Evaluation of Stacked Die Packages Using Acoustic Micro Imaging

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ABSTRACT
The limited available area and need for greater functionality in small electronic devices, such as cellular phones, has led to the development and implementation of stacked die packages. These packages conserve space and the closer connections in these packages result in higher speed. As with other microelectronic devices there is a need to be capable of evaluating the packages for internal defects that could adversely affect the operation of the devices or lead to premature failure. AMI is routinely used to evaluate a wide variety of microelectronic devices. The construction of stacked die packages however presents certain challenges for AMI analysis of the devices for internal defects.

This paper will present a brief background on the construction of stacked die packages and examples of analyses using various AMI methods to detect internal features and defects in the packages.

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

STACKED DIE PACKAGES
SIP (System in package) devices or stacked die packages vary in their configuration. The internal structure of a stacked device includes two or more die. The dies are typically very thin (75 to 150 μ) and in the future the plan is to go to even thinner die [1]. The die can be arranged in a singe stack or one module can contain more than one stack or a combination of single die and stacked die [2,3]. Interconnections are accomplished using wire bonds or in some cases flip chip interconnections. Typically an epoxy die attach material is used and the die bond layers are thin (≈20 – 25 μ) in these devices. Flip chip devices contain underfill encapsulant. Some packages types use spacers to provide room for bond wires, or the die vary in size to accommodate the wire bonds. And the parts are encapsulated using epoxy molding compounds. The structure of the devices is described in greater detail in the references. An example of one type of device configuration is shown in Figure 1. This diagram describes the internal construction of the sample shown in the analysis images later in the paper.

Figure 1: Diagram of a stacked die package containing two die of different sizes and a silicon spacer.

Similar to other microelectronic packages there is a need to be able to evaluate the devices for possible internal defects. The back thinning processes of the silicon or subsequent assembly can lead to die cracking. Delaminations of the die attach may be present. Delaminations of the molding compound may be present.

AMI (Acoustic Micro Imaging) is a method for evaluating the packages. The next section describes the technique and the issues relating to stacked die packages.

AMI
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 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 Fourier Domain imaging have been used to improve the resolution or detectability of features in acoustic images.

Through-Transmission
Through-transmission Acoustic Micro Imaging 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.

Figure 2 displays a through transmission image of a stacked die package consisting of two die with a silicon spacer. The die and the spacer are different sizes. The brighter areas indicate where the ultrasound transmits through the entire sample. Black areas indicate the shadows from voids in the sample. In this image the silicon die and the die attach adhesive are transmissive to the 30 MHz ultrasound. The arrows on the image indicate a voids in the device. The darker square in the center of the part in the image is caused by an array of solder balls on the underside of the device substrate.

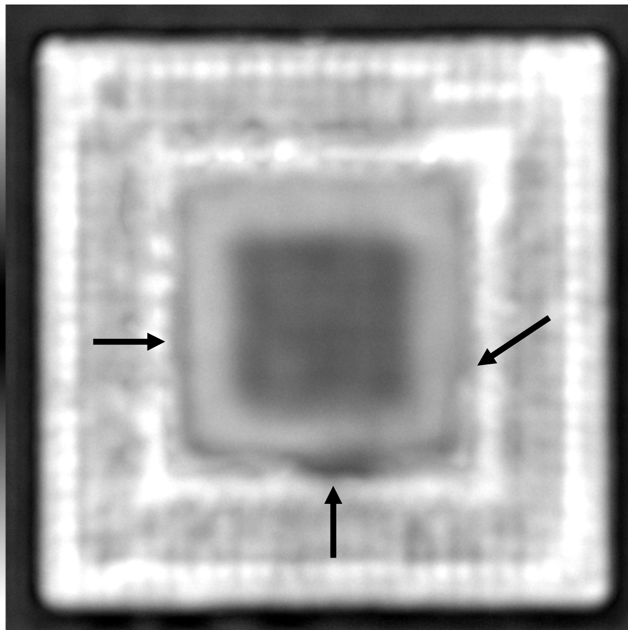

Figure 2: 30 MHz through transmission acoustic image of stacked die package

Reflection Mode

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 focus 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 3).

