# 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

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## ABSTRACT

Recently microelectronic components have become smaller, the internal layers have become thinner and the details that need to be detected are minute. In order to achieve higher resolution in the acoustic images there has been a shift to higher frequencies (for applications such as flip chip interconnect). Conventional transducers are designed for penetration through relatively thick materials. However, when these are used to inspect near surface flaws or thin samples the ultimate resolution in the acoustic images is compromised due to attenuation of the signal in the fluid couplant path. Therefore, detectability of the pertinent details in thin samples with very small structures would not be optimum. However, the design of the transducer can be altered and optimized for application to thin layer samples. This combined with a high acoustic frequency will produce very high definition acoustic images capable of detecting the defects of interest in thin layer devices.

Illustrative example applications will be discussed in failure analysis of thin layer samples.

## INTRODUCTION

In acoustic microscopy of IC packages, as in optical microscopy, focused beams are used to obtain good transverse definition and high beam intensity at a point of interest. A spherical lens focuses the beam from the piezoelectric element to a spot (much smaller than the element diameter) the size of which is limited by diffraction.

Some factors affecting transverse definition or resolution are discussed below. According to conventional ultrasonic theory two neighboring objects (flaws) can be distinguished from each other if the separation between them is $d_{\text{Resolution}} = \frac{1}{\sqrt{2}} 1.02\lambda F^{\#}$ (in pulse echo inspection). Here $F^{\#} \cong z_0/d$, where $d$ is the diameter of the transducer element, $z_0$ is the focal length and $\lambda$ is the wavelength of sound at the center frequency of the transducer. Therefore, a higher frequency transducer emits sound with a smaller wavelength and, hence, affords better resolution. The $F^{\#}$ of a lens is used as a measure of the degree of focusing achieved by the lens. For example, two transducers having the same frequency characteristics will exhibit the same resolution if their $F^{\#}$s are identical. In general when transducers are focused in a couplant such as water, a smaller $F^{\#}$ results in a more highly focused ultrasonic beam and a better resolution.

However, highly focused transducers are not suitable for all inspection cases. For example, flaws deep inside IC packages may not be detectable using highly focused transducers because very little of the ultrasound energy incident on the surface from such a transducer penetrates the package. This behavior follows Snell's law of refraction and rays incident at large angles suffer total internal reflection. Thus, there is a limit to which resolution can be improved by reducing the $F^{\#}$ when inspecting for flaws inside solids; the limit is controlled by the ratio of the velocities of the sound waves in the solid and couplant.

Another factor that controls resolution in broadband acoustic microscopy systems is frequency downshifting due to attenuation in the water path and material. Most acoustic microscopes employ ultrasound in the frequency range of 15 to 300 MHz . The ultrasound is emitted by a piezoelectric element as a short duration pulse. The finite duration of the pulse results in the ultrasound having a broad range of frequencies whose distribution is similar to a Gaussian function (bell curve). The central peak is usually close to the transducer's rated frequency. As the ultrasonic pulse propagates from the transducer through the water couplant into the IC package and back, the higher frequencies in the incident pulse suffer more attenuation (reduction) than the lower frequencies. The net effect is that the peak in the spectrum shifts to lower frequencies. In other words, an incident pulse with a center frequency of 50 MHz might resemble, after reflection from the target, a pulse from a 30 MHz transducer. This downshifting can cause a significant reduction in the resolution afforded by a high frequency transducer. In such cases a broadband resolution model can be used to predict actual resolution accurately [1]. It has been shown that a shorter focal length transducer will yield better resolution than a longer focal length transducer if all other parameters remain the same (the center frequency, etc.) because of less severe downshifting.

Short focal length is, therefore, a necessary condition but not a sufficient factor in selecting an appropriate transducer. In addition the focal length of the transducer selected should be sufficiently large to allow focusing of the ultrasonic beam to the required depth within the package. In other words, longer focal length transducers are required for inspecting thicker packages but these would not be optimal for inspecting thin packages or flaws close to the surface because of the excessive attenuation in the water. In such cases short focal length transducers are recommended.

