

# CHARACTERIZATION OF FLIP CHIP BUMP FAILURE MODES USING HIGH FREQUENCY ACOUSTIC MICRO IMAGING

Janet E. Semmens and Lawrence W. Kessler  
SONOSCAN, INC.  
530 East Green Street  
Bensenville, IL 60106 U.S.A.  
Tel: 630 766-7088 Fax: 630 766-4603  
E-mail: sonoscan@WorldNet.att.net

## ABSTRACT

Flip chip technology is being used increasingly as a method of interconnecting a die to a substrate. There are reliability concerns associated with the technique such as pre-existing voids in the solder joints or non-wet of the solder to the bond pads. Defects in the interconnections can also occur during use of the device or during life simulation tests such as thermal cycling. For reliability determination a nondestructive method is needed to examine the solder joints in the "as assembled" units as well as in the "post stress" condition. Acoustic micro imaging has been used as a nondestructive method to evaluate flip chip attach with promising results. Acoustic microscopes utilize high frequency ultrasound to examine the internal features in materials and components. The instrument used in this study was a C-SAM (C-Mode Scanning Acoustic Microscope) operating in the reflection mode at frequencies of 100 to 180 MHz. A previous paper presented analyses done on flip chip test samples. These samples contained known induced defects at the chip/bump and bump/substrate interfaces. Using these samples the optimum techniques for inspection of the flip chip attach were developed. This information was used as baseline for the work presented in this paper.

This presentation describes the analyses on a set of samples which showed failures after thermal cycling. The failures according to destructive physical analysis were thought to be cracks in the solder joints. However, a one to one correlation could not be seen between acoustic data and initial destructive physical analysis. With further investigation unexpected laminar cracks were discovered under the bond pad and in the surrounding glassivation layers on the

silicon die. These were difficult to see in the cross sections unless specifically looked for by referring to the acoustic analysis.

The data presented in this paper shows the acoustic images of flip chip samples before and after thermal cycling and describe the acoustic signatures of the defect types along with the supporting correlative analysis.

## BACKGROUND - ACOUSTIC MICROSCOPY

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

For the analysis of flip chip devices the C-SAM is specifically used. The C-SAM operates in the pulse-echo mode, typically over a range from 5 to 180 MHz, to produce images of samples at specific depth levels (Figure 1). With C-SAM a focused ultrasonic transducer alternately sends pulses into and receives pulses from reflected signal and discontinuities within the sample. Since the echoes are separated in time based on the depths of the reflecting features in the sample, an electronic gate is used to select a specific depth or interface to view. A very high speed mechanical scanner is used to index the transducer across the sample and produce images in tens of seconds.

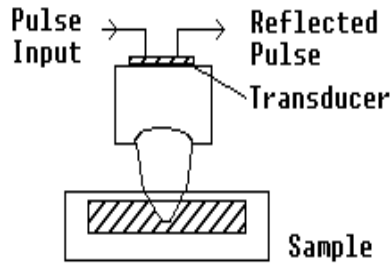


Figure 1 - C-SAM (C-Mode Scanning Acoustic Microscope)

For flip chip analyses the system is used at high frequencies ranging from 100 MHz to 180 MHz in order to provide higher resolution of the bumps themselves. Both spatial (x, y) and axial (z dimension) resolution is an important consideration in evaluation of flip chip devices.

#### FLIP CHIP INTERCONNECT EVALUATION

Flip chips are mounted circuitry side down (flipped) directly to the substrate connection sites by means of solder bumps (in most cases), or gold bumps. The devices are typically underfilled with an epoxy encapsulant to seal the device and add mechanical strength. A badly bonded bump or voids in the solder bumps can lead to faulty operation of the device.

