Transducer and System Dependency of Scanning Acoustic Microscope Images for Plastic Encapsulated Microelectronics

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ABSTRACT

Scanning Acoustic Microscope (SAM) has been evaluated for its capability and consistency in imaging plastic encapsulated microelectronics (PEMS) components. SAM has been used in the past as a tool to observe or measure package interfacial delaminations during and after accelerated environmental stress tests. We have been interested in establishing the SAM technique as a repeatable and reproducible method for contractor evaluation of PEMs reliability under temperature cycling and temperature/humidity stresses.

In the process of developing SAM contractor specifications, we have imaged selected PEMS components with SAM systems made by two different manufacturers. They are AD795 Si operational amplifiers and MMBT2222 NPN and MMBT2907 PNP Si bipolar transistors. Both SAM manufacturers use the same 15, 25, 30, 35, 50, and 75 MHz frequency ultrasonic transducers. With either system, the SAM reflection images for the same PEMs part and the same transducer are quite similar, but the delamination information produced by each system is different. Our studies indicate that the machine delamination information given by the built-in-phase inversion algorithms is system, transducer, and operator dependent. Thus, the delamination information given by the built-in-phase inversion algorithms requires careful interpretation to avoid either false positives or negatives. An experienced in-house SAM evaluation may be necessary to verify delaminations reported by an outside testing laboratory and any recommendation for a follow-up cross-section of the imaged parts.

For now, we consider SAM as a secondary tool during characterization and reliability test processes. No reject and accept criteria for a PEMs packaged part exists other than IPC/JEDEC J-STD-020A[1]. Delamination is frequently observed on the mold compound to the lead frame (die paddle) interface after an environmental test. Although this type of delamination is not listed as a "failure" in J-STD-020A, we consider it to be a warning sign.

Key words: Acoustic microscope, plastic encapsulated microelectronics, delamination

INTRODUCTION

Acoustic Micro Imaging (AMI) or Scanning Acoustic Microscope (SAM) is a non-destructive imaging method utilizing high frequency ultrasound and widely used in the microelectronic industry to evaluate the reliability and quality of the packages[2]. The mechanism of an acoustic microscope is to convert the electromechanical energy to acoustic energy and then reverting the acoustic energy back to electrical energy. Reflection of the acoustic signal occurs when the medium density and sound velocity change at the material interface within the microelectronic package.

Figure 1 shows the schematic diagram of an acoustic microscope and how the microscope images the interfaces. Figure 1 shows an IC package and transducer are immersed in water. The piezoelectric transducer sends an acoustic pulse, which is being reflected by the package interface and delamination within the package. Reflections of the acoustic pulse occur when the medium density and sound velocity change.

The reflected signal is inverted of its phase when the signal hits a delamination at interface, voids, and cracks in a medium. The phase inversions detected at the interface, voids, and cracks are significant and referred to as 'real' in this paper. The die coating and water bubbles on the IC package surface also reflect the signals. Die coating and water bubbles give us wrong impression (i.e., false delamination signal) that there is either a delamination or void. Those phase inversions are insignificant and referred to as 'false' in this paper.

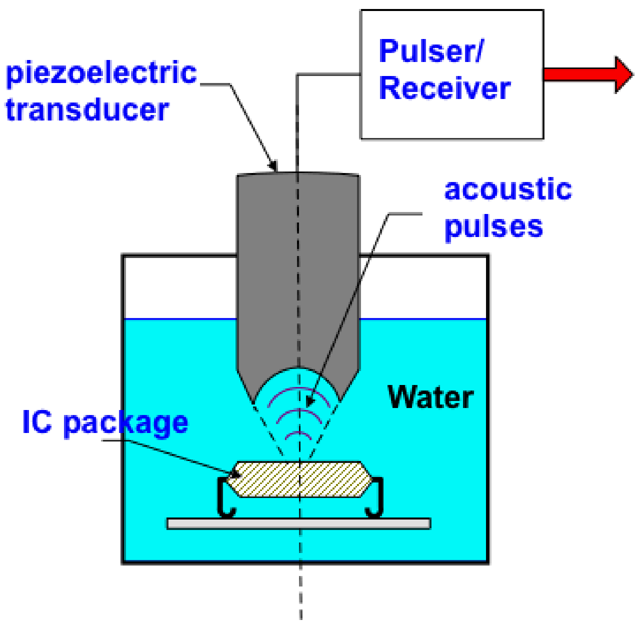


Figure 1. Schematic diagram of an acoustic microscope.