Thus, using a transducer with optimal characteristics, the resolution and detection capabilities in the inspection of thin layers and flaws close to the surface of low velocity below materials can be maximized. Sharply focused (low F#) very high frequency (100-230 MHz) transducers with short focal length are used here for obtaining superior resolution of near surface flaws in thin layered specimens and IC packages.

## APPLICATIONS

### Smart Card Die Attach and Wire Bonds

In the devices pictured in Figure 1 the die and the outer wire bonds are attached directly to thin metal pads that are exposed on the outer surface of the card. The image obtained with a 100 MHz $F^{\#}2$ transducer with focal length of 12.7mm is compared with the image obtained with a 150 MHz low $F^{\#}$ transducer. The outline of the die can be seen in the center of both images. The white features within the outline of the die correspond to voids in the die attach. In addition to the details appearing clearer in the 150 MHz image, notice that some smaller voids not visible in the 100 MHz image are detected in the latter image. Circular areas surrounding the die are the wire bond sites. Bonded wires appear as a dark spot on the bond pad. Missing spots indicate disbonded wires and/or unused pads. White areas indicate where the glob top encapsulation (on the opposite surface) is not bonded to the pad. In the areas surrounding the wire and die attach areas the metal pads are bonded to a reinforced polymer layer for structural stability. The structure of this layer is also visible in the images.

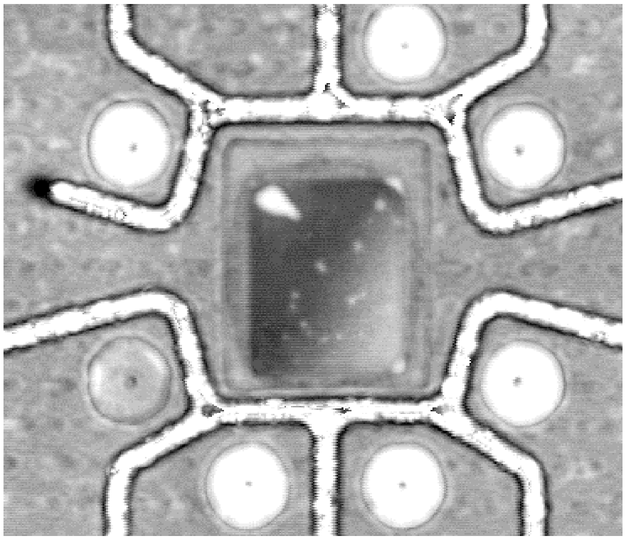

**Figure 1a – Image of smart card die and wire bond attach using 100 MHz conventional transducer.**

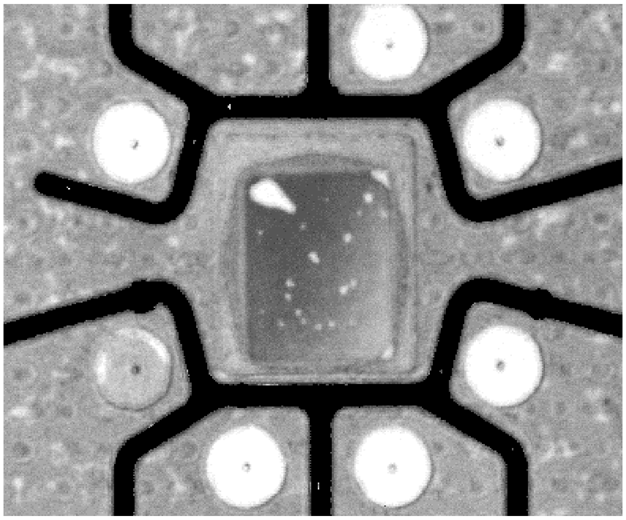

**Figure 1b – The same device imaged using a 150 MHz highly focused transducer. Additional small voids are detected using this transducer and the features are clearer.**

### Flex Substrates

The first set of pictures compare the images of a die mounted on a flex cable at 230 MHz using a standard design transducer and a highly focused transducer. The metallization on the die surface is detected using the standard transducer but notice how much clearer the detail is in the image using the highly focused transducer.