Voids in the underfill material can also cause problems. Flip chips are typically evaluated using the reflection mode technique due to the fact that the devices are mounted in many cases to multilayer substrates or composite boards. These types of substrates prohibit access to the bond interfaces of the interconnects in the through transmission mode. The reflection mode allows for single sided access through the back of the silicon die. The small size of the bonds necessitates evaluation at frequencies of 100 to 180 MHz. Scans are generally done at the chip/bump interface to show defects at this level, and, at the bump substrate level to detect defects occurring within the volume of the solder bump. Figures 2 and 3 show examples of C-SAM 180 MHz images of flip chip samples.

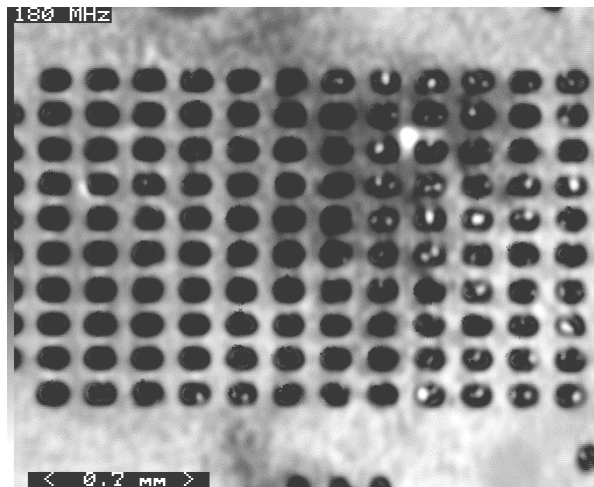


Figure 2 - 180 MHz C-SAM image of flip chip bond Small voids at the interface appear as white features. Bonded bumps appear dark. A void (white area) is also present in the epoxy underfill.

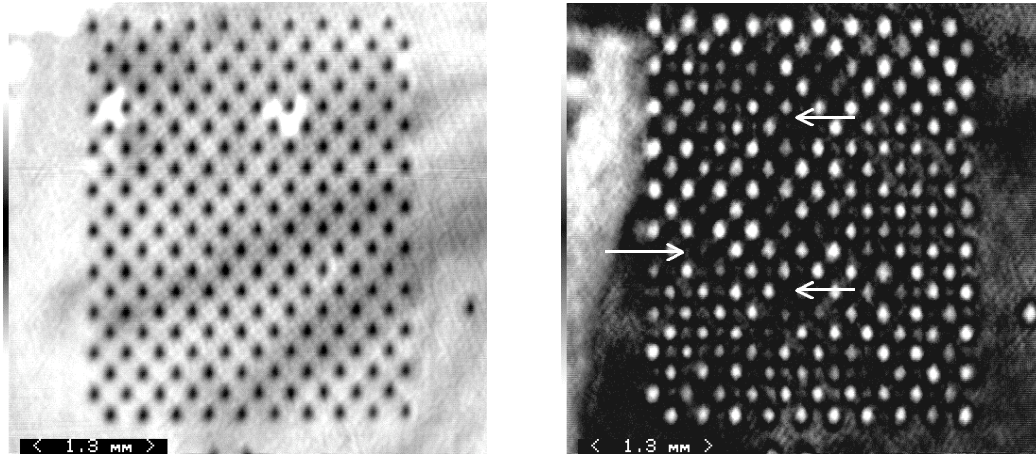


Figure 3 - Compares the acoustic image of the chip to bump level (left) to the bump to substrate level (right) in a flip chip sample. At the chip to bump interface bonded bumps appear dark in the acoustic image. At the bump/substrate level the bump should appear bright if there are no defects present in the image to obstruct the ultrasound from this level. Any defect at a previous level will block the ultrasound from this level causing the bump site to appear darker like the areas indicated by the arrows.

#### EVALUATION OF THERMALLY CYCLED UNITS

The devices used in this study demonstrated electrical failures after thermal cycling. The samples were examined with microfocus x-ray. Voids detected in the solder joints after thermal cycling were also present prior to cycling. Subsequent destructive physical analysis using standard optical microscopy revealed the presence of cracks in the solder joints which were thought to be the primary failure mode (Figure 4).

