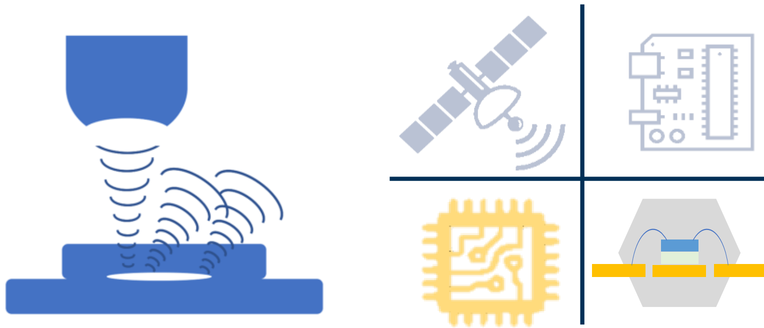
Scanning Acoustic Microscopy



Non-destructive detection of air flaws (delamination, voids and cracks) and related critical failures in plastic encapsulated systems by Scanning Acoustic Microscopy.

Francisco Javier Aparicio Rebollo
Juan Antonio Bermudo Molina

TÜV NORD GROUP

ALTER
TECHNOLOGY GROUP

Outline

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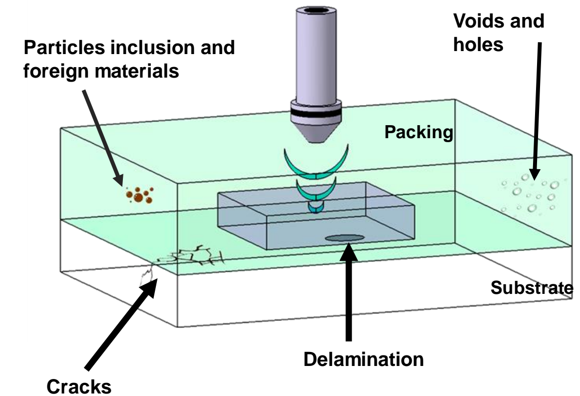
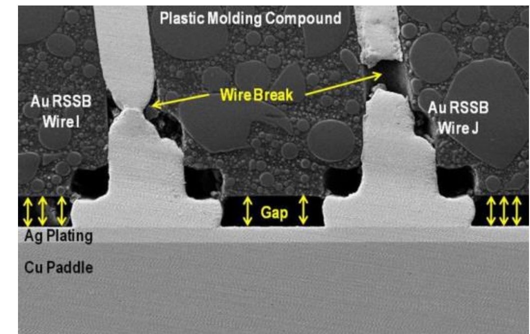
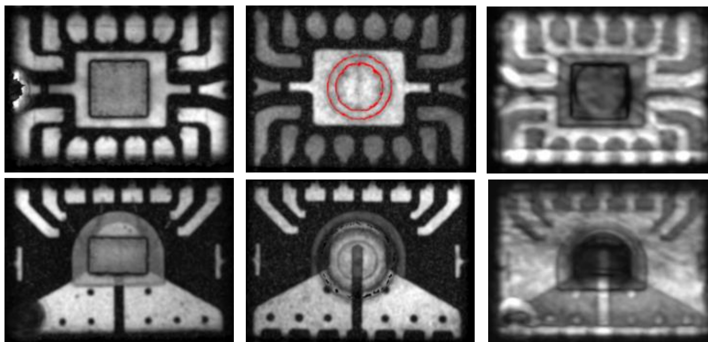
- ❑ Introduction
- ❑ The Scanning Acoustic Microscopy technique
- ❑ Inspection zones and typical failure modes
- ❑ ATN SAM capabilities