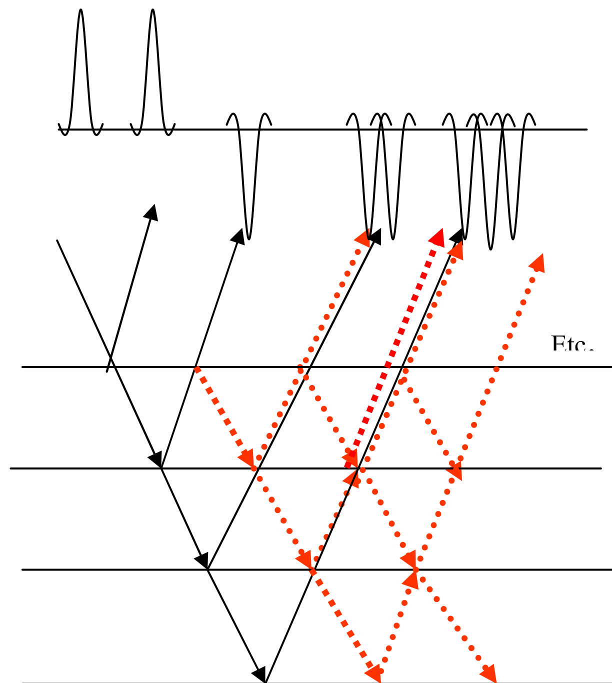

Figure 3: At each interface some of the signal transmits across the boundary (if there is no air gap) and some is reflected at the interface for both the incident and returned signal. This causes multiple reflections from the different interfaces that can interfere with the reflections from the actual 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. Color-coding the A-scan can be used to reflect the velocities and thicknesses of the internal material layers of the sample to aid in location of the interface echoes at the different depths however the multiple reflections will still be present on the A-scan.

In addition to the axial resolution issues there is also the spatial resolution consideration. Factors involved in spatial resolution are described in greater detail in the references [4]. Because the features in the stacked packages are typically small there is also a drive to use the highest possible frequency to achieve the best available resolution in the images. But the higher frequencies tend to scatter more readily off of filler particles and voids/porosity in materials and the higher frequency component of the signal is more attenuated by lower impedance/higher elasticity materials such as epoxy adhesives and molding compounds.

Though to this point we have discussed many of the challenges to imaging the internal layers in stacked die packages using the reflection mode it is possible to gain information at the various levels. Straightforward applications with stacked die packages are the adhesion of the encapsulation to the first internal interface and the die bond of the first die in the stack. The C-Scan, interface scan is the most common imaging method used to evaluate devices for voids and delaminations between layers. This method involves gating the A-Scan signal for the appropriate echo from the interface to be investigated. The gate corresponds to a time window that is selected and applied to each x-y position for the scan. The geometric focus of the acoustic beam is optimized for the interface as well. At each x-y position only the peak intensity value and the polarity of the echo within the gate are displayed.

The next group of images show C-Scan interface scans. The device used is the same package as used in the through transmission image (Figure 2). Several levels within the device are imaged using the reflection mode.

The first scan (Figure 4) shows the molding compound to die surface of the device. The wire bonds can be seen at the periphery of the die and some dark spots result from voids in the encapsulant above the die. No delaminations of the die surface from the encapsulation are evident.

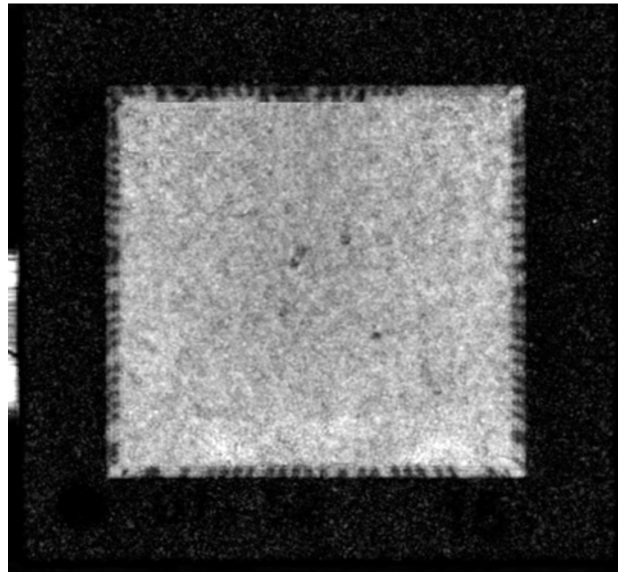

Figure 4: 90 MHz C-Scan of the molding compound to die surface interface.

The next image, Figure 5, shows the interface between the top die and the spacer. The spacer can be seen to be smaller than the top die and the bond appears uniform.

