

INTRODUCTION TO SONOSCAN

Dr. Lawrence W. Kessler developed the acoustic microscopy, non-destructive inspection technique at the Zenith Radio Corporation, and in 1973, he acquired patent rights to form the Sonoscan Inc. The original effort at Zenith was prompted by a need to screen for defects in Plastic Encapsulated Microcircuits (PEMs) to alleviate a rash of warranty return failures found to be primarily from voids at the die attach interface, and de-laminations in the epoxy encapsulate at the package to die/lead-frame interface(s).

Since 1974, Sonoscan has developed a variety of acoustic inspection instrument models and techniques to aid the microelectronics industry in developing and manufacturing plastic packaging (PEMs). This non-destructive inspection technique is useful in both PEM screening and reliability assessment of PEM product. Acoustic Microscopy Inspection is limited only to the material thickness and acoustic transmission characteristic.

The most widely used technique is the C-Mode whereby a device(s) can be inspected as if "mechanically" cross-sectioned. Slices of variable thickness are made at desirable interfaces e.g., the package to die, die to die paddle (die attach), and package to lead-frame. Anomalies and discrepancies are readily detected by observing the echo signal characteristics at the interface of interest. Anomalies and/or defects can be viewed as a "looking-down-thru" image of the slice on the Sonoscan image display screen. Also, the image can be presented as a printout for use in reporting.

A trained operator can detect anomalies and defects in both the construction and material of the device being inspected. The common anomalies and defects are voids, de-laminations, poor die attach, poor adhesion at interfaces, excessive porosity, cracks in the package and die, die misplacement and chipped die. Post environmental inspections will detect variations and changes in material characteristics by observing changes in the material grain structure. High temperatures typically cause surface oxidation, which is detected by a significant loss of echo signal strength

While the inspection of PEMs internal integrity is most widely used, inspections of other product defects and anomalies are also performed when non-destructive inspection and/or cross sectioning is required or desired. Some examples of ceramic, metal and plastics:

Solder Coatings - poor adhesion (cause of future flaking)

Surface Plating - inconsistent thickness, poor adhesion (potential bleed thru and oxidation)

Surface Quality (Ceramic/Glass epoxy) - mottling, porosity, oxidation, layer de-lamination

Surface Quality (Metals/Alloys) - scaling, pitting, corrosion (typically oxidation by oxygen & sulfur)

Material Integrity (Resins, Epoxies, metals, alloys, ceramics) - porosity, in-consistent density, internal fissures/cracks, blowholes, inclusions

Bonding Integrity (joints) - Anomalies in welds (Cracks/voids/inclusions) and adhesives (coverage/thickness/degree of adhesion)

Acoustic Microscopy Theory & Operating Procedure

I. THE "C-SAM" PRINCIPLE

This system uses transmitted acoustic signals and detection of the signal reflections - "echoes". The signal is transmitted through DI water (alcohol or mineral oil may used as well) into a solid sample, which may have one or more interfaces and may contain several elements throughout the sample. It is the differences in acoustic impedance between interfacing materials, which result in these echoes.

Transducer frequency is chosen for the type of sample being tested. Thick samples usually require a lower frequency transducer than thin samples because lower frequencies provide better penetration. Higher frequency transducers provide the best resolution for imaging details and locating thin interfaces. The frequency range in this system is from 5 MHz to 150 MHz; however, higher frequencies are now available.

NOTE: Typical values of acoustical velocity "V" and impedance "Z" for the most frequently encountered materials:

MATERIAL ACOUSTICAL V/Z (V = km/S)

Al	6/17
Au	3/63
Ag	3.6/38
Al ₂ O ₃	10/35
Epoxy Resin	2.5/3
H ₂ O	1.5/1.5
W	5.4/104
Air	zero/infinite (in this system)

The acoustic signal is focused at a depth dependent on the sample construction and the desired interface or element location (Target). When the transducer is focused to a specific interface or element, a maximum signal is detected and appears as a peak on the A-SCAN oscilloscope display; but, its amplitude is dependent upon the properties of the material, the thickness of the material, and its clarity may be affected by interfering echoes from elements and interfaces located primarily above the desired target.