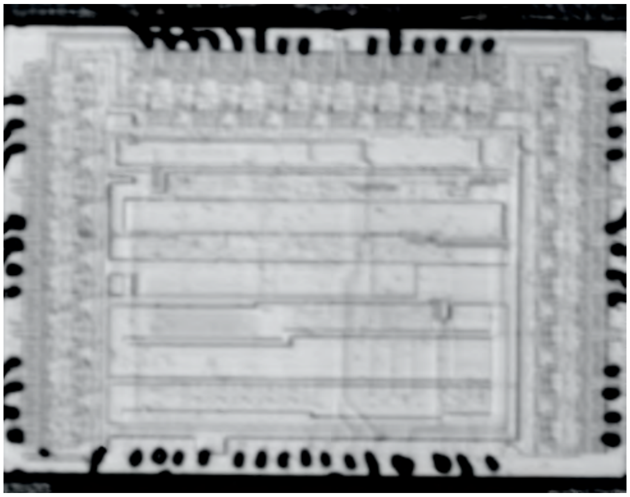

**Figure 2a - Flex circuit die surface using 230 MHz conventional transducer.**

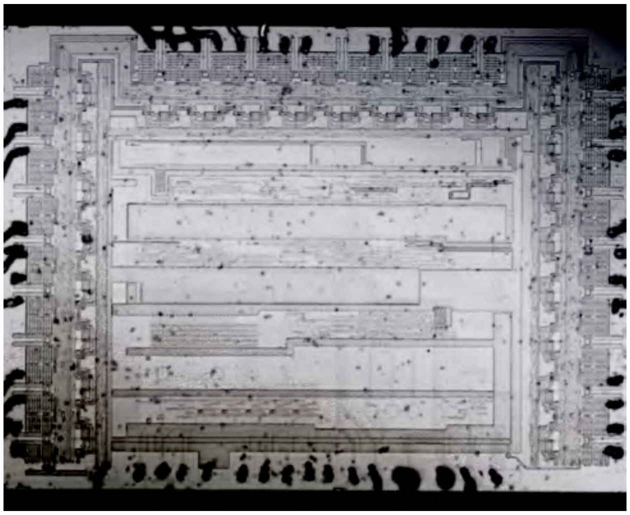

**Figure 2b - Flex circuit die surface using 230 MHz highly focused transducer.**

The advantage to using highly focused transducers on the flex tape or substrates is that the high resolution allows for high definition images of fine lines and other detail in the samples. Polyimide does not support a surface wave and, due to its material properties, does not produce a "dead zone" in the near surface layers. For these reasons the highly focused transducers will penetrate through a greater thickness of material than is possible in higher velocity materials. The following figure displays an area of a polyimide flex substrate that contains a large void and a nimber of smaller voids in the area of the metal traces.

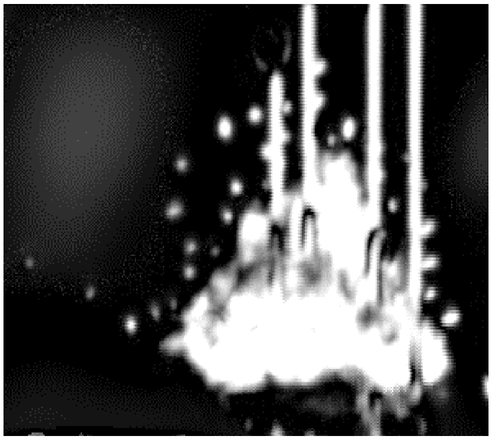

**Figure 2c – 230 MHz highly focused image of an area of a flex substrate showing voids between the traces.**

### Thick Film Voids and Inclusions

Previously, defects such as pin holes and bubbles in MCM-C LTCC (low temperature co-fired ceramic) were only detectable using destructive cross-sectioning methods. These defects can now be characterized nondestructively using Acoustic Micro Imaging [2]. The images shown in Figure 3 compare a surface image with a subsurface view obtained using a highly focused 230 MHz transducer. Surface defects appear as dark spots in the surface image (Figure 3a). In the subsurface image (Figure 3b) bright spots indicate subsurface bubbles. The light grey spots correspond to metallic grains. The acoustic data was confirmed by correlative destructive analysis including SEM and energy dispersive x-ray analysis and it is seen that the highly focused transducer reveals greater information about the defects in the specimen.