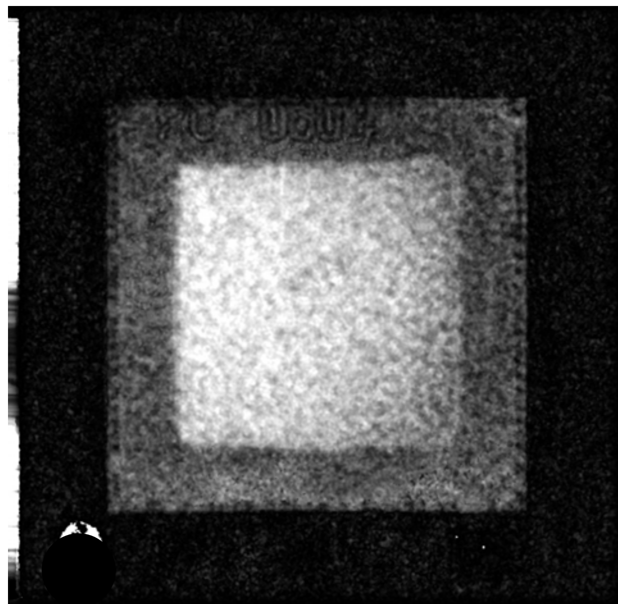

Figure 5: 90 MHz image of the top die to spacer level.

Figure 6 shows the spacer and the surface of the second die at the edges of the spacer. The second die is slightly larger than the spacer and there are voids at the edges of the spacer on the top of the die. The lower void corresponds to the position of the void seen in the through transmission image. The voids at the edges are clearer in the C-Scan image due to the higher frequency.

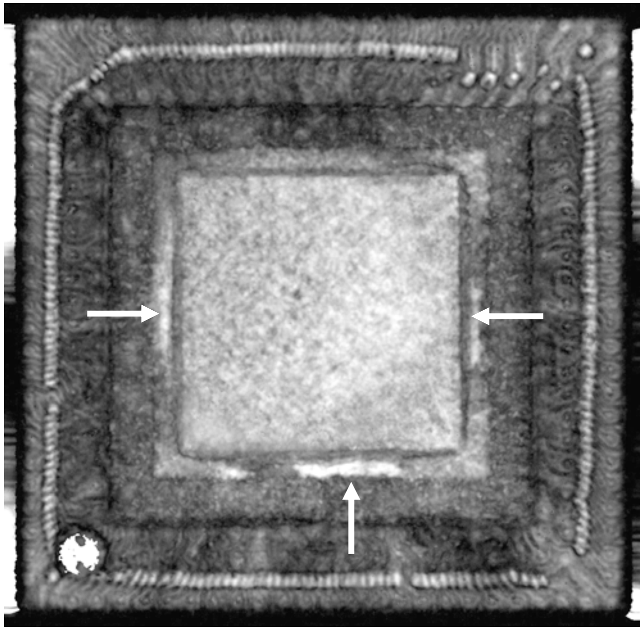

Figure 6: 90 MHz image at the second die level showing some voids.

The conventional C-scan output is only two-dimensional consisting of an x-y plot of one specific plane in the z dimension. Features existing in the device but not included in the electronic gate or features with lesser signal strength at a given position will not be displayed for analysis in the image. The A-scans for each point on the sample are not typically saved with the images due to file size considerations when documenting a significant number of samples. Since the A-scans are not saved, the data cannot be re-gated, nor can the echoes be reprocessed to create different image information. But the conventional C-Scan is very useful and has been the standard since acoustic micro imaging was developed.

A-Scan Storage and Frequency Domain Imaging

Currently a new 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 [5].

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 7 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 not have sufficiently wide frequency content. However, the data file including the stored A-scans makes this kind of manipulation possible, within limits.

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Figure 7: A-scan displaying typical waveforms (pulses) in the time domain.