The reflected signal and acoustic evaluation of the parts depend on the 'initial SAM setup' such as the focus, reflection gate, and rate of the scan settings. The package delamination detection also depends upon the manufacturer's detection algorithm, operator, and interpretation of the results such as the signal noise. It has to be noted that different transducers give different signals. It is important to choose a right transducer based upon the SAM operator's expertise and experience.

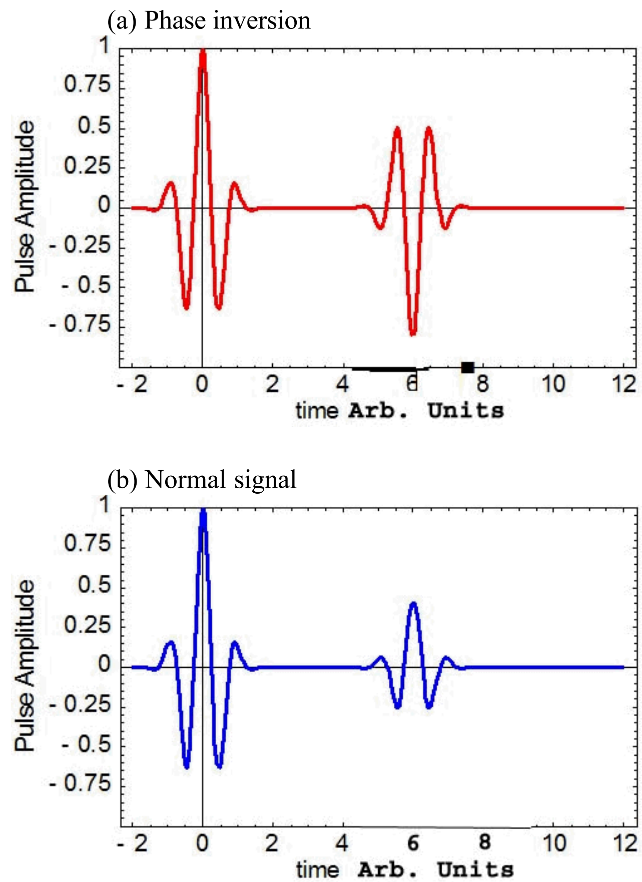


Figure 2. (a) Schematic diagram of a phase inversion, (b) schematic diagram of a normal phase signal.

The delamination detection using an acoustic microscope depends on many variables. Figure 2(a) is the schematic diagram of a phase inversion signal and Figure 2(b) is the schematic diagram of a normal phase signal. The Y-axis is the pulse amplitude in arbitrary units and the X-axis is a time in arbitrary units. The initial pulse signal is positive. If a delamination or void exists in a package interface, the signal is inverted as shown in Figure 2(a). If no delamination or void exist, the interface signal stays positive as shown in Figure 2(b).

This paper is focused on evaluating the SAM as a reproducible and repeatable method for PEMs evaluation for a small scale Hi-Rel PWA (Printed Wiring Assembly) manufacturing application and developing a "SAM specification" which can be used for making Accept/Reject decisions of the IC packages based upon the acoustic images taken by various outside testing houses. It delineates our experience and decision-making process to consider a SAM as a secondary tool during the characterization and reliability test processes for the surface mount manufacturing.

RESULTS OF THE DATA

The parts of interest are

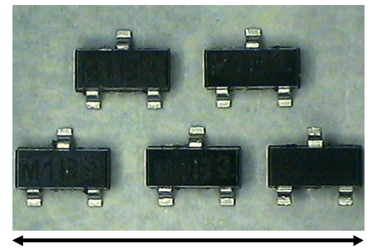
- On-Semi's MMBT2222ALT1 NPN Si bipolar transistor
- MMBT2907 PNP Si bipolar transistor
- Analog Device's AD795 Si operational amplifier
- Alpha Industries' GaAs Microwave switch
- Microsemi's GaAs RF limiter diode.

