Transmissive X-ray Applications for Electronics Manufacturing

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Course Outline

★ Introduction - How does X-Ray Inspection Work?
  ★ CT, Laminography & Real-time
★ Real-time X-ray Features
★ Role of Real-time X-Ray in Inspection
  ★ Failure Analysis
  ★ BGA Inspection
★ Conclusion
Introduction

How does X-Ray Inspection Work?
Introduction

X-ray imaging measures...

- presence or absence of material
  
  - wedge object
  
  x-rays
  
  detector
  
  image

- differences in material density
  
  - high density material
  
  x-rays
  
  detector
  
  image

  - low density material
  
  x-rays
  
  detector
  
  image
Introduction

Transmission X-ray Presentation
How do we generate X-rays?

• Electrons are produced from a hot filament (like a light bulb).
• They are accelerated using a high voltage into a beam tube.
• They travel at 80% the speed of light.
• They are focused by a magnetic lens into a small spot (1 – 5µm) onto a metal target.
• The sudden deceleration of the charged electrons when they hit the target produces 99% heat and 1% X-rays.
Introduction

Will X-ray inspection damage my microelectronics?

• Individual atoms will be damaged
• Tremendous military research underway
• Some large OEMs already have procedures to track exposure time
• My recommendation – Don’t leave your machine on over the weekend
Introduction

- Five Main Parameters of X-Ray Inspection
  - Penetrating Energy
  - Contrast Sensitivity
  - Geometric Magnification
  - Resolution
  - Field of View
X-Ray Parameters

- Penetrating Energy

The accelerating potential or keV of the X-ray source. Thicker and denser samples require a higher keV x-ray source to be able to penetrate and image the sample. A battery is shown above, imaged at 140keV.

Transmission X-ray Presentation
X-Ray Parameters

 Contrast Sensitivity

Determined by the type of X-ray source, detector and sample under inspection. Typically a modern X-ray system has a contrast sensitivity of approximately 1-2%. This means that an operator should be able to distinguish a feature that is $1/100^{th}$ of the thickness of the material under inspection.
Geometric magnification can be described as the true magnification. There is no degradation of image quality, unlike pixel magnification. Geometric magnification is calculated by dividing the detector distance, from the X-ray source emission point, by the distance from the emission point to the outermost part of the X-ray source emission window or sample.

The latest systems are capable of up to 2400X.

Geometric Magnification works the same way with light or X-rays.
Resolution in a µfocus x-ray system is a function of the spot size of the X-ray source. A 1µM spot size x-ray source should be capable of imaging a 1µM defect – however other factors such as contrast sensitivity, detector and subject matter all play a part in the ultimate spatial resolution of the system.
Size of subject that may be imaged in one view. This is a function of the detector size and how close the subject may be positioned to the input window of the detector. 2” – 3” field of view is typical.
Real-Time X-Ray Advantages

- Immediate feedback
- Minimal Set-up
- Relatively Inexpensive

Transmission X-ray Presentation
Real-Time X-Ray Dis-advantages

- Needs Skilled Operator
- Not Suitable for Most Automated Inspection
- Minimal ability to subtract data
CT X-Ray Advantages

- Moderate set-up
  - Most CT machines allow for real-time inspection
- Provides most complete data set possible
- Highest quality imaging available
CT X-Ray Dis-advantages

- Large data set can be over-kill
  - Sharing data can be a problem due to inadequate computing/data transfer
- Sample Size Limited
- Very expensive
X-Ray Laminography
X-Ray Laminography Advantages

- Automated inspection of large assemblies
- Can verify proper assembly for a multitude of component types
X-Ray Laminography
Dis-advantages

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- Extensive set-up
  - Difficult to balance inspection criteria
- Relatively expensive
- Real-time option not useful (if available)
- Slow

Transmission X-ray Presentation
Real-Time X-Ray
Real-Time X-Ray System

Lead Shielded Cabinet is essential for safety when working with any X-ray source.
X-Ray Power Settings

- **Voltage**
  - Expressed in keV
  - Highest potential energy
  - Determines penetrating power

- **Current**
  - Expressed in µ amps
  - Increases penetration
  - Reduces gray scale resolution
X-Ray Imaging Aberrations

X-Ray Camera System exhibiting Voltage Blooming and Pin Cushion Distortion

Voltage Blooming

Pincushion Distortion
Voltage Blooming – Effect on Void Size

Blooming or exaggeration of solder void area as voltage is increased. The area of the solder ball is reduced while the void area increases.