### Flip Chip - Evaluation of Back Thinned Die

Flip chips have been evaluated with great success for a number of years using more standard design high frequency transducers. When greater detail in the images is desired back thinning is sometimes used to enable better resolution imaging. Back thinning of the die, more commonly used in emission microscopy applications [3], can also be employed to eliminate the edge effect caused by the die thickness. This allows for detailed evaluations of interconnect sites near the edges of the die using highly focused transducers giving clearer detail of the metallization on the chip surface. Figure 4 shows the images through a normal thickness die using a conventional transducer along side an image of a thinned sample of the same type using a 230 MHz highly focused transducer. The levels of detail in the metallization and near the edge of the part are seen to be better in the images obtained with the highly focused transducer.

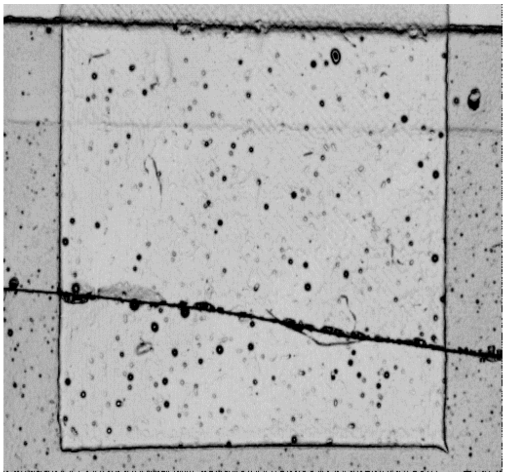

**Figure 3a – Surface image of thick film sample. The black spots correspond to surface defects. Grey spots indicate inclusions and subsurface voids.**

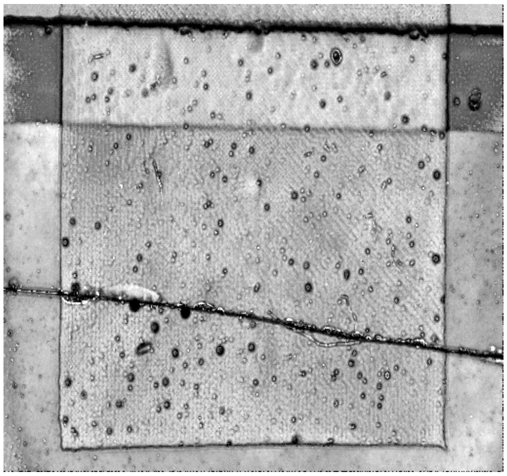

**Figure 3b – Subsurface image of thick film sample. The spots with a bright center indicate subsurface bubbles. Spots that appear grey on the surface and subsurface images indicate inclusions that can cause shot circuits.**

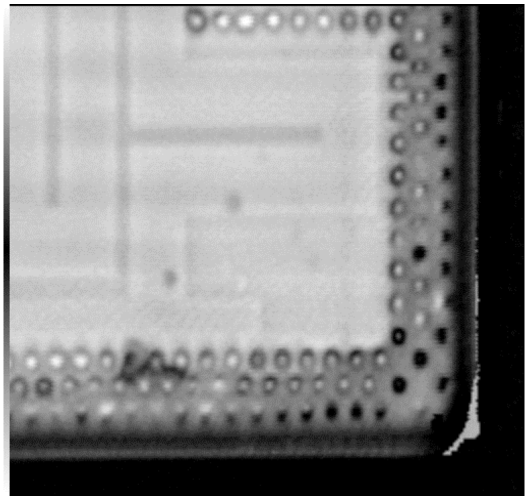

**Figure 4a - Image of the chip to bump interface using a conventional design transducer through a typical thickness, non-thinned die. The bright bumps indicate defective bonds.**