The amplitude, polarity and time location of the focused peak signal display are all dependent on the medium material and the distance the signal must travel. Focused signals going from a very low resistance to a very high resistance and vice versa will produce a relatively large echo (Large peak on the "A" scope). Echoes from voids in the sample always produce large negative peaks on the "A" scope display. The deeper the target, the longer the time for the peak display.

The result of a typically focused system in the C-SAM mode produces a discernable primary peak and multiple secondary peaks appearing at different times along the oscilloscope display baseline ("A" Scope,

Channel 1 in this system). This is because reflections can occur from interfaces (material differences or elements) that are located above and below the focused target interface. Since these are not focused they are usually reduced in amplitude, and ones closer to the surface will be observed on this baseline before the desired peak. Signals also penetrate deeper than the target interface and peaks may occur for each interface encountered - but usually at reduced amplitudes and significantly longer display times.

When a void or de-lamination consisting of air or a vacuum is encountered, the signal travel is stopped at that point; therefore, no interface or element can be inspected when located directly below a void or a complete de-lamination.

Note: Should a void or de-lamination cavity become filled with water, the anomaly will seem to have disappeared. A bake-out at 60 °C for ~ 4 hours is recommended after a device has been subjected to any significant high humidity environment.

A gate ("A" Scope - Channel 2 in this system) is used to reduce the number of unwanted peaks which might appear in the **Video image display** - the image generated at the end of the analysis cycle. The gate is placed at the display time (depth) of the desired peak from the focused targeted interface, and it's width is dependent on the width of the desired peak, e.g. for PEM inspection: die only, lead frame only, or die and lead frame together - the gate width is determined by operator tailoring while observing the "A" Scope display.

Samples with several interfaces of interest and elements (e.g. MCMs & ceramic capacitors) are more difficult to analyze. As mentioned earlier, a sample with a separation between layers or a cavity, cannot be analyzed through the separation layer or a cavity. It is often necessary to analyze such a sample from both directions. Several layers of different materials create troublesome multiple echoes, which can make depth determinations of interfaces difficult.

II. TYPICAL MODES OF OPERATION FOR PEM ASSESSMENTS:

A-SCAN - provides an **oscilloscope display ("A" Scope)** of vertical line information thru the depth of the sample at a predetermined point on the surface. It displays peaks at interfaces occurring at times proportional to their depth.

C-SAM - provides a **video image display** of a horizontal cross section of the sample at predetermined depth at which the transducer is focused and the gate is located. The image can be printed and/or stored on the hard drive or on the Floppy Diskette.

III. PEM ASSESSMENT CHECK LIST FOR ACOUSTIC MICROSCOPY INSPECTION

1. Consistent internal construction (FIGURES 1 & 2)
2. Consistent die size & die placement (FIGURES 1 & 2)
3. Consistent encapsulant material (Visual & Gain variations) (FIGURE 3)
4. Package & die integrity (Cracks & chips) (FIGURE 4)
5. Porosity (FIGURE 5)
6. Voiding (FIGURE 6)
7. Adhesion (encapsulant-to-die/leadframe) (FIGURE 7)
8. Die attach (FIGURES 1 & 8)
9. De-laminations (FIGURE 9)
10. Unusual anomalies (FIGURE 10)

ACOUSTIC MICROSCOPY INSPECTION 10 POINT CHECK IMAGES OF TYPICAL ANOMALIES

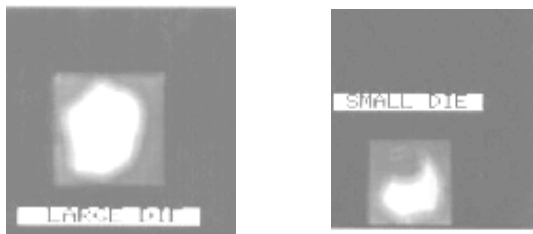


Figure 1 - Inconsistent construction from same Mfr. Large & small die under same PN. Which is available for future procurement? (Both gave poor die attach.)



