How to test and qualify packages with Scanning Acoustic Microscopy (SAM)

Owen Thomas
4th Feb 2014

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How to test and qualify packages with Scanning Acoustic Microscopy (SAM)

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Contents

- Introduction
- Acoustics background and a little bit of theory
- Case Study: Ultrasonic thickness measurement
- SAM's specifications, requirements and output
- Delamination Example
- Crack Example
- Summary
- Questions

SONIX UHR2001 Scanning Acoustic Microscope

- 5 micron step size
- 315 mm by 160 mm travel
- 15 MHz and 75MHz
- Pulse-Echo
Two types of SAM

- Pulse Echo – Measures the reflected acoustic wave. Uses same transducer to send and receive the signal.
- Through Transmission – Measures the transmitted acoustic wave. Two separate transducers.

![Pulse Echo](image)
![Through Transmission](image)

What is SAM for?

- Detecting defects/anomalies within Printed circuit boards (PCB) or encapsulated electronic components.
- Non-destructive testing (otherwise sectioning could also be used).
- Mainly for
  - Delamination
  - Cracks
  - Voids
Relevant Standard

- Joint IPC/JEDEC Standard J-STD-035
  Acoustic Microscopy for Nonhermetic Encapsulated Electronic Components

  Discusses the acoustic microscopy instrument, methodology, and evaluating results with respect to potential defects.

Ultrasound

- Frequencies above those picked up by human ear.

  - Infrasound: 20 Hz
  - Human hearing: 20 kHz
  - Ultrasound: 15 MHz, NPL’s Transducers
  - Highest freq transducers on market: 400 MHz
Uses of ultrasound

And typical frequencies

- Ultrasonic Cleaning (15-40 kHz)
- SONAR (10 - 500 kHz)
- Medical Sonography (2 to 20 MHz)
- Industrial NDE (10 - 400 MHz)
- Plus many more… sonochemistry, cavitation, welding, humidifiers, ….

How to make ultrasound

- Piezoelectric materials
  (change shape in electric field)
- Magnetostrictive materials
  (change shape in magnetic field)

- Magnetostrictive materials limited to few hundred kHz due to eddy currents.
- Ceramic Piezoelectrics ok to ~40 MHz.
- Polymer Piezoelectrics used above 40 MHz. E.g. Polyvinylidene fluoride (PVDF) as a thin foil film.
Pulse Echo

- Initially the transducer sends a pulse before listening to the echo. The echo is a combination of all the reflections of the acoustic wave.

i.e. we end up with something quite complicated:

Analysing the Echo

- The signal can be divided into blocks of corresponding to different times after the initial reflection.
- The strength of the signal in these blocks can give the contrast to an image.
- Since the signal at later times correspond to reflections returning from deeper layers, images can describe different depths.
- Since speed of sound varies with material, and we are looking at signals returning from a range of levels, we cannot associate a depth with an image even though later images will show deeper features.
**Speed of Sound**

- Speed of sound, \( c = f \lambda \).
- Smaller the wavelength, \( \lambda \), the greater the detail that can be imaged.
- Speed of sound depends on material and temperature.

![Graph showing speed of sound vs. frequency for different materials.]

<table>
<thead>
<tr>
<th>Material</th>
<th>Speed (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>343</td>
</tr>
<tr>
<td>Water</td>
<td>1433</td>
</tr>
<tr>
<td>Copper</td>
<td>3900</td>
</tr>
<tr>
<td>Lead</td>
<td>1160</td>
</tr>
<tr>
<td>Rubber</td>
<td>~100</td>
</tr>
<tr>
<td>Steel</td>
<td>6100</td>
</tr>
</tbody>
</table>

**Acoustic Impedance**

- Acoustic impedance, \( Z = \rho c \).
- Product of speed and density of the medium.
- Measured in Rayles (1 Rayle = 1 kgs\(^{-1}\)m\(^{-2}\)).
- Actually a complex number (\( Z = R + Xi \)).
- Useful for describing the interaction of an acoustic wave at the boundary of two media.

![Table showing acoustic impedance for different materials.]

<table>
<thead>
<tr>
<th>Material</th>
<th>Z (MRayles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>0.000415</td>
</tr>
<tr>
<td>Fresh Water</td>
<td>1.48</td>
</tr>
<tr>
<td>Polyimide</td>
<td>2.14</td>
</tr>
<tr>
<td>Glass (Silica)</td>
<td>13.0</td>
</tr>
<tr>
<td>Tin</td>
<td>24.2</td>
</tr>
<tr>
<td>Copper</td>
<td>44.6</td>
</tr>
</tbody>
</table>
Acoustic Reflection

- The greater the difference in acoustic impedance, the greater the amount of reflection.
- From the transducer to air and air to sample, there is too much loss (i.e. >99.9%) such that a coupling medium is needed.
- Water, gel or other liquid is used to couple the ultrasound into the medium under test.

\[ R(f) = \frac{Z_2 - Z_1}{Z_2 + Z_1} \]

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Acoustic Transmission

- Some of the sound is also transmitted.
- If the acoustic impedance is the same, it will appear invisible to the acoustic microscope.
- Whatever is transmitted will reflect/transmit at deeper layers and so on until the sound is absorbed.

