# UPDATE ON THE EVALUATION OF STACKED DIE PACKAGES USING ACOUSTIC MICRO IMAGING

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## ABSTRACT

An earlier paper concerning evaluation of stacked die packages using Acoustic Micro Imaging (AMI) demonstrated the feasibility of evaluating these devices in two and three die or die/spacer stacks [1]. Since that time additional experience and insight has been gained in working with these types of parts. As expected the die are thinner (≤ 75 microns), there are usually a greater number of die in the stack, and the methods for attaching the different layers varies. The increasingly thinner dimensions in stacked die packages present increasing challenges for AMI analysis of the devices for internal defects. The material in this paper will present an update on the methods presently available for stacked die evaluation and discuss observations on the behavior of high frequency ultrasound in the packages that may have impact on future techniques for analysis.

Key words: Acoustic Micro Imaging (AMI), stacked die packages

## INTRODUCTION

AMI (Acoustic Micro Imaging) is a non-destructive test method that utilizes high frequency ultrasound in the range of 5 MHz to 500 MHz. Ultrasound is sensitive to variations in the elastic properties of materials and is particularly sensitive to locating air gaps (delaminations, cracks and voids). There is a direct relationship between frequency and resolution in AMI. Higher frequencies have shorter wavelengths and therefore provide higher resolution. Lower frequencies, which have longer wavelengths, provide better penetration of the ultrasound energy through attenuating materials, thicker materials or multiple layer assemblies. Generally a compromise is found between sufficient resolution and maintaining satisfactory penetration and working distance for a given application. More recently methods such as Frequency Domain imaging have been used to improve the resolution/detectability of features in acoustic images.

As mentioned earlier the die are typically very thin as are the die bond layers in stacked die packages. Ideally high frequency would be used for analysis of the small cracks and/or thin layer delaminations if the samples are un-encapsulated. Although for process development some devices are evaluated prior to encapsulation ultimately the objective is to evaluate the finished encapsulated product. The molding compound however limits the frequency that can be used to examine the internal assembly in an encapsulated device. The lower frequencies required to penetrate through the molding compound to the depths of interest may not initially appear to provide sufficient special (x,y) resolution to locate small cracks in the packages, or sufficient axial(z) resolution to discriminate between thin internal layers. Presently there are software tools and imaging techniques available to enhance the detectability of features and assist in locating the sequential levels in the devices.

## STACKED DIE ANALYSIS METHODS

### Through Transmission

Through transmission imaging is still the quickest way to gain an overall perspective of the features present within a stacked die package. Through-transmission AMI relies on sending the pulse of sound through the entire thickness of a sample and detecting the transmitted signal using a separate receiver. The C-SAM through-transmission mode uses a second transducer as the detector. Defects, if present, may block the ultrasound from reaching the detector and will appear as dark shadows in the acoustic image. This method provides a shadowgraph image of the previous levels. The high sensitivity of the technique is due to the inability of ultrasound to traverse even a small 0.1 micron air gap. So, although the exact depth of the defect in the sample is not determined in through transmission imaging it is a very useful method to first determine the presence of defects throughout the volume of the part. Reflection mode techniques can be subsequently tried to establish the depth of the flaw. Recent developments with new generation through transmission imaging include improving the resolution in the shadowgraph images.

Figure 1 shows a through transmission image of an un-encapsulated six die stack test sample. The thickness of each die was estimated to be on the order of 75µ. The through transmission scan shows the presence of defects within the stack however, it is not known at which level(s) the flaws occur.