Figure 2 - Poor die placement. Not centered on die pad, Die attach strength questionable?

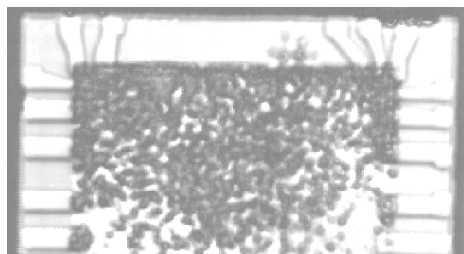


Figure 3 - Inconsistent grain size and particle distribution. Thermal shock property is questionable?

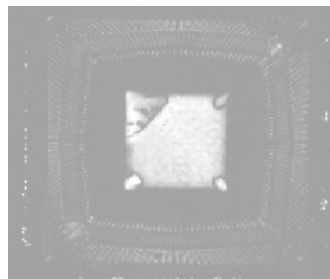


Figure 4 - Chipped die. Performance questionable?

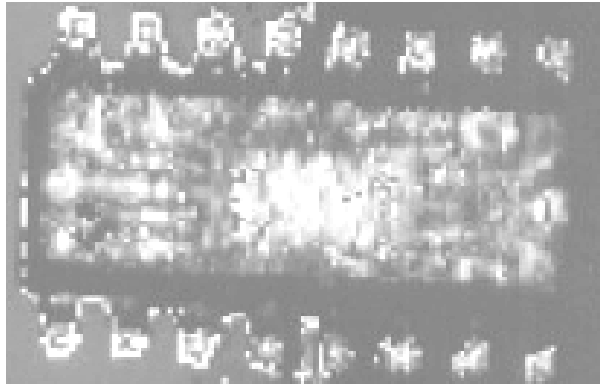
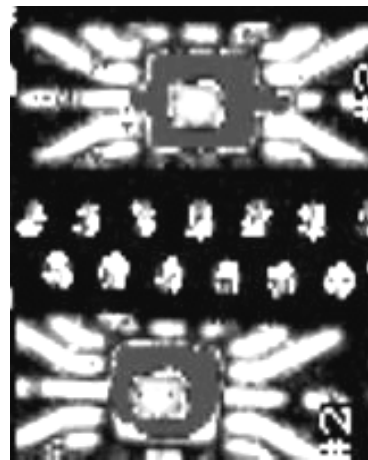


Figure 5 - Extreme porosity. Susceptible to detrimental moisture ingress.
(Unacceptable for further acoustic inspection)



Initial scan



Post pre-conditioning

Figure 6 - Evidence of voiding (Darkened areas) at die/lead-frame interface after pre-conditioning - simulated solder re-flow conditions in typical manufacturing proc.
(Voiding was confirmed by sectioning.)

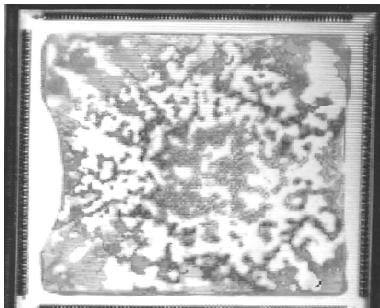


Figure 7 - Poor adhesion coverage (White areas). The ability to withstand thermal & physical stress is questionable.
(Condition was confirmed by sectioning)

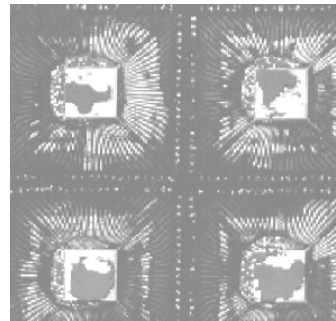
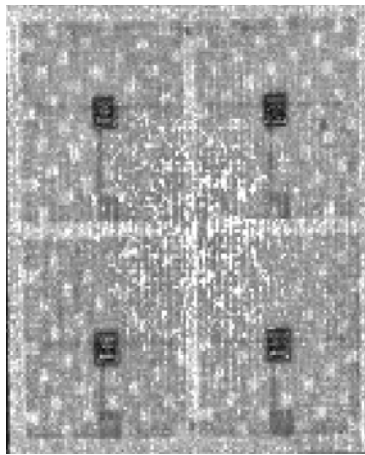
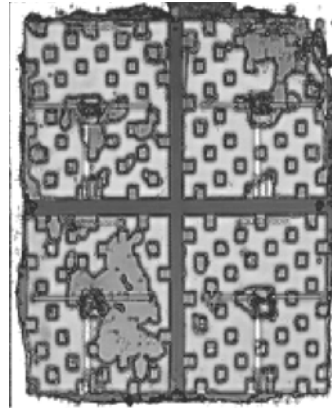