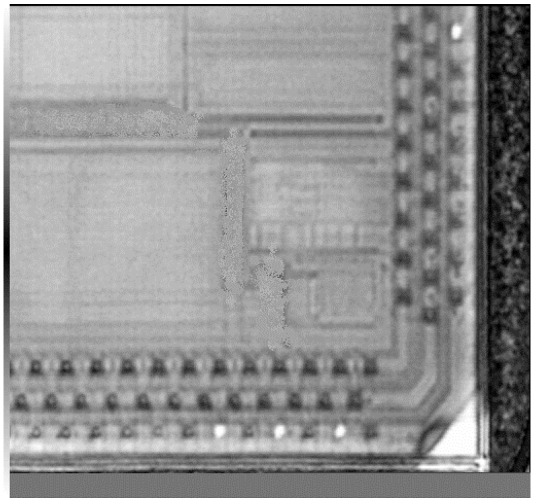

**Figure 4b- Image of the chip to bump interface using a highly focused transducer through a back thinned die. The white bumps correspond to defective bonds. Notice that the edge of the die and the metallization is clearer in this image.**

**TAB and Solar Cells - Lead Bonding**

The images shown in Figures 5a and b display a surface and a subsurface view of thermal compression TAB outer lead bonds, respectively. It is relatively simple to image the lead attach through the substrate using conventional AMI methods when the leads are bonded to a ceramic substrate. However, when the leads are attached to a composite PCB substrate, as in this instance, access to the bond has to be through the lead. The thinness of the metal lead creates problems in imaging the bond area using conventional transducers even at high frequencies because of the presence of a "dead zone" close to the surface of the specimen due to the strong surface reflection. In such cases the bond area can be clearly defined using highly focused transducers. The surface view shown in Figure 5a displays the impression of the bond head on the leads (as indicated by arrows) without revealing the nature of the bond. In contrast the quality of adhesion is shown in the subsurface view (Figure 5b). The dark areas indicate good bonding while light areas indicate poor bond.

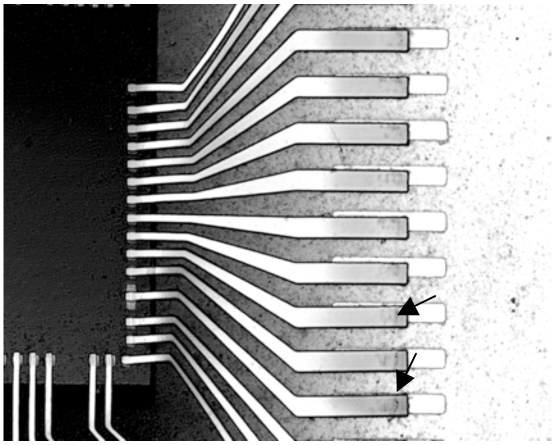

**Figure 5a - Surface view of outer leads. The arrows indicate the impression of the bonder.**

Similar to the outer lead TAB bonds, metal tabs are used to make the connections in a solar cell array. In this example thin metal tabs were ultrasonically bonded to the metallization on the solar cell. The surface view shown in Figure 6a indicates only the impression of the bonder (as indicated by arrows). The near-surface image with the highly focused transducer, however, reveals the good bond as the dark grey areas.