Up to this point acoustic micro imaging had not been employed. Now, flip chip samples which had been thermally cycled were submitted for acoustic analysis to determine if a non destructive method could be found to locate defects in the solder joints particularly the expected cracks in the solder joints. At first a technique was employed to look through the solder joints to the substrate level (Figure 5). In this way any defect within the volume of the solder joint would cause a shadow in the image rendering it detectable. (similar to Figure 3). In the initial acoustic data set a large number of solder bond sites appeared to contain defects.

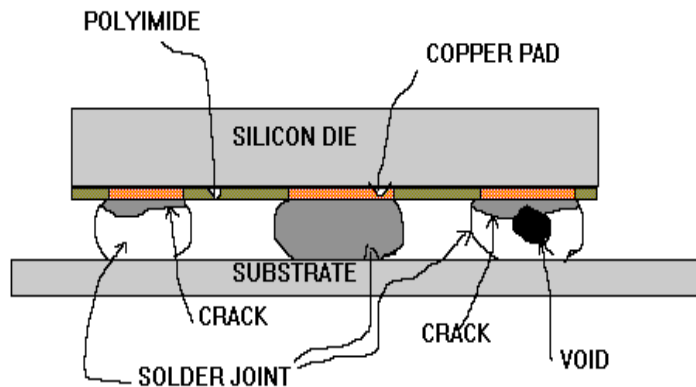


Figure 4 - The above diagram shows the general construction of the device and the expected failure mode, cracks in the solder bumps.

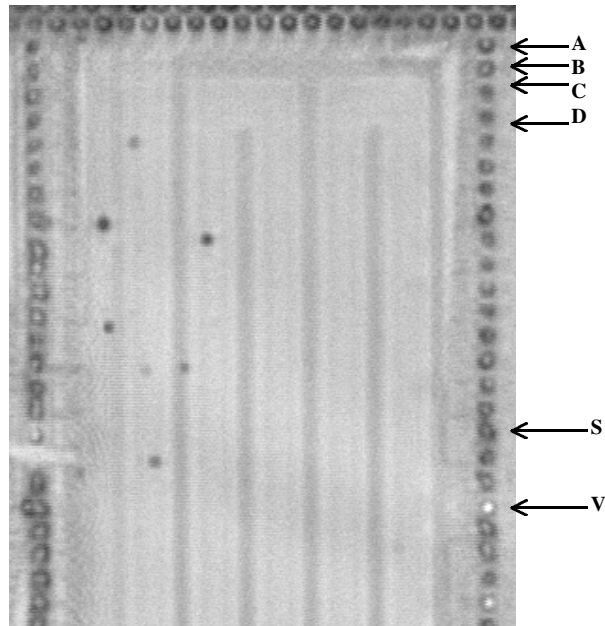


Figure 5 - Acoustic image of the bump to substrate level. At this level defects in the solder bumps above the interface cause dark shadows in the image of the bond site. The bright appearance of several bumps indicates they are the only defect free bumps.

The samples were then subjected to destructive physical analysis and conventional optical microscopy for correlative analysis. At this time the defects were assumed to be cracks and voids in the solder based on previous samples which had not undergone acoustic analysis. Initially the acoustic data did not show good correlation with the DPA results. Bumps which were cracked as seen in the DPA showed defects acoustically. However, many of the solder bumps indicated to be defective acoustically did not appear to have cracks in the solder joints. Figure 6 displays the optical micrographs for several example bumps which are indicated on the acoustic micrograph shown in Figure 5.

Additional samples of the same type were evaluated acoustically. Samples which had been thermally cycled showed many defects acoustically so a further effort was made to determine where the defects were located.