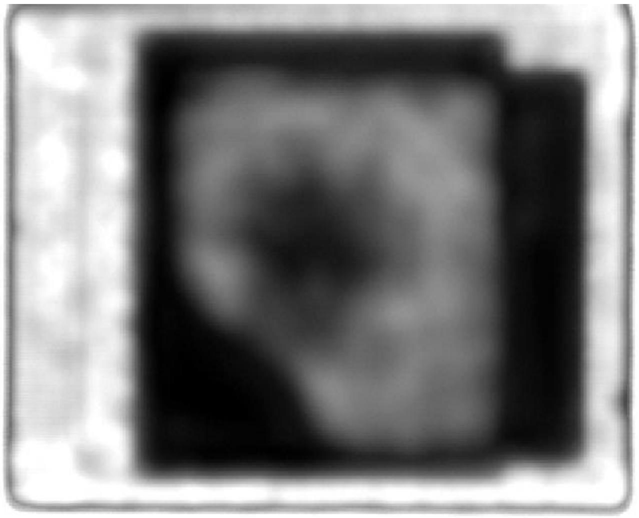


**Figure 1:** 30 MHz through transmission image of a six stack die sample. The black areas indicate air gap type defects within the total stack.

## Reflection Mode A-Scan and C-Scan

In reflection mode Acoustic Micro Imaging the fundamental information is contained in what is called the A-Scan. The A-Scan displays the echo depth information in the sample at each x, y coordinate. Echoes displayed in the A-Scan correspond to different interfaces in the device being examined. The amplitude and phase (polarity) information of the echoes is used to characterize the condition at the interface and is dependant on the acoustic impedance value of the materials involved. The equation that describes the pulse reflection at an interface between materials is as follows:

$$R = I \frac{Z2 - Z1}{Z2 + Z1}$$

Where R is the amplitude of the reflected pulse, I is the amplitude of the incident pulse, Z1 is the intrinsic acoustic impedance of the material through which the pulse is traveling and Z2 is that of the next material which is encountered by the pulse.

As the equation indicates the greater the impedance difference between materials the stronger the reflection at the interface. Whereas bonded areas between similar materials or materials with similar impedances (such as solder die attach) show very little signal reflection at a bonded interface die attach using epoxy bonding shows a significant reflected echo even in the bonded areas. Also multiple reflections for the same interface occur periodically at regular intervals based on the thickness to the interface. The magnitude of these echoes maximizes at deeper focus levels in the sample and often is coincident with the time position on the A-scan and focus for actual subsequent interfaces in the sample (Figure 2).

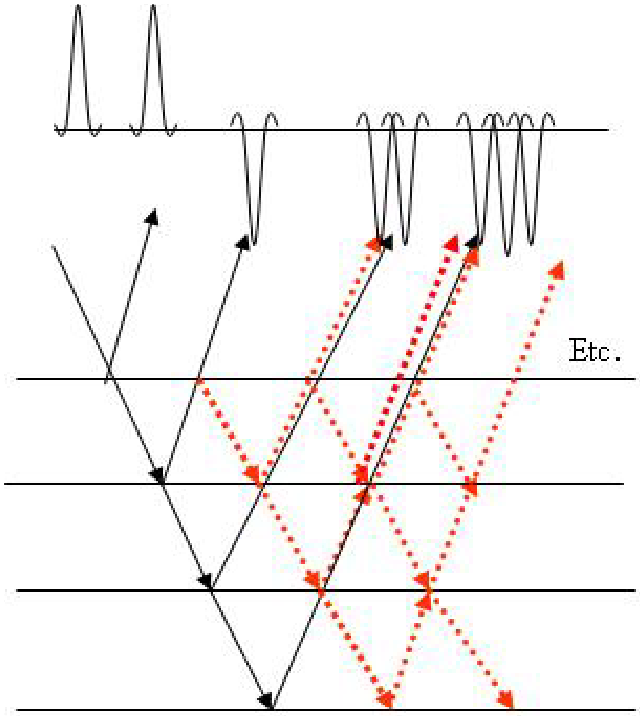


**Figure 2:** At each interface some of the signal transmits across the boundary (if there is no air gap) and some is reflected at the interface for both the incident and returned signal. This causes multiple reflections from the different interfaces that can interfere with the reflections from the actual levels of interest.