For an acoustic wave normal to surface:

\[ R(f) = \frac{Z_2 - Z_1}{Z_2 + Z_1} \quad T(f) = \frac{2Z_1}{Z_2 + Z_1} \]
Case Study: SAM for conformal coating thickness measurement

• Measurement of the time of flight between the reflection of the coating and the substrate.

• If the speed of sound for the coating is known, its thickness can easily be calculated.

\[ d = \frac{c \times \text{TOF}}{2} \]

Inverted signals

• When going from a medium of higher acoustic impedance to one of lower acoustic impedance, the reflected signal is shifts by 180 degrees.

• The strength of the reflection is dependent on the relative magnitude of the acoustic impedance.

• This scan is into a silicone conformal coating, which has a slightly lower acoustic impedance to the water coupling medium.
Good Correlations

- With the 75 MHz transducer, below 30 microns of coating thickness, the two reflected waves start to interfere. A higher frequency transducer and/or mathematical techniques to improve resolution of technique.

Some SAM Requirements

Size
- Max area that can be scanned: 315 mm by 160 mm.
- Tank area 380 mm by 430 mm.
Cant be afraid of Water

Might not be NDE if PCB or components damaged by water

Topping up with deionised water

Sample Geometry

- Needs to be flat.

- Components can also be looked at from beneath.

Usually both top and bottom scans will be done as defects show up better in one orientation which depends on their location.
15 MHz or 75 MHz Transducer?

15 MHz
Less Detail
Greater Depth

75 MHz, Greater Detail, Less Depth

In most cases, the 15 MHz transducer is sufficient

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Scan Resolution and Image Size

- Step size of 5, 10, 20, 50, 100 or 200 microns.
- Each pixel of resulting image corresponds to step size.
- Compromise between scan time, resolution and image size. (Scanning the full area at 5 microns would produce an image 2000 megapixels in size).
- Image typically takes a few minutes to an hour depending on size and resolution.
- Output is usually a multiple layered TIF file.

- Resolving capability of features will decrease with depth as more of the sound is absorbed/scattered.
Focus depth

- Normally focused at a depth of ~8 mm
- Beam size >> step resolution
- At discontinuity, even if beam is larger than defect, some of the reflection will back to the detector will result in a change in signal and contrast in the image.
- If the defect scatters the acoustic wave, it will be harder to see.

A-Scans, B-Scans and C-Scans

- Scanning Acoustic microscopes deliver results in 3 different types of Scan
- Scan A, the response of the transceiver Vs time for a single position
- Scan B, Along a line (looking from above), A-scans interpreted to give an image showing depth information.
- Scan C, Image over an area.
A-Scan

- Simply the echo response of the transceiver from a single position above the sample.

- Already seen A-scans used in case study for coating thickness.

B-Scan

- Going across a line, the A-Scans are plotted as contrasts giving depth information
C-Scan

- Scanning over an area, an image is generated from analysing the amount of signal within a gate to determine the contrast.
- C-Scans are most commonly used, are more easily interpreted and show features like delamination best.

Example 1: Delamination

- Looking from top of component
- Looking from bottom of component
Example 1: Delamination

- B-scan from top

- B-Scan from bottom

Example 2: Crack

- SOIC was thermally shocked, by dipping left half into molten solder at 280 °C.
- Compared with a control sample, not thermally shocked.
Image at different depths

By gating the A-scan at different times after the front surface, we can generate a stack of images showing features at different depths.

Close up of layer 5
Alternatives to SAM

- Whilst SAM is a good non-destructive way of evaluating for defects within a package, there are other alternatives.

X-ray Computed Tomography (XCT)

Uses X-rays to probe the internal structure. Cannot see light elements (unless in vacuum).

Thermography

Pulses a light source on the DUT and watches it cool with an IR camera. At breaks (delaminations, voids), the heat cannot diffuse as fast, so it will appear to cool slower and show up as a different contrast in the image.

Summary

- SAM is non-destructive way of looking for defects such as cracks, voids and delamination within a component package or PCB material.

- Results often subjective. Having a good sample for comparison is a good idea.

- Electronic packages are getting smaller, higher frequency transducers can see more detail and are likely to be used more in the future.

- [www.npl.co.uk/ei](http://www.npl.co.uk/ei) for more information on NPL, measurement services, downloadable reports, defect database, …
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