Capabilities of Acoustic Micro-Imaging (AMI) for Opto-Electronic Packaging

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Abstract

Acoustic Micro-Imaging (AMI) is a non-destructive technique utilizing high-frequency ultrasound to inspect a wide range of part types and materials including opto-electronic components. This technique is very sensitive to physical changes within a material and the quality of the bond between different materials. AMI techniques are particularly sensitive to air-gap type defects including cracks, delaminations, voids, and porosity as well as material variations. An advantage of AMI is the non-destructive nature of the ultrasound, which can detect defects inside packages while still leaving them available for further testing and analysis or end use. AMI has applications at many points in the life cycle of a product design, including research and development, process development, quality control, and failure analysis. AMI can be utilized to evaluate many types of materials and sub-components that make up an opto-electronic product. Typical areas of analysis include, but are not limited to, die/chip attach, substrate attach, lid seal, window frame seal, and material investigations. This paper will discuss the applications of AMI for the inspection of typical opto-electronic packages, including both qualitative and quantitative analysis.

Introduction

Acoustic micro-imaging (AMI) is a sensitive technique for determining air gap type defects such as cracks, delaminations, or voids as well as material changes such as porosity, inclusions, and interfaces in a wide range of materials. In the pulse-echo or reflection mode, high-frequency ultrasound (typically 5 to 300 MHz) is pulsed from a focused transducer through a coupling medium (most commonly distilled or deionized water) into the unit under test. At each interface between materials, some of the ultrasound is reflected back to the sending transducer, resulting in an echo from that interface.

These echoes have a particular polarity and amplitude, based on the acoustic impedance of the materials at the interface. This is shown in the following formula:

$$R = (Z_2-Z_1) / (Z_2+Z_1) \qquad (1)$$

where R is the reflection coefficient and Z_1 and Z_2 are the acoustic impedances of the top and bottom materials of the interface, respectively. The mismatch of the acoustic impedances dictate the polarity and amplitude of the echoes; positive echoes are generated by traveling from a material with lower acoustic impedance to a material with higher acoustic impedance, while negative echoes are the reverse. In addition, the larger the mismatch, the larger the resulting echo. At the ultrasonic frequencies used in AMI, no transmission of ultrasound occurs through an air gap; therefore, at a delamination or void all of the ultrasound is reflected back to the sending transducer and no depth below that air gap can be inspected in that part orientation. The result is the largest amplitude echo expected from this particular interface.

The echoes from each interface are separated along the time axis, depending on their depth in the sample and the velocity of ultrasound in that material. The collection of all the echoes from the different interfaces at a particular point in the sample is called the A-Scan. Images of a particular interface or depth within the sample are created by using an electronic gate to select the echo from the interface or level of interest. The transducer is then scanned over the sample to collect this gated signal from the entire interface. Changes in the echo from the interface of interest are displayed on the image in different colors or grayscale values, which correspond to changes in the echo's polarity or amplitude.

It is important to have a basic understanding of the sample's construction in order to best interpret the images generated. Knowledge of the part construction allows for the prediction of the echo location for each interface of interest in the A-Scan, as well as the expected shape (polarity) and size (amplitude) of the echoes for bonded and disbonded areas at the interface.

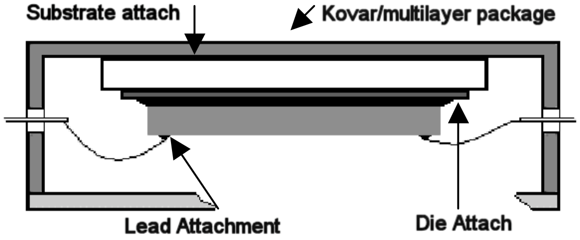

Figure 1. A cross-sectional view of a generic butterfly hybrid package.