Figure 3 shows the MMBT2222s, and Figure 4 shows the AD795s.

- MMBT2222ALT1 NPN and MMBT2907 PNP Si bipolar transistors are chosen for the SAM evaluation because they are rather small and thus, the spatial resolution is difficult.
- AD795s are chosen because it has a silicon gel die-coating which inverts the signal.
- AS186s are chosen because the GaAs die doesn't have any chip passivation.
- GC47225 is chosen because of its small RF package style, and the SAM imaging of a die was rather difficult.

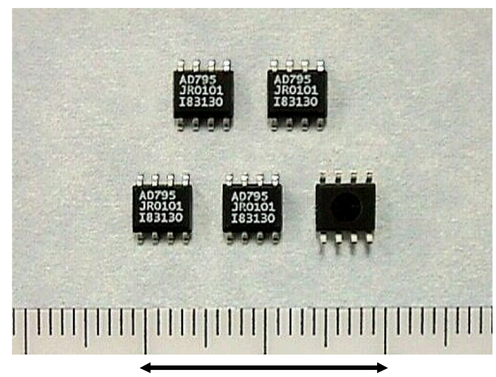
MMBT2222 NPN Transistor and AD795 Op Amp

In this paper, our Hi-Rel Commercial Off The Shelf (i.e., COTS) microelectronic process development and our use of the SAM in our characterization processes are delineated using the results of MMBT2222 and AD795 evaluation. It is noted, however, we have evaluated the SAM images of all five IC packages MMBT2222, MMBT2907, AD795, GaAs switch, and GaAs diode before making the decision of whether to use the SAM as our secondary tool in the COTS characterization process or not.



0.3 inch

Figure 3. OnSemi's MMBT 2222 NPN Transistors.



2 inch

Figure 4. Analog Device's AD795 OP AMPs.

Figure 5 shows the MMBT2222 Transistor's 50 MHz transducer SAM image and X-ray image as received and optical image after decapsulation. Figure 5a) shows the Si die, die paddle, and lead finger. The red circle on Figure 5a) marks the area where the bond wire is located. One cannot see the bond wires in the SAM image, however, the dark area inside the red circle is the result of the reflected signals at the gold bond wire interface. The phase inversion signals are noted with red and yellow colors. It tells that the delamination exists between the mold compound and the die paddle. JEDEC STD-20 sets the failure criterion as a 10% delamination of the die surface or wire-bonding surface on the lead frame. Figure 5a) shows that application of the JEDEC standard criteria to this part would be difficult because the die and wirebonds on the lead frame can't be imaged accurately due to the required spatial resolution.

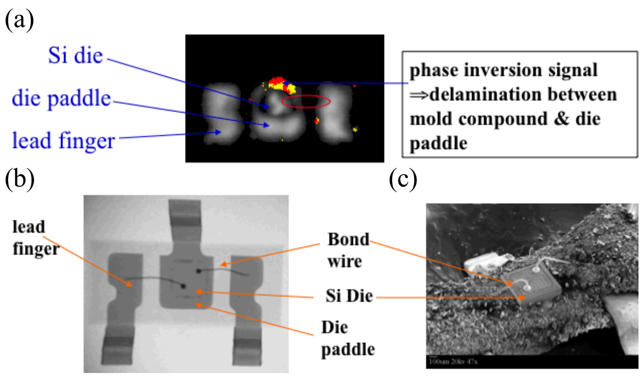


Figure 5. MMBT2222 NPN Transistor's (a) Scanning Acoustic Microscope image with a 50MHz transducer (b) X-Ray image, and (c) scanning electron microscope image after a decapsulation.

Figure 6 shows the AD795 Operation Amplifier's SAM image taken with a 25MHz transducer, X-ray image as received and optical image after a cross-section. Figure 6a) shows an approximate location of the Si die, die paddle, and lead fingers. The die and die paddle region are painted red by strong phase inversion signals. The existence of the silicone die coating between the mold compound and die prevent acoustic imaging of the die and die paddle. Figure 6b) and c) show the corresponding Si die, die paddle, lead fingers, and bond wires more clearly than those of Figure 6a). The silicone die coating is shown in Figure 6c). One needs to be alerted about a 'false' delamination with the apparent phase inversion signal in Figure 6a). An experienced operator would examine the phase inversion signal by evaluating the SAM images side by side with the X-ray and optical images and by performing a cross-section. It is to be noted that the part construction information is necessary to understand the SAM images and the phase inversion signal.