An initial hint of the problem came from the observation that some of the bond sites appeared larger than others and somewhat irregular in shape (Figure 7). This did not correlate with any part of the

construction process. In reality, the “chip/bump interface” consists of several very thin layers - silicon, glassivation, bond pad, polyimide and solder bump. Shadows or destructive interference of the signal caused by a defect in the surface layers on the silicon could cause the bonded and defective bond sites to appear similar in the acoustic image. By using a microslicing acoustic imaging technique the complex interface could be inspected more closely. In the region closest to the silicon, just prior to the bump, the scans now exhibited strong signal reflections in some of the bond sites characteristic of the presence of disbonds. Some features were observed which appeared larger than the size of the solder joint. The position of the echo signals suggested that defects were present in the layers preceding the bond pad to bump level. It was also likely that the cracks were very thin. Acoustic microscopy is capable of detecting laminar flaws below 0.1 micron in the depth dimension. This could account for the flaws being missed during the initial correlative studies. Figure 8 displays an acoustic image of a thermally cycled sample containing the white, irregular defects.

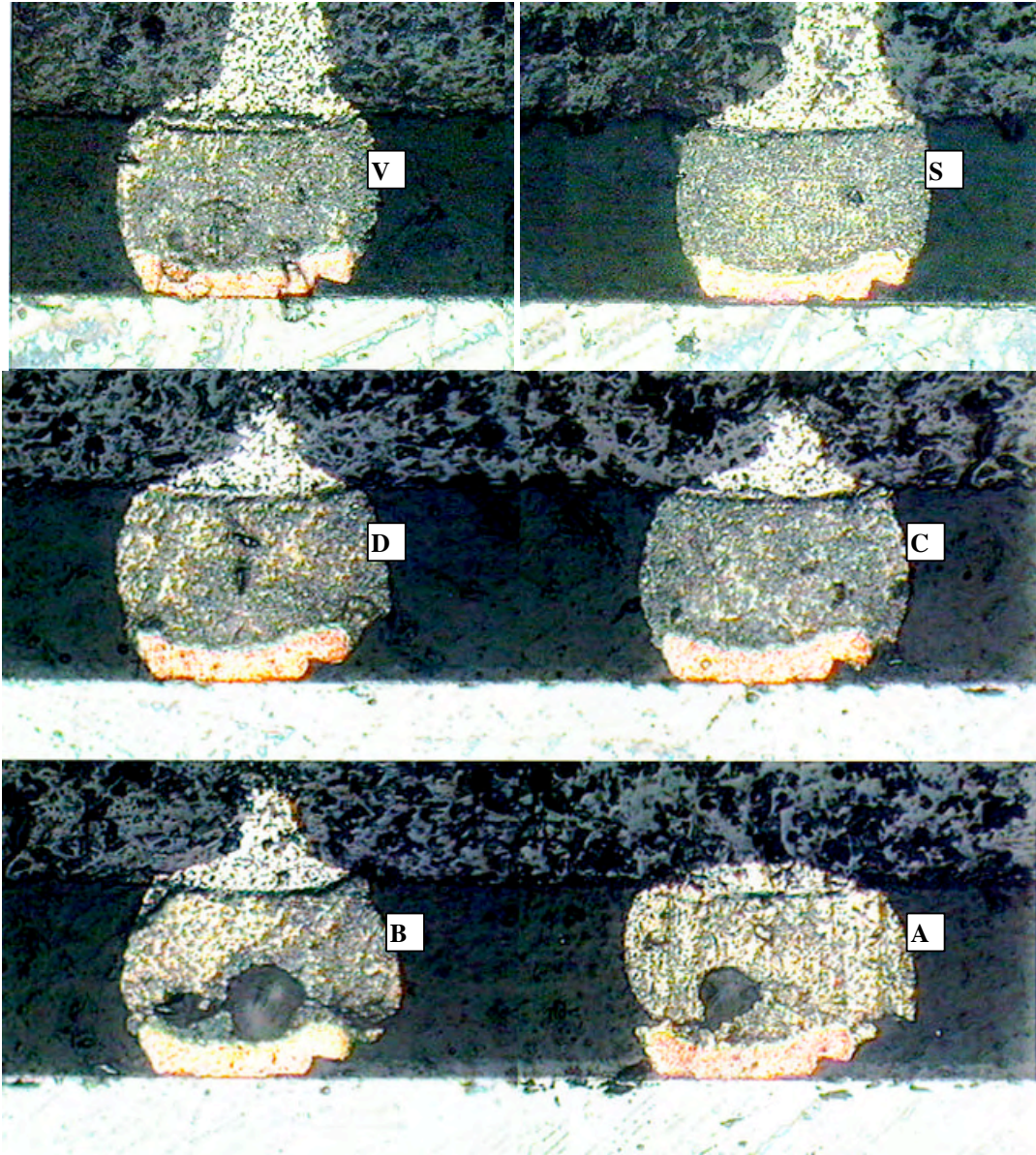


Figure 6 - Optical micrographs of several bumps pointed out in the acoustic micrograph are shown here. Bump V appears bright in the acoustic image indicating no defects above the interface and the optical micrograph also shows no defects within the solder ball. Bump S, however, appears defective acoustically but also shows no defects within the solder ball in the optical micrograph. C and D also appear defective in the acoustic image but do not show voids or cracks in the solder bumps. A and B appear defective according to the acoustic image and display cracks and voids in the solder bumps.

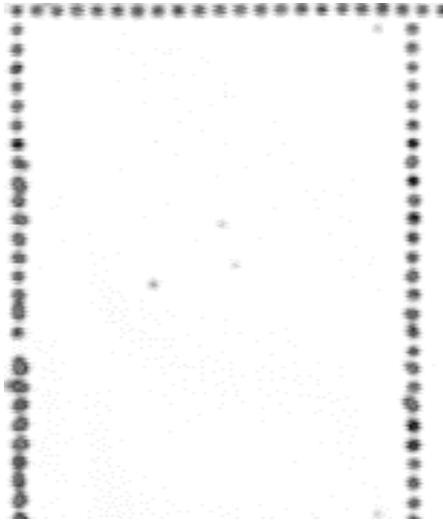


Figure 7 - Acoustic image of chip/bump interface using conventional imaging method. The bond sites show low reflection levels which would typically indicate bonding at the interface. However, some of the sites appear larger than the nominal size of the bonds and irregular in shape.

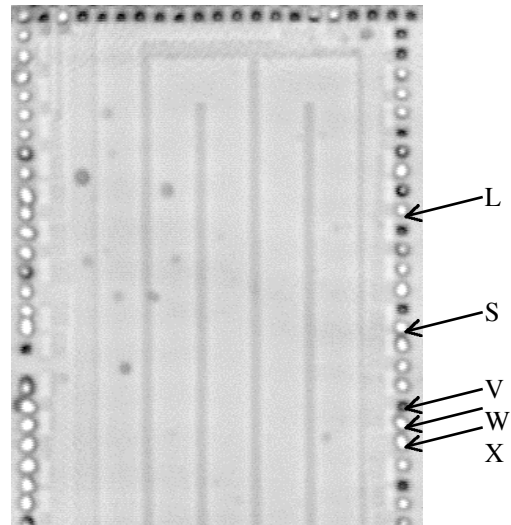
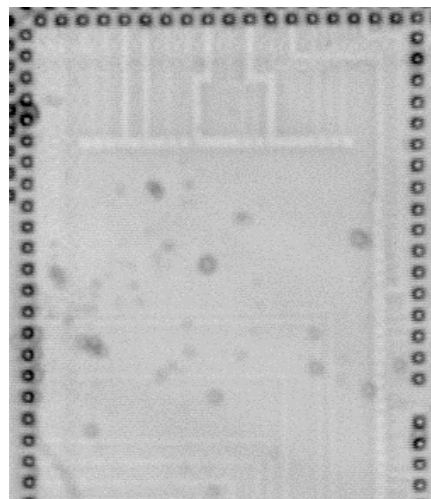


