Central Texas Electronics Association

Advancements in Acoustic Micro-Imaging
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A review of the latest advancements in Acoustic Micro-Imaging for the non-destructive inspection of semiconductors devices and microelectronic packaging for defect and flaw detection.

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OVERVIEW

Acoustic Micro Imaging (AMI) is an established non-destructive inspection technique that applies ultrasound for the inspection of microelectronic packaging and semiconductor devices for bond assessment, defect or flaw detection and material characterization.

Recent advancements and new developments have expanded the role of AMI for semiconductor, MEM’s and microelectronic device inspection, including the following:

- Very High Frequency Transducers
- Waterfall & Water Plume™
- 3-D Imaging (Virtual Rescan Mode (VRM™))
- Frequency Domain Imaging (FDI™)
- Micro-slicing (Sonolytics™)
- Integral Mode Imaging
- Surface profilometry (Acoustic Surface Flatness (ASF™))
- Subsurface profilometry (Profile Mode™)
- Multi-layer analysis (Sonosimulator™)

This presentation will cover these latest advancements through examples and case studies depicting a variety of advanced packaging, wafer and MEM’s applications.
From the lab......

APPLICATIONS

........to the fab.
From the lab...... EQUIPMENT .......... to the fab.
C-SAM Gen6
The Latest Generation of C-SAM Technology

- Sonolytics/Polygate
- Windows7
  (targeting Windows10 in 2017)
- Plumbed for water management
- Class 1000 Cleanroom ready

C-Mode Scanning Acoustic Microscope
Theory of Operation

Input

Output (A-scan & Image)

Transducer

Water Tank/Bath

XYZ Scan Motion

Delamination

Porosity & Voids

Acoustic Shadow

Density Variations

Crack
**C-scan C-mode Interface Scan Technique**

- **Die face to mold compound interface scan**
- **Die face & lead frame to mold compound interface scan**
- **Mold compound bulk scan**
Advancements in Transducer Technology

\[ \wedge \text{Low to High Frequency} / 5 \text{ to } 100 \text{ MHz} \]
\[ \vee \text{Very High Frequency} / 230, 300 \text{ & } 400 \text{ MHz} \]

\[ \wedge 30 \text{ - } 100 \text{ MHz} \]

THRU-Scan™
Beam from Focused Transducer

The energy field is an hourglass shaped beam that narrows to the spot size at the waist.

\[ F^# = \frac{\text{Focal length}}{\text{Diameter}} \]

\[ \lambda = \frac{\text{Velocity (mm/\mu s)}}{\text{Frequency (MHz)}} \text{ in mm} \]

Resolution \((\Delta X) = 0.707 \times 1.22 F^# \lambda\)

Depth of field \((\Delta Z) = 7.1(F^#)^2 \lambda\)
Very High Frequency
Low Frequency

Rule of thumb:
- Ultra/Very High Frequency (230, 300 & 400 MHz)
  (ex. flip chip bump, bonded wafer, MEMs & stacked die)
- High Frequency (100 – 180 MHz) (ex. uBGA, TSOP, hybrids, flip chip under fill, bonded wafer and capacitors)
- Low Frequency (10 - 50 MHz) (ex. BGA, PLCC, PQFP, TSOP and capacitors)

~30 um to ~300 um resolution

Transducers

Very High Frequency

1. Higher resolution
   * shorter wavelength
   * smaller spot size
2. Shorter focal length
3. Less penetration

1. Lower resolution
   * longer wavelength
   * larger spot size
2. Longer focal length
3. Greater penetration

~3 um to ~30 um resolution
Resolution Simplified

- Resolution is the ability to distinguish features that are closely spaced as distinct features.
- Detectability is the ability to find a feature but not necessarily distinguish them from each other.
- Lateral resolution is determined by the transducer spot size which is a function of frequency and lens design.
- Axial resolution is determined by the pulse length which is a function of frequency and transducer damping.
- Resolution at high frequencies is deteriorated by sample and coupling fluid absorption.
180 MHz C-scan Image
Voids/disbonds –
focused and gated within the solder balls

230 MHz C-scan Image
Voids/disbonds –
focused and gated within the solder balls

C4 Flip-chip Solder Bump Inspection
Bonded wafer resolution test sample
Ultrasound impinges connected interface

Glass wafer (Borosilicat glass)

400 µm

Trenches with defined width and distances in triplets

Silicon wafer 525 µm

Ultrasound impinges disconnected interface
<table>
<thead>
<tr>
<th>Spots / Lines</th>
<th>Distance between Lines</th>
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<tbody>
<tr>
<td>3 µm</td>
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<td>5 µm</td>
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</table>
Resolution test target showing 3 and 5 micron lines/spacing
Enlargement of 3 micron lines/spacing
Advancements in water management and hardware to aid sample handling and minimize water contact with the sample
C-SAM

Advancements in water management and hardware to aid sample handling and minimize water contact with the sample.

