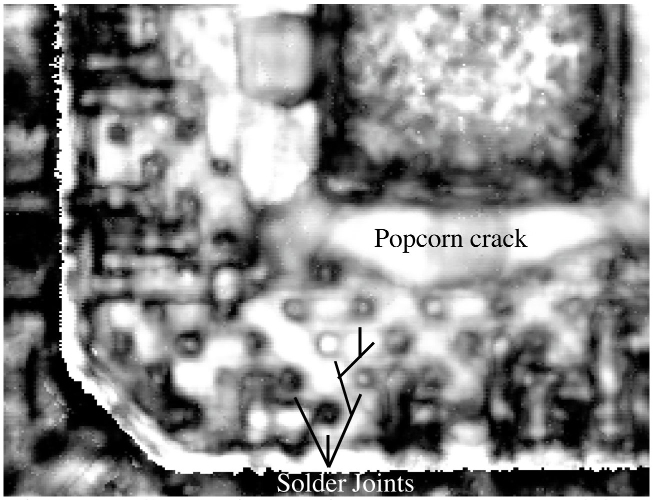

Figure 8B: C-Mode image of a popcorn cracked BGA at the solder joint level.

black traces are delaminated at the same level as the popcorn crack. The "daisy chain" pattern is evident at the bond pad level. Figure 8B shows the solder joint level. In the areas where there is access to the solder joints a variation in the acoustic appearance of the bonds indicates a variation in the quality of the bonds. The solder joints can not be seen below the popcorn crack. Both images were obtained at 15 MHz.

As the images demonstrate, access to and evaluation of the solder joints in PBGA packages is not as simple as an evaluation for delaminations in the package itself. However, this preliminary work shows some promise.

Examination of Voids in Solder Joints In Flip Chip Devices

In this sample the chip was bonded to a composite substrate. A frequency of 180 MHz was used for evaluation of the solder joints. Due to the composite substrate all access to the solder joints was through the chip side of the sample. The composite substrate was too attenuating to the high frequency ultrasound for examination through this material.

Figure 9 shows a comparison of scans at two levels in the attach. Figure 9A shows the chip/bump level. The bumps (pattern of dark spots) appear bonded at this interface. Voids in the underfill are apparent as white features in the image.

The bump/substrate level is displayed in Figure 9B. The bumps appear white at this level. Note that compared to the pattern at the previous level, some bumps are missing. This indicates that voids are present within the solder joints, which are blocking the gated interface.

Figure 10 shows another example of flip chip attach. This 180 MHz image displays the chip/bump interface. Voids are present at the attach site in some of the joints. Voids are also present in the underfill.

These same acoustic microscopy techniques have been applied to other types of area array packages, such as TBGA and microBGA with similar results.

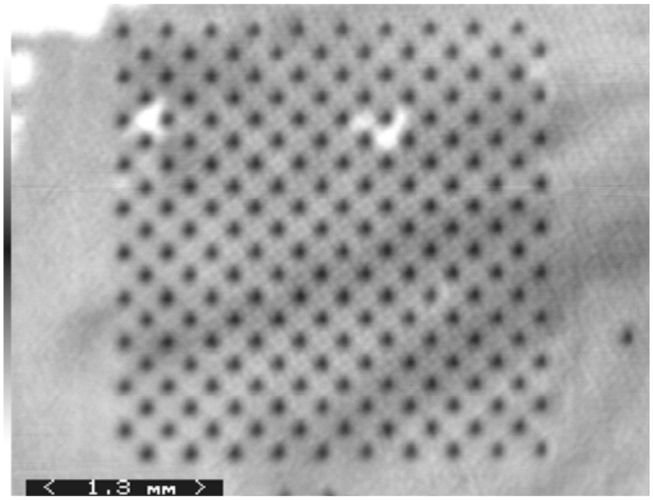

Figure 9A: C-Mode image Flip Chip sample at the chip to bump interface.

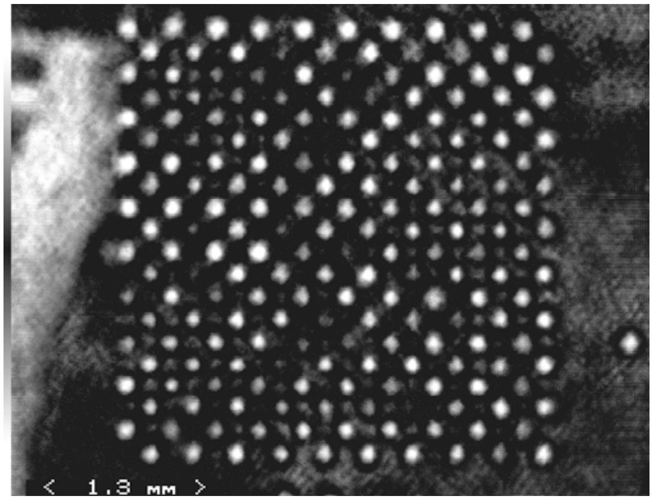

Figure 9B: C-Mode image Flip Chip sample at the bump to substrate interface.

CONCLUSION

Area array packages do present some challenges to the inspection of their quality. The data presented in this study shows that Acoustic Micro Imaging (AMI) methods can be used to evaluate the devices. There are various operating frequencies and/or techniques of gaining information from the packages which can be implemented to accommodate different package constructions and materials. Further correlative studies are recommended with regard to the analysis of the solder joints in PBGAs, but, for detection and characterization of defects within the devices themselves, Acoustic Micro Imaging (AMI) has proven to be a valuable method for the evaluation of Area Array Packages.

References

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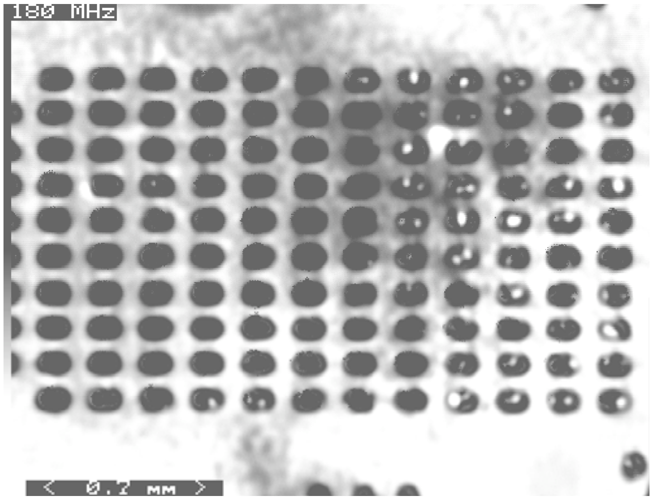

Figure 10: C-Mode image Flip Chip @ 180 MHz showing voids in the solder joints and underfill.