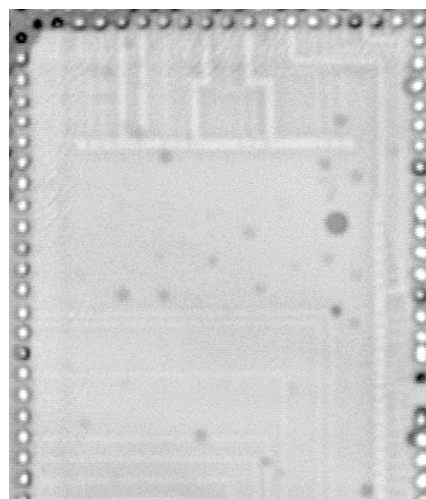
Figure 8 - Acoustic image of chip/bond pad level using level specific imaging technique. Now variations in the signal intensity are apparent from one bond site to another. The strong signal reflections characteristic of voids and delaminations are shown in white. The white bumps also are the ones which display the larger, irregular shapes. Dark spots indicate the bonded pads at this level. Several of the sites are indicated by the arrows for reference in the corresponding DPA images.

Another device of the same type which had not been thermally cycled was also evaluated acoustically using the same technique. The defects were not present in this sample at this time. The bond sites appeared uniform. This sample was subsequently thermally cycled and evaluated again acoustically after cycling.

Now the device showed similar defects. Figure 9 compares acoustic images of the same device before and after cycling. Clearly the thermal cycling was inducing defects, and the types of defects being induced by the testing were not just the cracks within the solder balls.



Before Thermal Stress



After Thermal Stress

Figure 9 - Acoustic images of the same device before and after thermal stress. The bond sites appear as dark circles, uniform in size before stress. After stress most of the bond sites now appear bright white and some are considerably larger in size and irregularly shaped.

For the purposes of correlative analysis one of the thermally cycled parts was evaluated using micro focus x-ray (Figure 10). The x-ray results did not detect any cracks or delaminations but did show voids in some of the solder bumps. The voids could also be

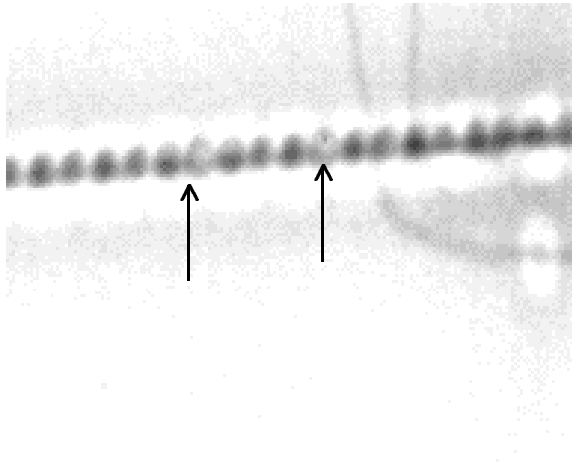


Figure 10 - X-ray image of solder bumps. Two of the bumps appear brighter indicating the presence of voids. These two bumps correspond with the bumps shown in the acoustic image.

The part was then cross sectioned and this time Scanning Electron Microscopy was used to examine the section. The SEM evaluation did reveal the defects which caused the anomalies seen in the acoustic images. The defects were thin laminar cracks under the bond pads on the chip (Figure 12). In some cases the cracks extended out beyond the bump location under the glassivation layers. This is why some of the defects appeared larger than the expected size of the bond pads. A good correlation was now seen between

detected in the acoustic images of the device prior to thermal cycling. (Figure 11). After thermal stress the defects induced by the cycling obscured this level from ultrasonic inspection.

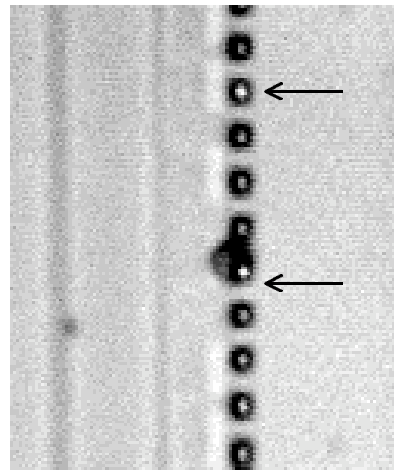


Figure 11 - Acoustic image of a row of solder bumps. Two of the bumps appear brighter in the center indicating the presence of voids in the solder bumps.

acoustic data and DPA results. In retrospect, the original cross sectioning had produced over rounding of the sample in the areas of interest and optical microscopy did not provide high enough resolution to image the thin cracks at the interfaces, but the optical microscopy did show bumps with large internal cracks upon which the attention was focused. This is why the other defects were not detected in the DPA initially and why the results of the DPA and acoustic analysis did not appear to show correlation at first.