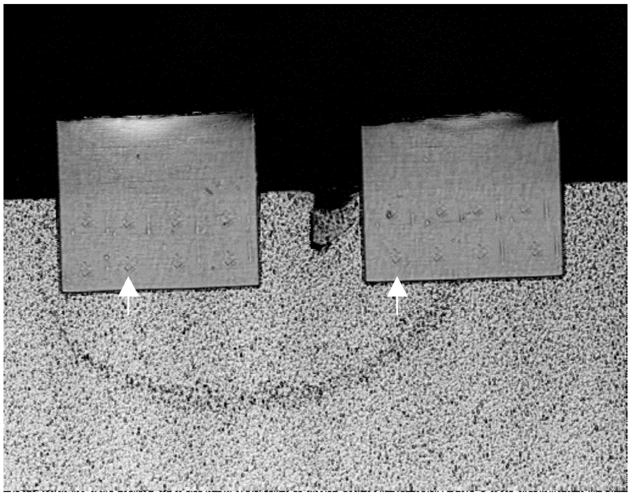

**Figure 6a - Surface image of solar cell tabs. The arrows point out the impressions of the bond head. A crack is present in the silicon between the tabs.**

## CONCLUSIONS

Some of the factors affecting the resolution afforded by a given transducer such as frequency, F# and the length of the fluid path are discussed. Highly focused transducers optimize the above factors to obtain the best possible resolution for inspection of near-surface flaws and thin packages. Example applications are discussed to demonstrate the effectiveness of highly focused, high frequency transducer as compared to conventional transducers.

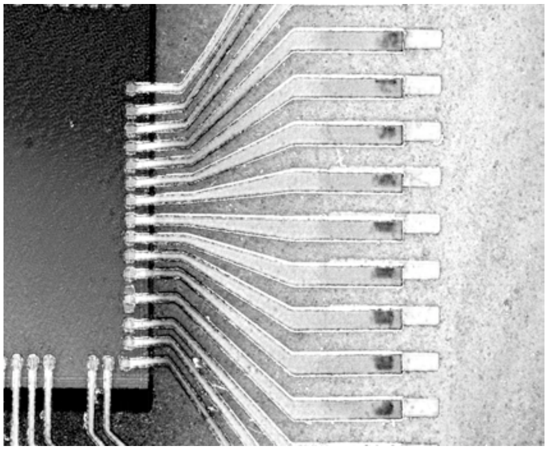

**Figure 5b - Image of the lead bond interface. The dark areas within the outline of the leads indicate the bonded areas.**

In both instances of the TAB leads and solar cell tab bonds, near surface images of the bond interfaces were obtained using a 230 MHz highly focused transducer in cases where the bond interface could not be imaged using conventional subsurface transducers.

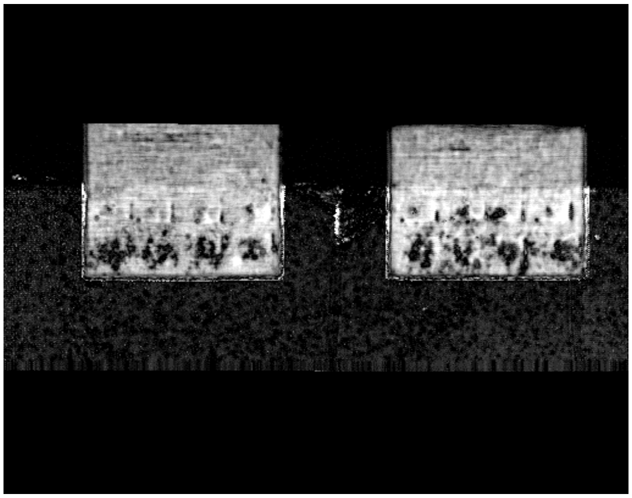

**Figure 6b - Bond interface of the tabs. Dark areas within the outline of the tabs indicate bond.**

## REFERENCES

[1] S. Canumalla, "Resolution of Broadband Transducers in Acoustic Microscopy of Encapsulated ICs – Transducer Selection.," - manuscript in progress.

[2] G. Harsanyi, J.E. Semmens, S.R. Martell, L. Percsi, and E. Toth, "Analyzing MCM-C Multilayer Defects by Using Acoustic Micro Imaging", Proceedings – IMAPS '98, San Diego, California.

[3] M. Mahanpour, D.T. Hurley, Dr. L.W. Kessler, "Die and Solder Ball Defect Inspection in Flip Chipped Packaged Devices", Semiconductor Fabtech, 1997.