AMI Analysis of Opto-Electronic Packages

The evaluation of the various bonded interfaces in an opto-electronic package is important to help ensure the reliable operation of the unit. Voids in the bond line of a die attach can result in uneven stress on the die or component, leading to reduced performance or failure of the die. An incomplete bond may also compromise heat transfer through the attach. In hermetically sealed packages, voids in the window frame seal can create a leak path to the outside. Missing or misplaced wire bonds can cause failures.

An example of a typical opto-electronic package inspected using AMI is a Kovar butterfly (hybrid) package. A generic sample construction cross-section is shown in Figure 1. Interfaces of interest in this kind of package are the base (Kovar or multilayer package) to the substrate attach interface, base to ceramic window frame seal interface (not shown in the above diagram), TEC attach (not shown in above image), substrate/submount to die attach interface, and wire bond to die interface. In many cases, the die or active component may be attached directly to the base. If the part is sealed, enclosing the die and substrate in a hermetic package, the only approach is to propagate the ultrasound through the base to reach the attach interfaces. The acoustic microscope is then set up so that the echo from the interface of interest is maximized ("in focus") and within the electronic gate, and an image is generated of the interface. An example of a base to die attach image is shown in Figure 2.

The components directly attached to the base have a built-in calibration method: in most cases, the substrate or active component is smaller than the base, and so there is some unbonded area left around the attach region. This unbonded area will reflect a larger echo than a bonded area, due to the larger acoustic impedance mismatch between the base to air/water interface (unbonded area) and the base to attach interface (bonded area). Any voids or delaminations in the bonded area will have an echo amplitude similar to the unbonded area. In the images shown, the bonded areas of the attach regions are darker gray, while delaminations in the attach regions and the unbonded regions are both brighter gray and white. This same procedure of focusing and gating the echo is followed for each interface of interest inside the sample. Any defects at one interface will cast an acoustic shadow over interfaces deeper inside the package, because of the total reflection of the ultrasound from the air gap. A complete analysis of the sample may then involve turning the sample over and imaging directly through the die or component to the attach interface (assuming the part is open or can be delidded).

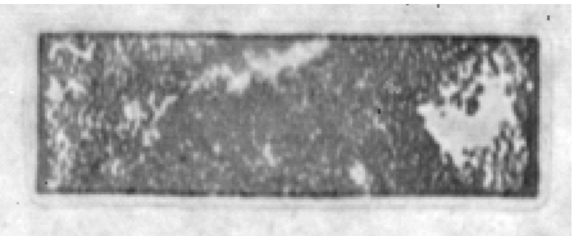

Figure 2. An image of the base to die attach interface using AMI. Bright gray areas in the rectangular attach area indicate voiding; darker gray areas indicate bonding. The bright gray outside the attach area is designed to be unbonded.

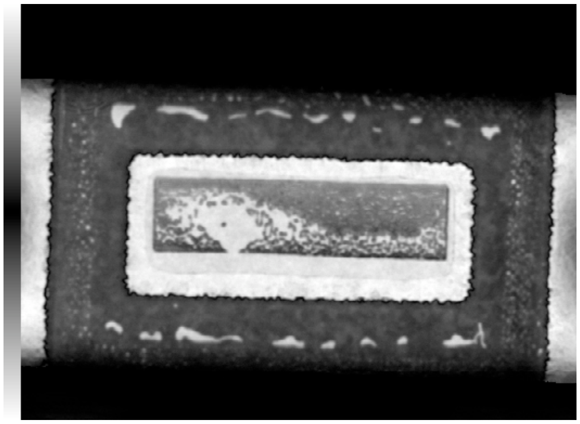

Figure 3. An image of the base to die and ceramic window frame interfaces using AMI. The grayscale bar on the left side of the image indicates the scale used to display the data; bright gray and white areas indicate disbonded or unbonded areas, while dark gray areas indicate bonded areas in the attach regions.