Figure 8 - No die attach (White areas). The ability to withstand thermal & physical stress is questionable.
(Condition was confirmed by sectioning)

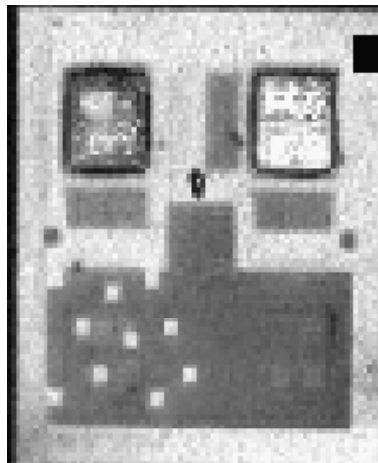


Initial Scan

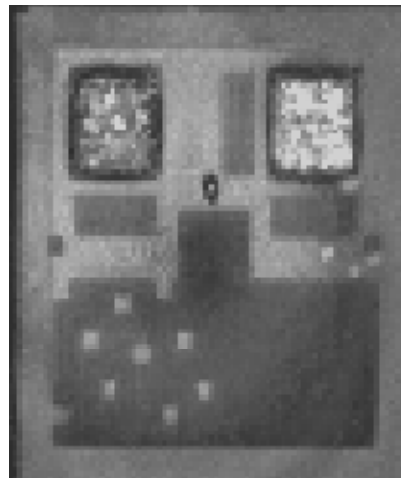


Post HAST

Figure 9 - Multi-layered device incurred de-lamination damage after 50 hours of HAST.
(De-lamination was confirmed by sectioning.)



Initial Scan



Post HAST

Figure 10 - Multi-layered device with evidence of oxidation damage after 100 hours of HAST.
(Echo signal strength greatly reduced by oxidation results in darkened image)

IV. SIMPLIFIED PROCEDURE

SONOSCAN MODEL DAC244, CSAM MODE



↑
Power "ON" / "OFF" Switches

1. Replace de-ionized water if over 1 week old.

NOTE: Be sure there is no "FLOPPY DISC" in the computer compartment.

2. Push green switch located under console...turns unit on (red switch turns it off). Log on and select, "VISUAL ACOUSTICS" and follow the window prompts.
3. The system automatically sets the X-Y axis limits...this takes a couple of minutes.
4. "A" scope Channel 1 is the main signal trace, 2 is the "GATE" trace, and Channel 3 is the Trigger input - setup as follows:
 - 4.1 Channels 1 & 2: 500 mV, sweep at 200 nS ("A" scope displays), and "DC" ("A" scope panel).
 - 4.2 Trigger on channel 3 at "Auto", "+", and "DC" ("A" scope panel).

NOTE: This scope will shut off the display after several minutes of inactivity...push "Beam Find" button to re-activate. Also, if the "SETUP/AUTO" button ("A" scope panel) is inadvertently pushed, it will change the sweep and trigger settings - re-set to 4.1 & 4.2 conditions.

5. The main screen displays two "RF SLICES" - which provides the opportunity to scan two levels of penetration with a single scan, however only the selected "RF SLICE" will appear at the separate C-SAM image display monitor. Both "RF SLICES" will always appear on main display (reduced in size).

6. Activate the desired channel to be used and filed. Both channels may be used and filed.

7. Select the Scan Size & Speed... initially, use a size to just cover the sample package and a maximum allowable speed (usually 8 inches per second).