90kV

110kV
Role of Real-Time X-ray in Inspection
Role of X-Ray in Inspection

- **Failure Analysis**
  - Non destructive method for analysis of components/boards/assemblies
  - Can be used for measuring dimensions

- **Process Control / Audit**
  - Provides quick feedback
  - Voiding studies
  - Manufacturability studies

- **Incoming Quality Control**
  - Bare Board/components
  - Completed assemblies
  - Mechanical parts

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Measurement Capabilities

- Two Methods for measurements
  - Use of C&C manipulator
  - Calibrate with standard
    - After setting sample height or calibration – manipulator can only move X & Y
Color Enhancement

- During inspection it rarely provides advantage
- Due to digitization loss, very useful for images when contrast is minimal
Mapping Feature

Overview entire sample

- Know your location on sample when at high magnification
  - Must maintain exact position when changing samples
  - Quality of the stitch not high
Annotation Feature

- Quick & easy way to present important data
- Keep track of locations
- Point out defects
  - Most people reviewing data can’t decipher X-ray images

Transmission X-ray Presentation
Incoming QC
Incoming QC

Cracked Copper in Flex

Over-etched copper in Flex
Incoming QC

- Connector/ Wire Harness QC
Incoming QC

- Subassembly QC

Transmission X-ray Presentation
Incoming QC

- Counterfeit Component Detection
- Parts smuggled from MRB

No Die

No Wires

Transmission X-ray Presentation
Incoming QC

- Counterfeit Component Detection
- Lead-frame differences
Incoming QC

- Counterfeit Component Detection
- Variation in metallization thickness
Incoming QC

- Counterfeit Component Detection
- Variation in bond pattern or die size
Failure Analysis
Failure Analysis - Component

- Broken Wires
  - Will not typically see aluminum
Failure Analysis - Component

Transmission X-ray Presentation

Color enhancement
Failure Analysis - Component

- Broken Wedge Bond

 Transmission X-ray Presentation

Color enhancement
Failure Analysis - Component

- Mechanical Contacts

Applied voltage to relay; contact still open
Failure Analysis - PCB

• Burned Assembly

Cross-section of board in X-ray

X-ray of failed area

Metallurgical cross-section image

Transmission X-ray Presentation
Failure Analysis - PCB

Component Analysis

Transmission X-ray Presentation
Failure Analysis - PCB

- Board Inspection
  - X-ray can be very helpful in determining areas to section, and monitoring position while grinding/polishing

Transmission X-ray Presentation
BGA Inspection

Transmission X-ray Presentation
BGA Inspection

- Will I see an interfacial ball separation?
  - NO

- Will I see a cracked BGA solder ball?
  - NO...

Well, Maybe
Why will I not see an interfacial ball separation in X-ray?
When Will I See Cracks?

- Broken trace at rigid-flex interface
- Broken braided copper
- Crack in Peltier Cooler Crystal

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When Will I See Cracks?

360° scan of mirrored memory preserving geometric magnification

Transmission X-ray Presentation
BGA Opens

Transmission X-ray Presentation
BGA Opens

- Head in “Pillow” open

Both paste and ball have clearly been in contact in a soft or liquidous state, no bonding occurred.
BGA Opens

- More “pillow” opens

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BGA Opens

- Head in “pillow” open – Bottom side BGA
- Sometimes you need to orient the sample upside down to preserve geometric magnification
BGA Opens

- Corner Open

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BGA Opens

- Insufficient Reflow or Deflection

Transmission X-ray Presentation
BGA Opens

- Insufficient Reflow
BGA Opens

* DQFN Opens

Transmission X-ray Presentation
BGA Opens

- LGA Opens

Transmission X-ray Presentation
BGA Opens

- LGA Opens
BGA Opens

- DQFN Opens
- Severe Deflection

Transmission X-ray Presentation
BGA Opens

- DQFN Opens
- No Solder
BGA Defect Aberration

- Solder mask defined pads can look like opens in off-axis inspection

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BGA Shorts

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BGA Shorts

- Typical Shorting Failure Mechanism
  - Deflection of component / substrate

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BGA Shorts

- Misalignment

Transmission X-ray Presentation
BGA Shorts

- Short Caused by Voiding

Transmission X-ray Presentation
BGA Shorts

- Short Caused by Stray Resistor

Transmission X-ray Presentation
BGA Shorts

Short Caused by Stray Resistor

Transmission X-ray Presentation
BGA Shorts

- Shorts Caused by Delamination

Transmission X-ray Presentation
BGA Shorts

- LGA Short

Transmission X-ray Presentation
BGA Shorts

- Via Short
- May need schematics to see if common via
BGA Shorts

- Shorts Under Connector Body

Transmission X-ray Presentation
BGA Shorts Aberration

- Capacitors can look like shorts
BGA Process Indicators
BGA Process Indicators

- Incomplete Wetting

Transmission X-ray Presentation
BGA Process Indicators

- Insufficient Volume
- Missing Solder Mask

Transmission X-ray Presentation
BGA Process Indicators

- QFN Voids

Ground Slug Voids

QFN I/O Void Calculations

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BGA Process Indicators

- More QFN Voids

Transmission X-ray Presentation

Heat Slug Voids with/without calculations
BGA Process Indicators

- More Voids
BGA Process Indicators

Measuring BGA Voids

Transmission X-ray Presentation
BGA Process Indicators

Measuring BGA Voids

Transmission X-ray Presentation
BGA Process Indicators

- Measuring BGA Voids
Through-Hole Inspection

- Hole Fill

Transmission X-ray Presentation
Conclusion

- There are three categories of machines for transmissive X-ray inspection of electronics
  - CT, real-time, laminography
- X-Ray is a valuable tool for non-destructive BGA inspection and failure analysis
- Proper training is required for effective use of transmissive X-ray
  - Defects & Process Indicators can be hard to spot
Thank You