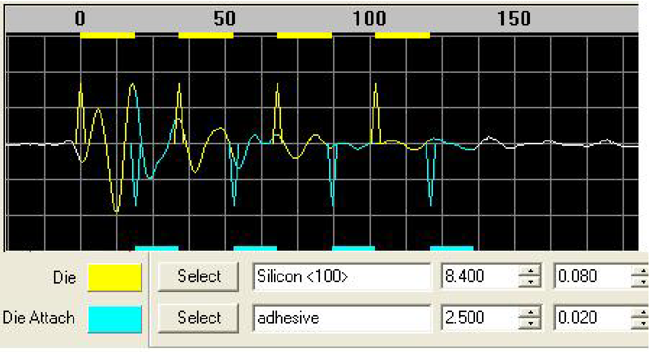
There is a time/distance relationship between the echoes based on the acoustic velocities in the materials that can be used to predict the positions of the interface echoes for the various levels.

Velocity = 2 x distance/time

However, in stacked die packages, typically the layers are very thin relative to the wavelength of the frequency needed for inspection. In some instances the echoes from the various levels may not be completely separated from one another on the A-scan and this causes interference effects that can be difficult to interpret.

In the reflection mode software overlays using a Waveform Simulator function can be superimposed on the A-scan. The simulated A-scan overlay can be used to predict the location of an interface based on the acoustic velocity and the thickness of the material(s) but depending on the thickness (or thinness) of the layers and the influence of multiple reflections that can be overlapping these tools may only have utility to the first two or three interfaces.

Information from the multiple reflections (resonances) has proved useful to examine the individual layers. The location of the different interfaces is determined empirically at this time but will be consistent within a part type.



Die 🟨 Silicon <100> 8.400 0.080

Die Attach 🟦 adhesive 2.500 0.020

**Figure 3:** A color template based on the velocities and thicknesses of the materials in an un-encapsulated four die stack has been superimposed on the A-scan for the device.

In the next example the same six die stack that was used for the through transmission image is shown using reflection mode C-Scans. As this sample was un-encapsulated it could be evaluated at a frequency of 230 MHz. In Figure 4 the die attach interface of the first to second die is shown. A large delamination at the lower left corner of the die attach is present in the image as well as a band of smaller voids. The corner delamination corresponds to the position of one of the dark areas in the through scan image but a more central dark area in the through scan is not accounted for at this level. At a subsequent level in the stack a large void area is detected that corresponds to the more circular area toward the center of the part in the through scan (Figure 5). Please note that the orientation of alternating dies was rotated 90º creating an area of intentional disbond at the edges of the stack which also shows up in the images.

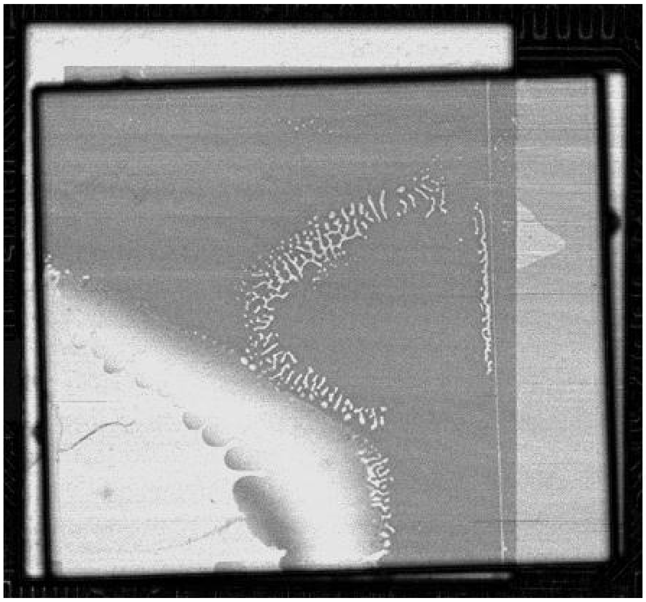


**Figure 4:** Reflection mode C-Scan image of the first die attach level in a stacked die part. A large corner void and additional smaller voids (white areas) are present in the bond.