Rotational Stage ^
Virtual Rescanning Module (VRM)

- VRM allows the entire A-scan to be stored at every pixel position within the image (field of view).

- A-Scan data from an entire sample is digitally stored in a 3 dimensional data matrix for each X, Y, Z location.

- Now the part may be “rescanned” and analyzed offline “without needing the part”.

Advancements in software
Virtual Rescanning Module (VRM™)
Virtual Rescanning Module (VRM™)

Horizontal & Vertical B-scan
**Time Domain vs. Frequency Domain Imaging**

- **Time Domain Imaging (TDI)** is the common and familiar mode in which the brightness or color of each pixel in the image represents the strength (magnitude) and phase (polarity) of an echo in the gate.

- **Frequency Domain Imaging (FDI)** is a new analytical mode (FFT) in which the brightness of each pixel represents the strength of a particular frequency component of an echo. FDI can reveal features that are missed with TDI. Contrast and resolution can be improved.

- An echo is a pulse and, therefore, composed of a broad range of frequencies on either side of a peak frequency.
A pulse may be analyzed to determine the range of frequencies that comprise it.
VRM™ – Frequency Domain Imaging (FDI)
Time Domain vs. Frequency Domain

VRM™ – Frequency Domain Imaging (FDI)
Advancements in software (Polygate Mode)
Multi-focus
Multi-gate

1 nanosec gating with up to 100 gates

Polygating provides micro-slicing (> 1 ns gating) with multiple gates so that numerous interfaces can be collected simultaneously.
Advancements in software
Polygating provides micro-slicing ($\geq 1$ ns gating) with multiple gates so that numerous interfaces can be collected simultaneously

(example; BGA)
Integral Mode

Each pixel value incorporates the area above and beneath the baseline (not just the largest amplitude). This gives weight to smaller echoes.
Acoustic Surface Flatness (ASF)

- The ASF feature is an acoustic profilometer. It is based on the velocity of sound using existing C-Mode Scanning Acoustic Microscope (C-SAM) technology.

- The ASF feature ‘profiles’ the sample surface to an accuracy of ± 1 micron.

- A major new option for both product R & D and Failure Analysis labs

- Compliments current C-SAM capability. For a modest additional cost and no additional floor space the analyst gets the benefits and capability of an additional tool to determine what is wrong with a part.
4.17.14 Flatness

Place the package on the seating plane. Measure flatness of the package by verifying that the highest point of the top surface fall within the package tolerance ccc (see Fig. 4.17-18).

Figure 4.17-18
Acoustic Surface Flatness (ASF)

- The ASF feature ‘profiles’ or “tracks” the position of the front surface echo.

- It assigns a color in the image based upon the echo’s position in time.

- Echoes that are located farther to the left in the A-Scan are closer to the transducer and will appear white and/or purple in the image. Echoes that are located farther to the right in the A-Scan are further from the transducer and appear orange and/or red in the image.
Acoustic Surface Flatness (ASF)

Wafer 2D AMI Image

Wafer 2D ASF Image with 140 μm Warpage Center to Edge

Wafer 3D Contour
Acoustic Surface Flatness (ASF)

ASF - Flip Chip and Substrate Warpage

Substrate: At least 80 µm of bow

Die only: Acoustic Reflection

Die only: Acoustic Flatness

Acoustic Flatness
C-scan, Q-BAM & Profile Modes

Profile Imaging
Note: die-tilt in all images

C-scan image (above)
Q-BAM image (below)
(cross section)
Multi-layer (Stacked Die) Issue
Sonosimulator - A model of the sample can be built to simulate its acoustic structure with known defects at layers of interest.
Sonosimulator - Using a reference waveform a model of the A-scan is generated and compared for each layer of interest.
Transducer frequency, focus level, and gate positions can then be established, tested and refined prior to transferring the imaging settings. The example shows levels five (5) and six (6) of an eight (8) multi-stack array.
Multi-Die Stack Example

- 4 Stacked Die
  - Adhesive layer between each die
  - Wire bonded
3 DIE STACK - 2D C-Scan IMAGE

Molding Compound to Multiple Die Surface Interface Scan
3 DIE STACK – 3D RECONSTRUCTION
CONCLUSION

Acoustic Micro Imaging has evolved to meet the needs of the Semiconductor and Microelectronic packaging markets. AMI development will remain to be in the forefront in response to the industry’s changing needs.

- High frequency transducer development and optimization
- Edge effect reduction for flip chip bump arrays
- Signal processing and interpretation (new imaging methods)
- Smart and automated systems
- Thin layer metrology
- Frequency Domain Imaging exploration for better analysis.
- Correlation studies between internal defects and surface warpage
- Stacked Die analysis program development