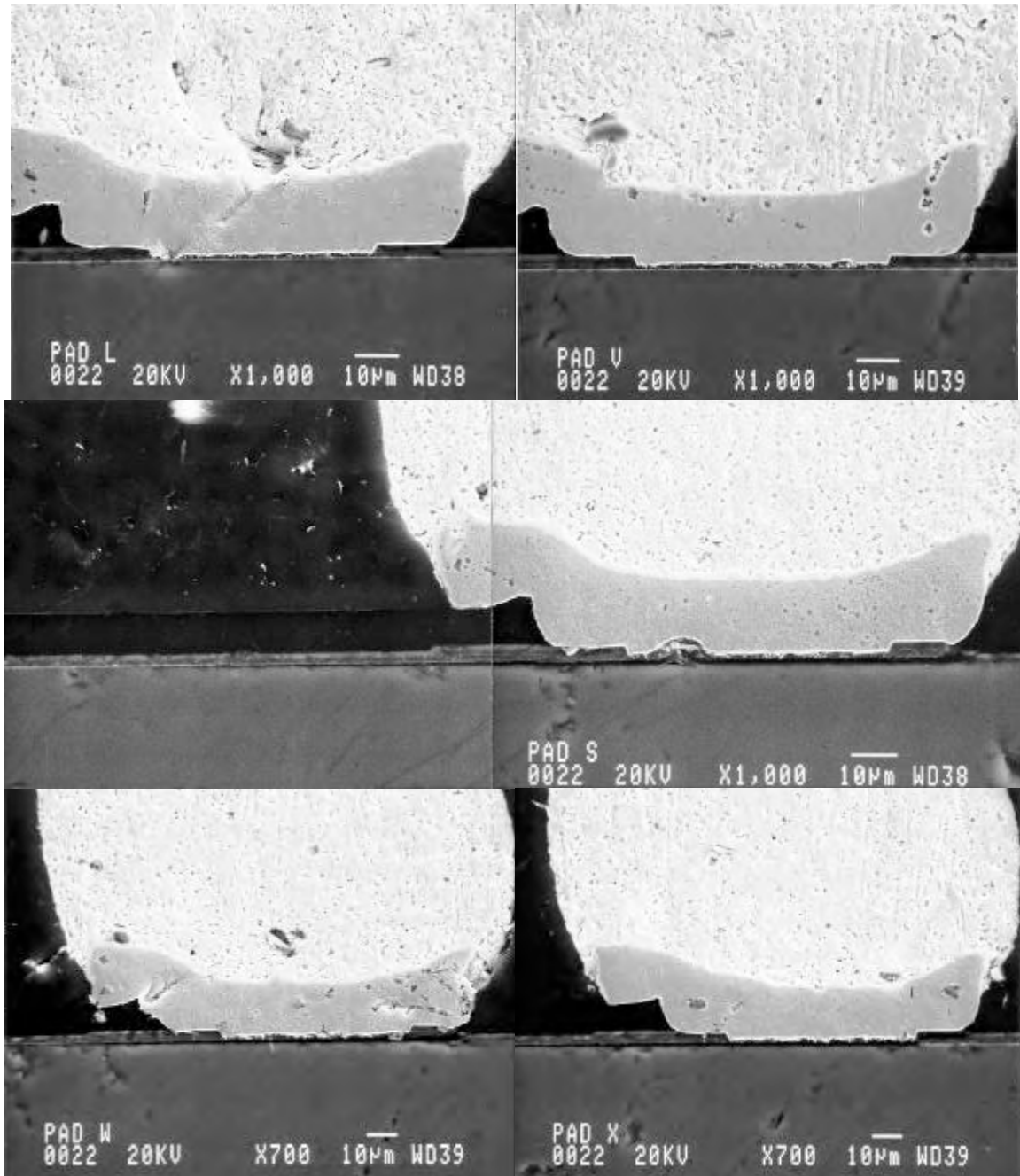


Figure 12 - SEM micrographs of DPA cross sections of several bumps shown in Figure 8. Site L and V appeared dark in the acoustic image indicating bond at this level. The DPA section shows no defects in the bond of the bond pad to the silicon or glassivation layers. Sites S, W and X display a laminar crack under the bond pad. The cracks extend under the surrounding glassivation layers. These bumps appeared bright indicating defects in the acoustic image.

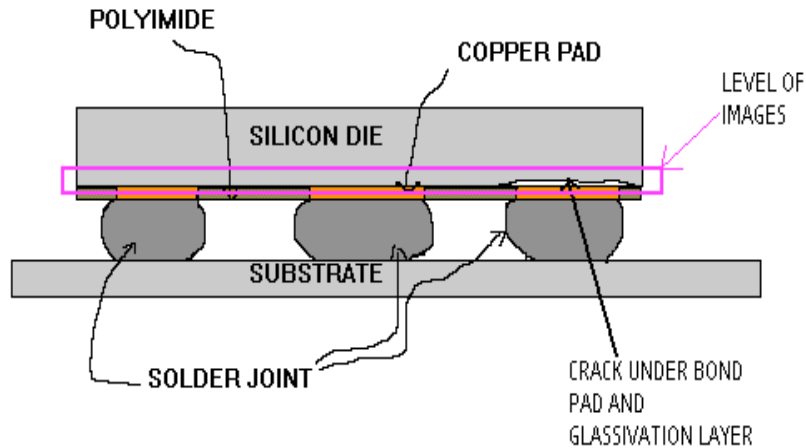


Figure 13 - Diagram of device showing level of the defects detected in the acoustic images.

## CONCLUSION

Proper investigation of bumps in flip chip devices requires the proper acoustic micro imaging technique to reveal subtle flaws. The DPA techniques employed must also be suitable to reveal the same type of defect when attempting correlative analysis.

Thin laminar cracks were detected using AMI at the silicon/bond pad level. These defects were not detected by any other nondestructive imaging method and were not easily detected in the DPA except by the SEM when knowing what locations to examine. The defects prevented acoustic access to any other levels in the solder once the defects were encountered. This would prevent detection of the solder cracks; however, the cracks under the bond pads are clearly detrimental to the operation of the device.