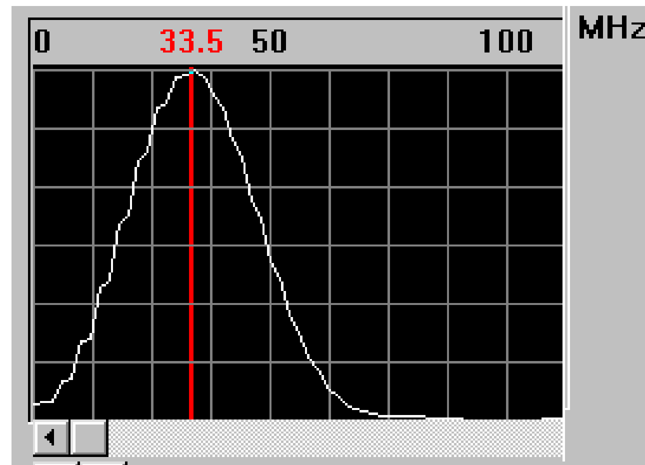

Figure 8: Broadband pulse content in the frequency domain for the echo within the gate on the A-scan in Figure 7.

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 8 shows the frequency content distribution of the gated echo shown in Figure 7 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 [6]. 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 the following example a TQFP plastic encapsulated package is shown using time domain imaging and frequency domain imaging. Using time domain imaging the most significant echo over the duration of the gate is displayed for any given point (Figure 9). The various levels in the package can be seen such as the die surface, die pad surrounding the die and the lead frame. A delamination at the die pad can be seen as a red region (dark grey in the black and white print of the color image), the red color indicating the area of inverted polarity. Information below the die (die attach) is not evident in this image as the die surface and die attach echo compete within the gate at the same x-y position for display to the image. The die surface echo in this case shows the stronger signal and is the one displayed. The frequency domain image (Figure 10) of the same gated area however brings out the detail not present in the time domain image. A delamination at the die attach interface now can be seen which is continuous with the die pad delamination and the dimple pattern of the die pad becomes visible.

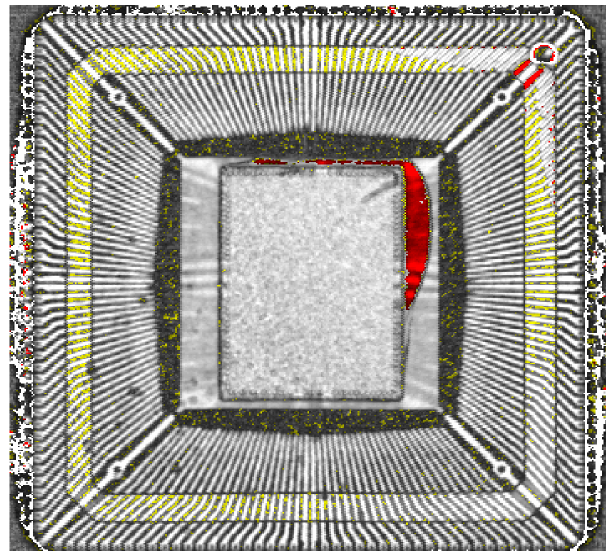

Figure 9: TQFP time domain image

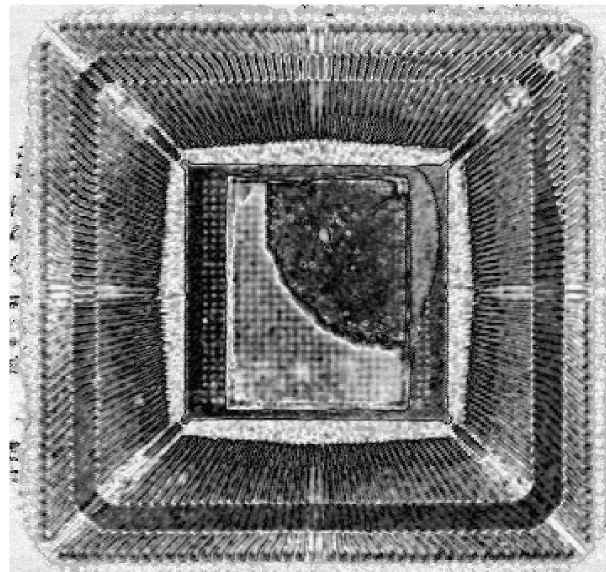

Figure 10: TQFP frequency domain image

The next example shows the stacked die part again using a frequency of 50 MHz for analysis. In Figure 11 a wide gate was used that includes several levels however the most significant signal is coming from the encapsulant/first die surface echo and so this is what is displayed in the image. Using the frequency domain imaging mode (figure 12) a single frequency is selected from the bandwidth and now the spacer and second die are seen in the image. The voids at the edge of the second die surface are visible in the image as well. The features in the 90 MHz image (Figure 6) of this interface appear clearer due to the higher resolution available at the higher frequency and the focus was optimized for this layer.