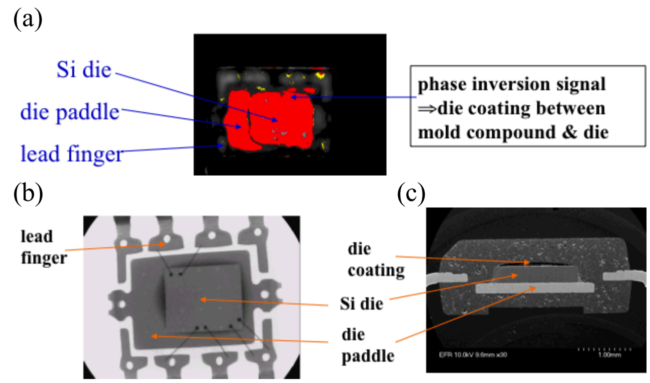


Figure 6. AD795 Op Amp's (a) Scanning Acoustic Microscope image (b) X-Ray image, and (c) optical image post a cross-section.

Figure 6a) demonstrates how application of the JEDEC standard criteria of 10% delamination of the die surface or wire-bonding surface on the lead frame as failure to the AD795 is not applicable.

Test Flow

Figure 7 shows the schematics of the IC package test flow. The parts were procured, underwent initial electrical or functional testing (i.e., e-test) and completed SAM. To have a repeatable image after each increment of environmental testing, we used control samples to recreate the SAM images as closely as possible before imaging the parts.

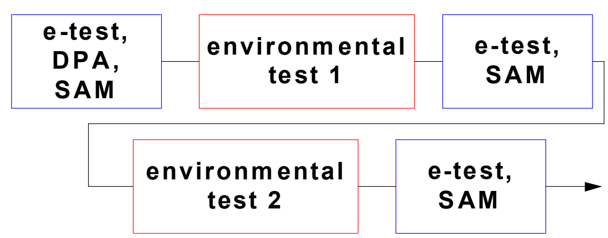


Figure 7. Schematics of the IC package test flow.

SAM Image Comparison of functionally Good vs. Failed Parts

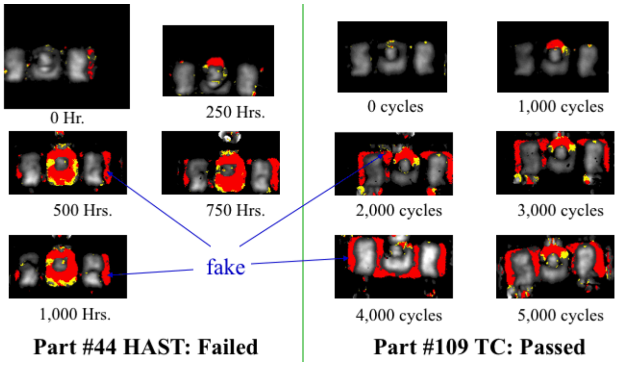


Figure 8. SAM images of the MMBT2222ALT1 NPN transistor using a Manufacturer 1's microscopy and 50 MHz transducer.

Figure 8 shows the SAM images during the reliability testing of MMBT2222s. The left hand side is the HAST part #44 which failed the e-testing post 1,000 hrs. HAST. The right hand side of the figure 8 is the TC part #109 which passed the e-testing post 5,000 TC. The SAM images of the same part is similar, but not the same even the operator, setup parameters, and transducer are the same.

Figure 8 shows that the delamination information per the phase inversion signal changes substantially as the environmental testing progresses. The HAST part #44 shows increasing delamination in the die paddle area post 500 hrs. HAST. Per subsequent cross-section of the package, it was found that the delamination information was 'false'. The artifacts or 'false' delamination show up because of the required spatial resolution for a very small part. For the TC part #109, Figure 8 shows that the die paddle delamination is less than that of the HAST part #44. The thermal expansion mismatch of the mold compound and die paddle has little consequence for a small part. Thus, the MMBT2222s didn't degrade or delaminate much under the TC.