## ACKNOWLEDGMENTS

The authors would like to thank Bruce Smith and David Drake of Northrop Grumman for their valuable assistance in providing the x-ray, DPA and SEM analyses.

## BIBLIOGRAPHY

1. L.W. Kessler, "Acoustic Microscopy" in Metals Handbook, Ninth Edition, Vol. 17 - Nondestructive Evaluation and Quality Control - ASM International, Materials Park, OH, 1989, pp. 465-482.
2. J.E. Semmens, S.R. Martell, L.W. Kessler, "Evaluation of Interconnects Using Acoustic

Microscopy for Failure Analysis and Process Control Applications", 4th International Conference & Exhibition on Multichip Modules, April 19-21, 1995, Denver, CO, pp. 279-285.

3. J.E. Semmens, S.R. Martell, L.W. Kessler, "Analysis of BGA and Other Area Array Packages Using Acoustic Micro Imaging", Proc. of First Pan Pacific Microelectronics Symposium, February 6-8, 1996, Honolulu, Hawaii, pp. 285-290.

4. O. Diaz d'Leon, J. Bartlett, R. Chowdry, "Flip Chip and BGA Failure Analysis Through Acoustic Microscopy", The 22<sup>nd</sup> International Symposium for Testing and Failure Analysis, November 18-22, 1996, Los Angeles, CA