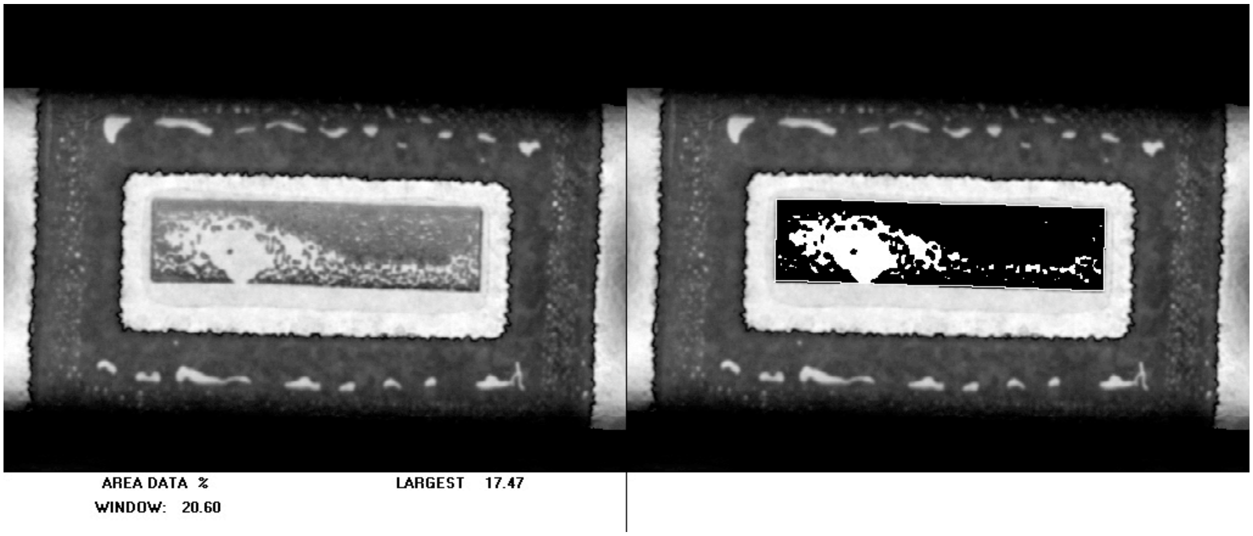

Figure 4. An example of quantitative analysis performed on the image in Figure 3. The original image is on the left side, while a binary image of the die attach area is on the right. White in the binary image indicates defect; black indicates bonding. This unit exhibits defects over 20.6% of the die attach area, with one single void comprising 17.47% of that total.

In this orientation, areas of the attach may be obscured by wires bonded to the component or structures on the component surface.

Uses of AMI Analysis

AMI techniques are useful at many points in the life cycle of opto-electronic packages. During the design phase, it can be utilized to characterize various materials as well as evaluate bond methods and manufacturing parameters best suited for the assembly of the device. By inspecting the bond quality using a variety of materials and processes, the optimum materials and conditions can be evaluated. For process development, the effect of conditions and equipment on the quality of the bonding can be evaluated. Figure 3 shows an image of the window frame and die attach interfaces; voiding appears bright gray and white in the attach regions, while bonded areas are darker gray. In this particular sample, the window frame attach contains some voids, none of which cause a leak path from the outside of the package to the die cavity. The die attach, however, contains a large void as well as smaller voids along one edge. The large void could indicate a hot spot which will affect the functionality of the unit. By comparing the analyses of units under various process conditions, the effect on bonding may be monitored. As a quality control tool, AMI can help ensure that the components remain within specifications, by analyzing units using both qualitative and quantitative methods. Figure 4 shows an example of a quantitative analysis of the die attach shown in Figure 3. In this example, the total amount of delamination in this die attach is 20.6%. Nondestructive evaluation of failed or suspect samples using AMI also allows for the detection and documentation of the unit before any destructive testing is performed, as part of a failure analysis or root cause investigation.

Conclusion

This paper has presented an introduction to Acoustic Micro-Imaging and its use in the evaluation of opto-electronic packaging. This technique is a useful, non-destructive method for inspection of a wide range of materials and constructions. Evaluating units during the entire life cycle of the product can yield valuable information about the materials, integrity, and control of the product and manufacturing process, while still allowing the product to be tested and used.