NOTE: When the scan size is less than 20, the maximum speed is limited to 4 inches per second. Also, for very small samples a slow scan speed is recommended to prevent movement of the lighter samples which will produce a blurred image.

7.2 If necessary, install the appropriate transducer (available frequencies are 10, 15, 20, 30, 100 , & 150 MHz). Use higher Frequencies when observing details of small sample areas. Use lower frequencies for thick materials to achieve greater penetration. Set the proper transducer frequency...it is displayed on the picture of the transducer at left of the main screen.

7.3 Set the channel 1 (Main sweep) "GAIN" to around 35/55 DB and channel 2 to 25 DB (Gate sweep) using the mouse at the "GAIN" locations in the main display. The total available "SIGNAL" gain is 95 DB, but ringing can occur with excessive gains - typical gains are 25DB (Channel 1) and up to 63.5DB (Channel 2). The gain is normally adjusted to achieve the best image during the initial scans, but needs to be tailored for the final displays to achieve the best image for printouts.

8. Place the sample into the water tank under the transducer. Place the mouse arrow on the "UP" or "DOWN" arrow displayed at the transducer picture. Lower and raise the transducer with the mouse buttons. Then lower the transducer into the water about 1/2 inch Do not allow the transducer to hit the sample. Probe under the transducer with a finger to remove any trapped bubbles.

NOTE: It is imperative to remove all traces of bubbles. Also, the sample should be as level as possible to keep the interface planes in focus during scanning...this is significant with large samples or when scanning a group of samples at one time - a variation greater than 0.2 uS in " TOF" can change the required gate position and gain setting significantly.

9. Set the trigger level to 1.000. The gain of the transducer may require tailoring and the "A" scope settings may also require tailoring or re-setting to obtain a usable display of the peak. The words "NO ECHO" will change to a number ("TOF") when the transducer is over the sample and there is no bubble under the transducer to block the signal.

10. Center the transducer over the sample visually by using the mouse in transducer location window in the main display.

11. Place the mouse cursor on the "UP" or "DOWN" arrow displayed in the "TOF" window. Lower and raise the transducer with the mouse buttons to find the position of maximum peak amplitude of the first peak found on the "A" scope display...this would be the point where the 1st interface is in focus. Adjust transducer slowly (using the middle mouse button) to confirm it is at the maximum peak. This will be the top of the sample (or bottom, for up-side-down sample analysis). Using the mouse place the gate at the start of the channel 2 "A" sweep - a gate width of 0.2 uS or slightly wider is recommended.

12. A C-SAM may now be made to verify this by placing the mouse arrow on the "START " box and activating the C-SAM with the mouse button. The gain will probably need tailoring during the scan to achieve the best image. After the image is displayed, center the transducer cursers using the mouse at the "X-Y" movement matrix window - then "HOME" to establish transducer at the center of the sample.

NOTE: There are several choices to enhance the video image with combinations of "MAP" colors or black & white; begin with Map "2"...it is usually best for the initial scan, and it is normally the best for most samples. Map 24 is usually used to enhance voids or de-laminations found in PEMs. The map choice can be made and changed during the scan with the mouse. Other color maps are available for enhancement of images, as required, to be used in published reports.

13. To locate other interfaces, estimate the time it may take (TOF) to reach the wanted interface and return to the transducer. Set the gate width to approximately 0.2 uS initially. Move the gate on channel 2 of the "A" scope to the expected location of the "A" scope (CHANNEL 1), then lower the transducer while observing both "A" scope channel displays. It may be necessary to tailor the system gain, gate width, and "A" scope settings to see very small peaks.

14. When a peak is observed, optimize the scope sweep time and sensitivities...it may be necessary again, to tailor the systems gain and gate settings. If near maximum gain is required, be sure the focus is not at an echo of the desired interface. Then focus the transducer for maximum peak (raise & lower with the mouse at "UP" & "DOWN" arrows) tailoring the gate position and width to select the wanted peak.

15. When a peak is at maximum, and fairly well isolated by the tailored gate width, initiate a "C-SAM".

16. Repeat steps 12-15 until a quality image of the wanted interface is obtained on the "C-SAM" display.

NOTE: As mention earlier, if near maximum gain is required, be sure the focus is not at an echo of the desired interface.