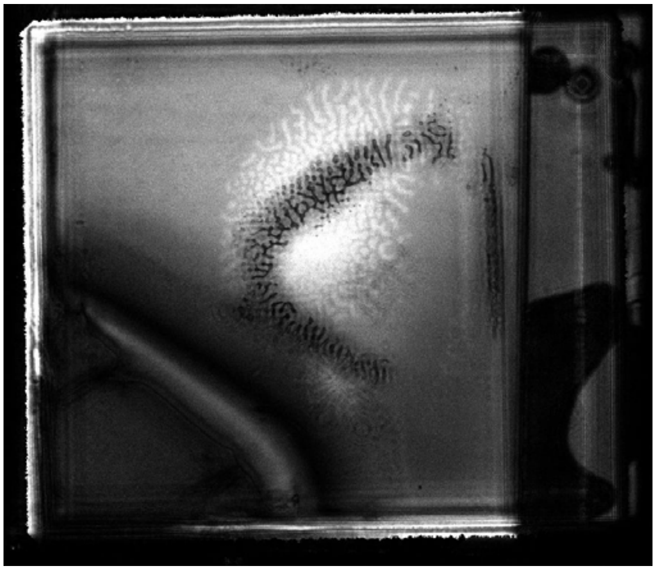


**Figure 5:** Reflection mode C-Scan of a die attach level deeper in the stack revealing another large void (white area). The shadows from the voids at die attach level one are also present in the image.

### Frequency Domain (FFT) Imaging

Frequency Domain analysis has been used to enhance the resolution of features in acoustic images. In addition it has been observed that in some instances the detectability of certain internal features or defects is dependant on the frequency content of a specific echo.

Currently a method is used that stores the A-scan information for each x-y point in a scan. From the stored information images of depths within the device not included in the original gate for the image can be recreated and/or waveforms (echoes) can be viewed for analysis without rescanning the sample. In addition to this the echoes can be digitally processed, frequency filtered, etc., to extract further information about the condition of the sample, or extract information at or slightly beyond the limits of conventional AMI.

Frequency Domain imaging is one method that can extract further information by using the frequency content of the signal. In this technique each A-scan of the image relates to the localized frequency response of the corresponding pixel in the sample. For reference, the conventional image is a time domain image in which each pixel relates to the magnitude of a return echo [2].

The transducers used in AMI range in center frequency from 5 MHz to 300 MHz and above. In conventional acoustic imaging, the choice of transducer determines the spatial resolution, penetration, and other parameters. These transducers typically have highly damped waveforms in order to achieve better resolution, both spatial and axial, using time domain imaging. Figure 6 displays an A-scan with typical echoes (pulses) as seen in the time domain. However these highly damped waveforms contain broad-spectrum frequency information that can be displayed in the

Fourier (frequency) domain. When using time domain imaging at a center frequency of 50 MHz, one can not manipulate the image data to produce a 30 MHz image or a 75 MHz image, because in the time domain the acoustic pulses themselves do allow frequency separation. However, the data file including the stored A-scans makes this kind of manipulation possible, within limits.