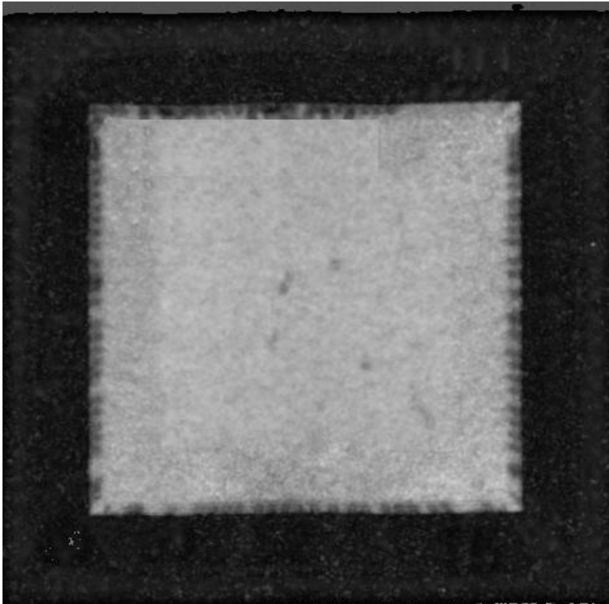

Figure 11: Time Domain image shows the first die in a stacked die sample

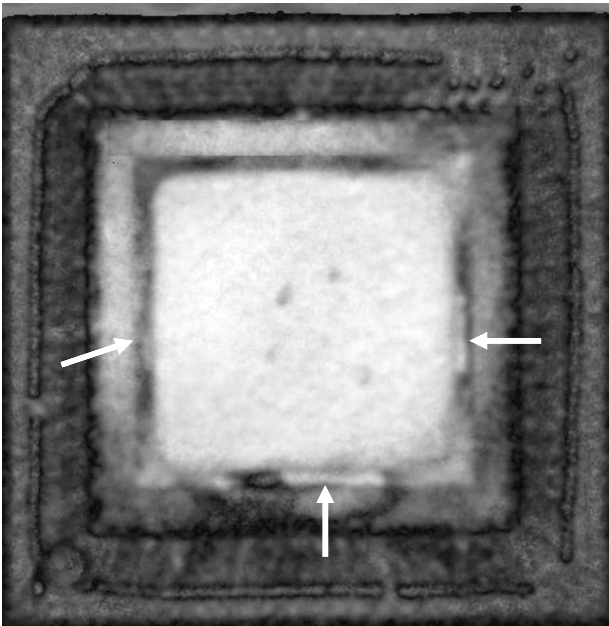

Figure 12: Frequency Domain image in a stacked die sample

In either case it can be noted that the die attach delamination or second die voids can be readily imaged in the time domain by changing the gate for the image. And, using A-scan storage the new image can be generated instantaneously without rescanning the part. However, there may be instances where the levels are too thin to be gated separately and the examples demonstrate how additional features at different levels can be brought out using frequency domain imaging to insure that no details of the condition of the device are overlooked.

CONCLUSION

Stacked die packages are becoming more common in electronic devices. The internal construction of the packages varies and poses some challenges to nondestructive evaluation of the packages using AMI. Using different imaging modes and techniques such as through transmission and FFT imaging however can compensate for the challenges.

REFERENCES

[1] Intel Website, www.intel.com/research/silicon/ mobilepackaging.htm.

[2] Amkor Website, www.amkor.com, Stacked CSP Data Sheet.

[3]Dave Tovar, “OSE-USA Stacked Die Advanced Interconnect Technologies”, Internet Article, www.ewh.ieee.org.

[4] Janet Semmens and Sridhar Canumalla, “Application Of Highly Focused, High Frequency Transducers For Evaluation Of Near-Surface Flaws And Thin Packages: Smart Cards, Flip Chip, Flex Circuits And Thick Films”, Proceedings of Pan Pacific Conference, Hawaii, 1999.

[5] Janet Semmens and Lawrence Kessler, “Acoustic Micro Imaging in the Fourier Domain for Evaluation of Advanced Packaging”, Proceedings of Pan Pacific Conference, Maui, Hawaii, 2002.

[6] Sridhar Canumalla and Bryan P. Schackmuth, “Metrology of Thin Layers in IC Packages using an Acoustic Microprobe: Bondline Thickness”, Proceedings of the 49th Electronic Components and Technology Conference (ECTC), San Diego, CA, June 1-4, 1999