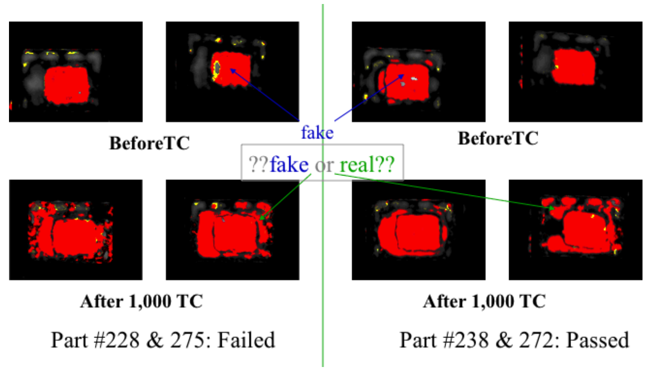


Figure 9. SAM image comparison of the Analog Device's AD795 Si operational amplifier taken with a Manufacturer 2's microscopy and 25MHz transducer.

Figure 9 shows the SAM images of AD795s. The left hand side is the failed TC part #228 and #275 post 1,000 temperature cycles. The right hand side is the TC part #238 and #272 that passed the e-test post 1,000 cycles. The die and die paddle cannot be accurately imaged due to existing silicone die coating. The die regions show 'false' delamination signal with the die coating.

From these four post-TC images one can see that the part #228 and #272 have the most severe delamination whereas #275 and #238 have limited delamination. You cannot simply pick failed/passed parts based on the SAM images. One may raise a question about whether these colored regions in the die paddle area post TC are 'false' or 'real' delamination. The question would require a pain staking effort to resolve the phase inversion signals of the melted die coat flowing into the die paddle area during the TCs from the actual package delamination. Numerous cross-sectioning and material analyses after separating the silicone die coating from the mold compound would be needed to identify whether the delamination is 'false' or 'real'.

Comparison of the SAM Image Taken from Two Different Manufactures' Systems

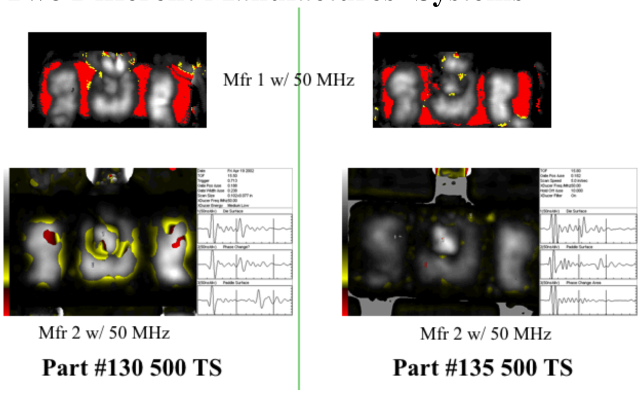


Figure 10. SAM image comparison of the MMBT2222NPN transistor from two different manufacturers' systems while using the same 50MHz transducer.

Figure 10 shows the SAM images for MMBTs. The top images are made with the acoustic microscope from Manufacturer I. The bottom images are imaged with a Manufacturer 2's system. The left hand side shows the images of the part #130 and the right hand #135 post 500 thermal shocks. Please note that both SAM manufacturers obtain transducers from the same vendor. The SAM images taken from two different systems are somewhat similar but are not the same. The delamination information is, however, completely different. For the SAM to be our primary tool to reject/accept IC packages, we need to have the same delamination information regardless of the system or manufacturer.