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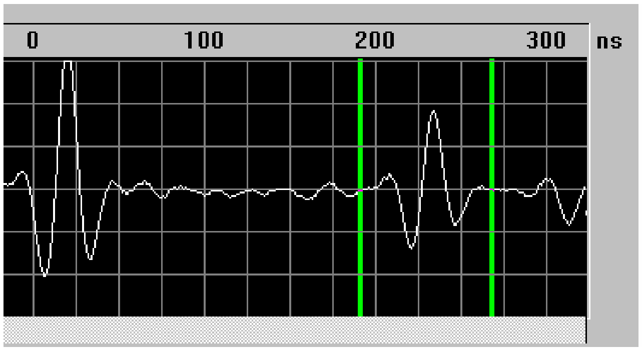

**Figure 6:** A-scan displaying typical waveforms (pulses) in the time domain.

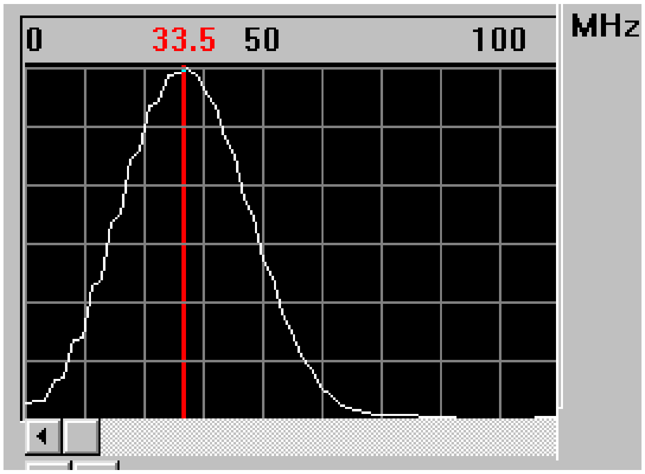

**Figure 7:** Broadband pulse content in the frequency domain for the echo within the gate on the A-scan in Figure 6.

Because the A-scans for each point in the image are collected with the image changes in frequency that may occur during reflection can be analyzed. For example, a pulse of 15 MHz ultrasound launched toward a material interface (such as molding compound to die) may be reflected with a different frequency content than originally pulsed, and this change – not otherwise detectable – may be indicative of the interface condition. The gated echo(es) from the stored A-scans can be filtered by means of a Fast Fourier Transform (FFT), also called a Frequency Domain algorithm, to isolate a given frequency. The Fourier transform decomposes the selected waveform(s) into sinusoids of different frequencies. The FFT identifies the different frequency sinusoids and their respective amplitudes. Figure 7 shows the frequency content distribution of the gated echo shown in Figure 6 in the frequency domain. Images can then be reconstructed from components of the frequency information. Specific features may yield more information at one frequency than another. Therefore, FFT filtering of the echo can bring out image detail that may not be visible with conventional time domain imaging.

Advancements have been made in recent years with respect to higher resolution in the acoustic images by increasing the frequency/design of the transducers. However, there is a point where the thickness and type of material in the packaging will limit the use of even higher frequency ultrasound even though package features are becoming increasingly smaller and internal layers increasingly thinner. Frequency domain (FFT) analysis of the waveforms has been used in the past to measure bond line thickness and has shown the capacity of measuring to thickness well beyond the axial resolution limit of a given frequency [3]. Frequency domain imaging can be used to improve detection/resolution in the lateral dimensions by removing the low frequency component from the image. Conversely by selecting a lower frequency component of the bandwidth features that were masked by the high frequency portion of the signal have been detected.

In another example which follows (Figures 8, 9, and 10) voids were detected in an encapsulated four stack die package with 80μ nominal die thickness using through transmission imaging. However, initial reflection mode scans using 75 MHz did not reveal the presence of several of the defects. Subsequent scans at 100 MHz did show the presence of the defects at the deepest die attach level (die 4 to substrate). Using Frequency Domain imaging the appearance of the voids in the image was much improved when the image was reconstructed using a single frequency of 51 MHz.