17. To retain and document the "C-SAM" analysis of the sample, the image can be given a file name/number, stored; and, also labeled with text, and ultimately printed.

17.1 To save the image, access the desired "IMAGES " files of the main display using the mouse, then select "SAVE". Then create a file name for the sample and enter it.

17.2 To save the image on the floppy disc, same as 17.1 access "Convert Image" and select the file name. Then enter it into the "TIFF" format. Both files ("TIFF" and the

standard image file) will appear in the main directory. Access the main directory and select the "TIFF" file - then drag it into the "A" file.

17.3 To label the image to appear on filed images, use the mouse to access "ADD TEXT". Locate the text area with the cursor and type the desired label with the keyboard - be sure to press enter at the conclusion of each line or end of text.

17.4 To printout the image, be sure the image is the best attainable quality (tailor the gain and map) and labeled for sample identification.

V. APPLICATION EXAMPLES

NSWC-Crane has examined PEMs, MCMs, ceramic capacitors, and a variety of samples. Comments follow:

PEMs:

The set-up used the 15 and 20, and 30 MHz transducers to obtain required penetration for imaging the die, die attach and lead frame. Map # 2, at moderate gains provided a good image for highlighting voids (shows up as red in color map # 24). The peak at the first interface was easy to find. Focusing on the die and lead-frame interfaces and obtaining good C-SCAN images was also relatively simple.

MCMs:

Some problems were encountered as these were a cavity device. It was necessary to analyze them bottom up to avoid the cavity. The sample was a ceramic package with a ceramic substrate epoxy cemented to the package. Die and other elements were mounted on the substrate. A 100 MHz transducer and MAP # 1 (Black & White images) were chosen; The 100MHZ transducer presented some penetration difficulties.

A C-SAM image of the bottoms revealed the hand written sample numbers on each device. The stamped part number also showed on most samples when imaging the bottom. The 1st interface (bottom) was easy to find. In some cases the hand written sample numbers were visible in the image scanned at the interface level. It would best to avoid this labeling practice.

The epoxy interface presented some difficulty as peaks could be found at two places close together on the "A" Scope display. the 3rd peak was decided on as it produced the best epoxy-to-substrate interface image. It was not possible to obtain an image of the element/substrate interface with this transducer. The 30 MHz transducer was tried but it was very difficult to isolate the two epoxy interface peaks, and not much benefit was gained in penetration.

The entire group of 35 samples was analyzed with the 100 MHz transducer and good images of the epoxy interface were obtained.

Two significantly different interface images were found. About half appeared to be a smooth layer of epoxy and half were mottled in appearance indicating less than 100% coverage. This could be a problem in dissipating heat during operation.

CERAMIC CAPACITORS:

Ten ceramic capacitors, containing 47 inter-digitated plates, were analyzed using the 15 MHz transducer, by first finding the top interface, then the bottom interface and setting the transducer focus midway between them. Using a wide gate and MAP # 1 (Black & White images) produced a good image and showed de-laminations on three of the ten samples. However, it was discovered that the samples must be scanned from both the top and bottom to see all of the de-laminations that occur much closer to one surface than the other.

Heatsink - Al₂O₃/Al SUBSTRATE:

This assembly consisted of ALUMINA/EPOXY/ALUMINUM/EPOXY/ALUMINA fabricated in alternate layers, approximately in thickness of .060/.005/.125/.005/.060 inches respectively. Interest was in the alumina-to-epoxy/epoxy-to-aluminum interfaces.

Both the 100MHz and 30 MHz transducers were used with some success. The epoxy interfaces were located and no voids or de-lamination were detected (Echoes from voids would have produced large negative peaks). It was necessary to scan from both sides to reach both epoxy interfaces. Calculating the gate position of the epoxy was helpful and made possible by the material and dimensional information provided with the sample. The 100 MHz transducer provided the better image of the pattern found at the epoxy-to-aluminum interface (a very narrow gate was used after locating the interface).