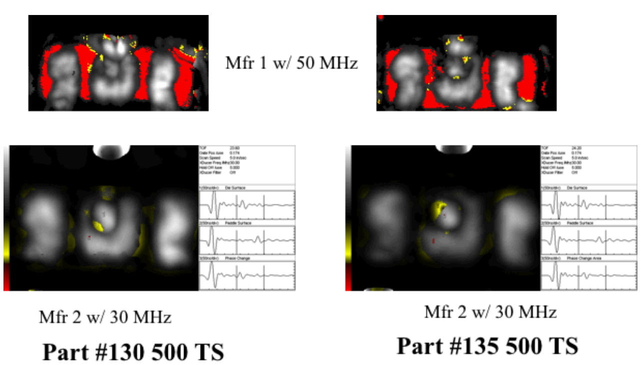


Figure 11. SAM image comparison of the MMBT2222NPN transistor taken with two systems built by two different manufacturers while using two different frequency transducers.

Figure 11 shows the SAM images of the MMBT2222s taken with a 50MHz transducer with the Manufacturer 1's system and a 30 MHz transducer with the Manufacturer 2's system. The left hand side shows the images of the part #130 and the right hand side the part #135 post 500 thermal shocks. The top and bottom images are still similar to each other, but the delamination information taken with the Manufacturer 1's system cannot be reproduced by the Manufacturer 2's system. For imaging, 50 MHz transducer is favored with the Manufacturer 1 system; 30 MHz transducer is favored with the Manufacturer 2 system. This preference of 50 MHz for Manufacturer 1 and 30 MHz for Manufacturer 2 is limited for the MMBT222. Please note that both manufacturers obtained the transducers from the same vendor. The favor of one transducer vs. another is an operator preference. The manufacturers generally recommend higher frequency transducer for more refined SAM imaging. It seems that the preference can be given to a lower frequency transducer depending on the IC package type and system manufacturer.

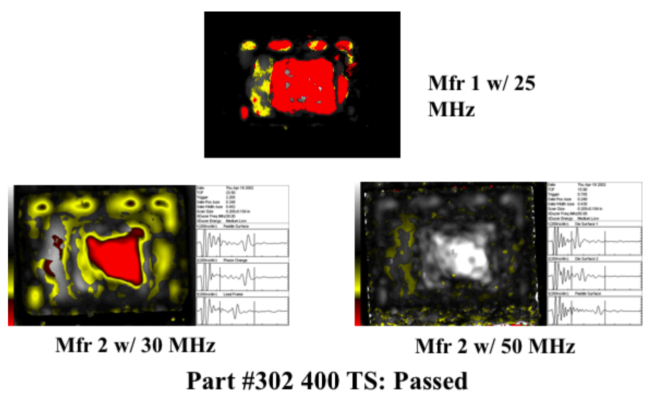


Figure 12. Comparison of the AD795 Si operational amplifier SAM images taken with two different manufacturers' systems while using two different frequency transducers.

Figure 12 shows the SAM images of the same AD795 taken with the Manufacturer 1 and 2 systems. The part was undergone 400 TS and passed the subsequent e-test before imaging. Different frequency transducers are chosen to experiment which transducer gives most refined and consistent images for each manufacturer system. In this case, the 25 MHz transducer is preferred with the Manufacturer 1's system whereas the 30 MHz transducer is preferred with the Manufacturer 2's system. In Figure 12, the top image is somewhat similar with the bottom left image, but again the delamination information is different. It is noteworthy that the Figure 12's bottom right image taken with the Manufacturer 2 and 50 MHz transducer is different from the two other images in Figure 12. The bottom right image doesn't even report any moderate phase inversion/delamination signal. It is imperative that the operator uses a most optimal transducer for different SAM system. Figures 11 and 12 show that the higher frequency transducer is not necessarily better even though that is assumed generally. As reported[2], it is necessary that the transducers are more sample specific to get an optimum image.

CONCLUSION

The case studies presented show that scanning acoustic images are dependent upon the system and transducer. Generally, similar but not the same SAM images can be taken with different systems. Particularly, the delamination information resulted from the phase inversion signal can be significantly different if different system or transducer is used. In this paper, it is also shown that the higher frequency transducer is not necessarily better[3].

We have been interested in establishing the SAM technique as a repeatable and reproducible method for contractor evaluation of the PEMS reliability under temperature cycling and temperature/humidity stresses. With the variability of the SAM imaging, we are not able to use the SAM as our primary tool in our Hi-Rel surface mount manufacturing process. For now, we consider a SAM as a secondary tool during the characterization process.

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