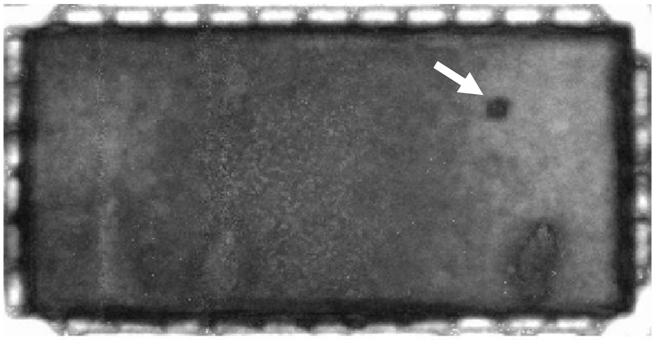

**Figure 8:** 75 MHz acoustic image of deepest die (die 4) attach to substrate. The shadow of one void from a previous level is seen (white arrow).

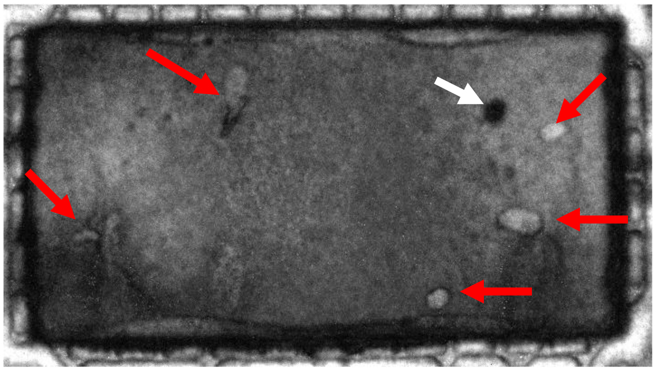

**Figure 9:** 100 MHz acoustic image of die 4 to substrate. In addition to the void at a level above the interface (white arrow) additional voids are revealed at the interface (red arrows).

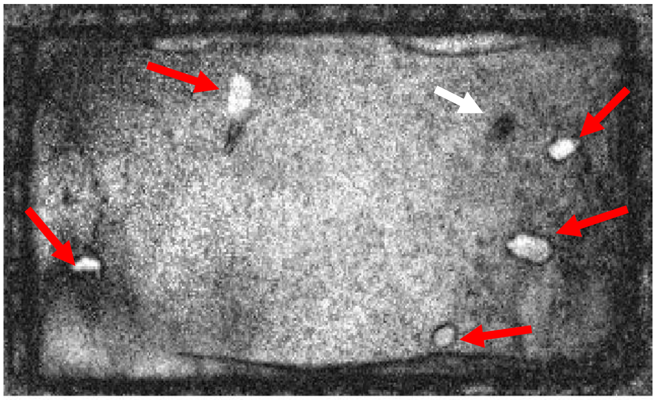

**Figure 10:** 51 MHz Frequency Domain image of the same die attach level as shown in Figures 8 and 9. The voids in the die 4 attach (red arrows) are much more evident in this image. The shadow of the void from an earlier interface is still present (white arrow).

In this case the interface and defects of interest required sufficient frequency content in the bandwidth of the transducer around 50 MHz to be detected. However it is not as easy as simply using a 50 MHz transducer to begin with. Due to downshifting of the transducer center frequency in the fluid path and in the molding compound 50 MHz and 75 MHz transducers no longer contained sufficient frequency response at 50 MHz to detect the defects.

This example also illustrates the utility of through transmission imaging to provide a general overview of the part to insure that defects are not missed.

## CONCLUSION

The results presented here demonstrate the successful analyses of a six die un-encapsulated sample and a four die encapsulated stacked die package using Acoustic Micro Imaging technology in the frequency range of 30 MHz to 230 MHz. Both reflection mode and through transmission modes are useful to gain a thorough knowledge of the presence or absence of defects in the devices. However, the direction observed in the design and construction of stacked die devices suggests that in the future the internal dimensions of the layers and the number of layers will stress the capabilities of conventional AMI analysis. Larger stacks, for example eight die, may rely more on through transmission than reflection mode AMI. Future work is underway to improve the analysis of larger stacks of thin die using mathematical methods and sophisticated A-Scan waveform simulators.

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