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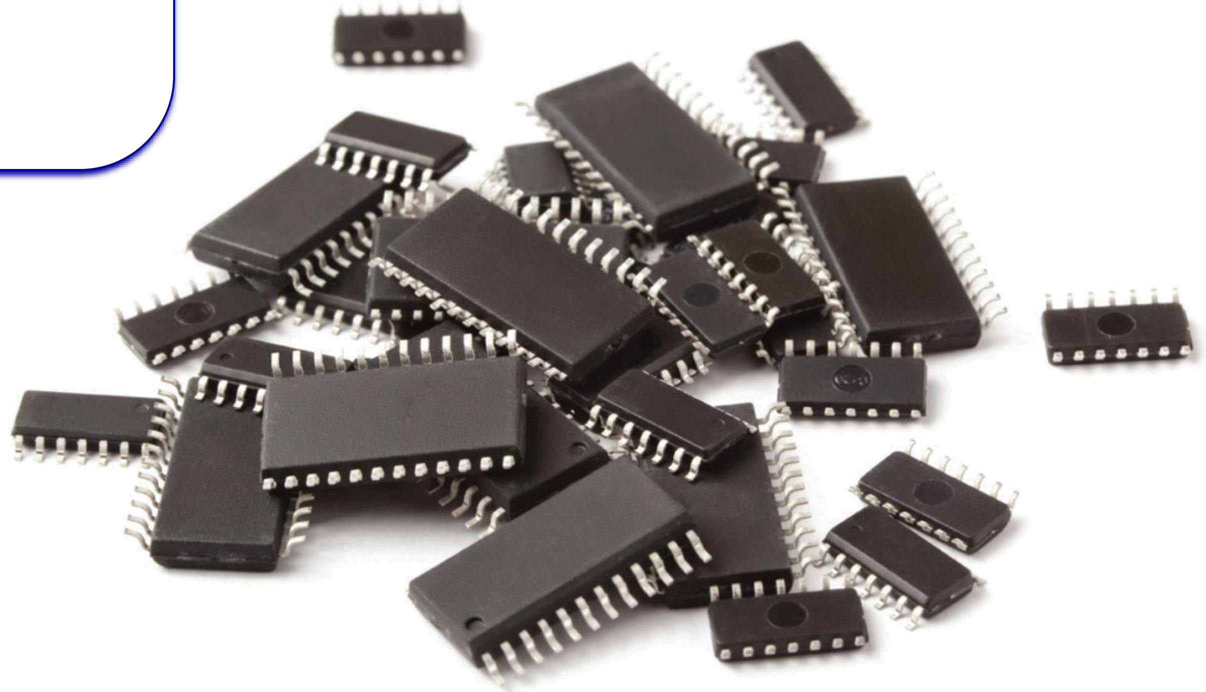
Plastic Encapsulated COTS offers:

- Lower procurement cost
- Shorter procurement time
- More performance and functionality available
- Reduced size and weight



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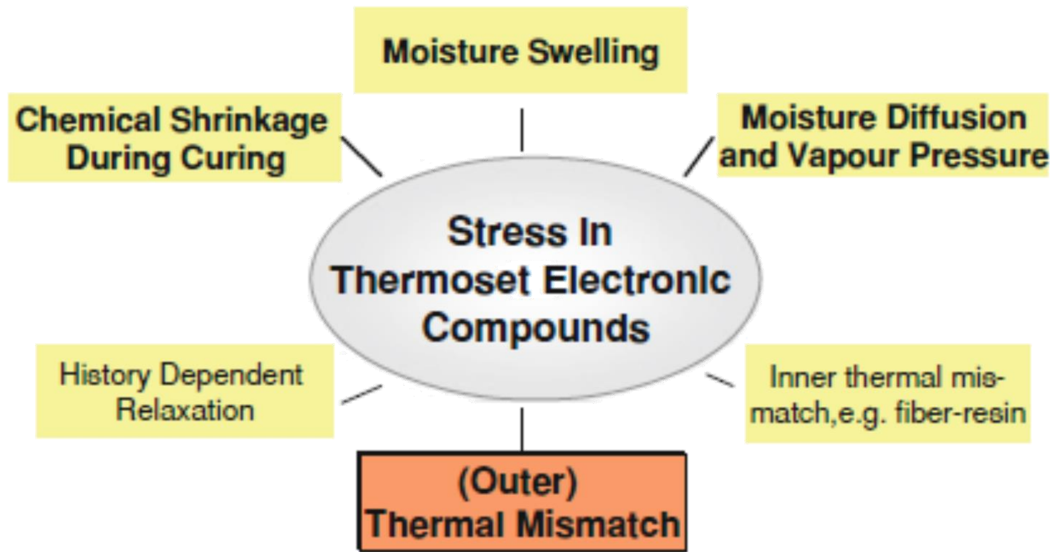
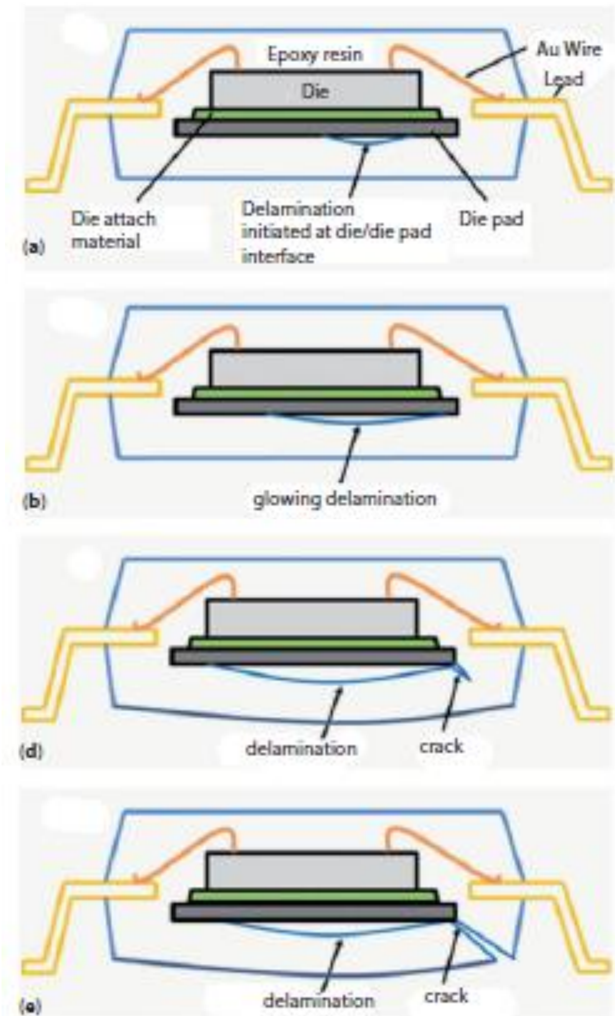
Inherent risk of PEMs are related to:

- Lack of Hermeticity (high internal vapour pressure)
- Stress build-up in plastic encapsulated systems



Pop corn cracking



Main anomalies in plastic packages

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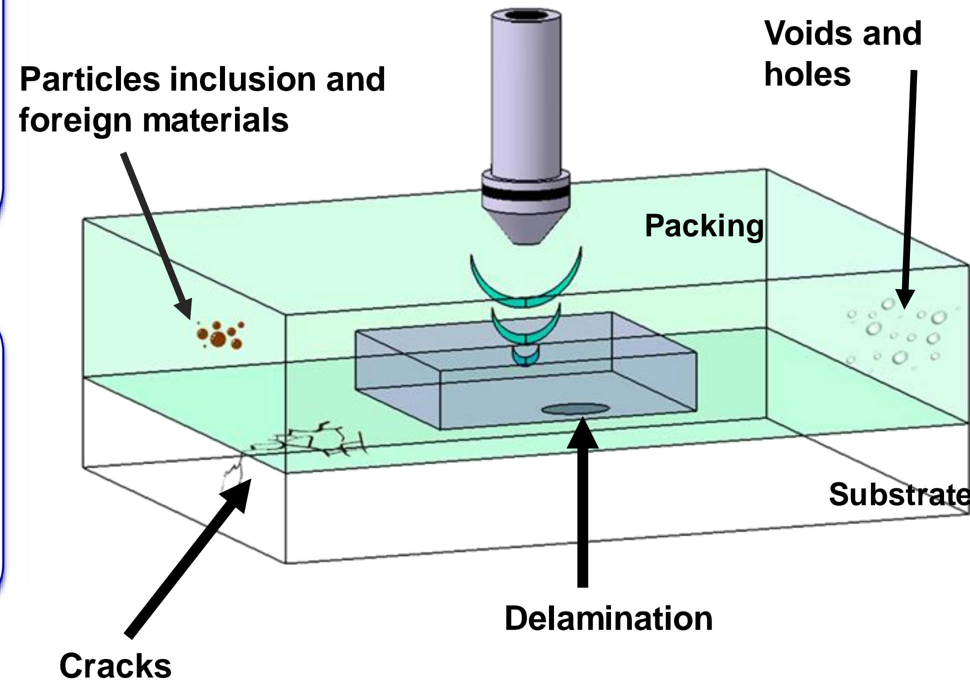
- **Delamination: Lack of adhesion** at the **interface** between different materials; typically between the moulding compound and an internal inorganic part

- **Crack: Fracture** in the **bulk** or on the **surface** of a given material, either the moulding compound or internal inorganic parts

- **Void: Lack of material** within the **bulk** for instance within the die attach or in the moulding compound due to improper injection



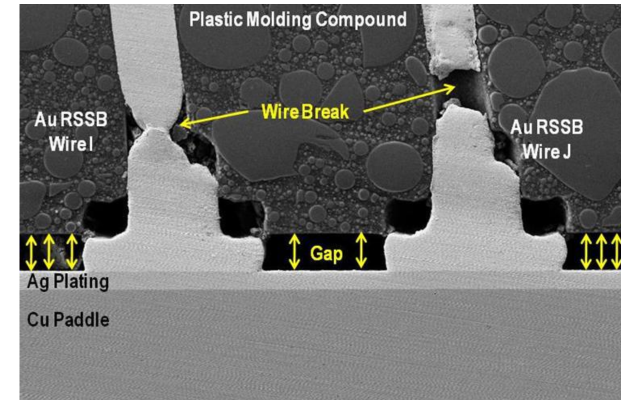
Main package defects involve air/solid interfaces

Failure modes

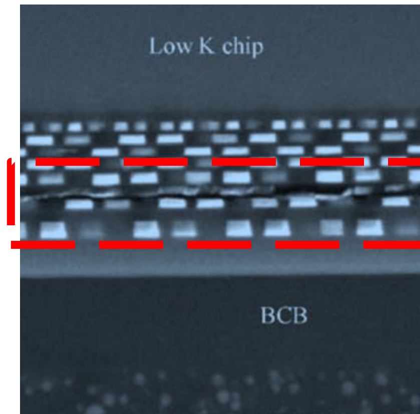
Delamination voids and cracks are the root case for different failure modes

- Poor mechanical stability
- Permanent or intermittent electrical opening
- Inefficient heat dissipation
- Metal corrosion
- Cracking or fracture of die or encapsulant

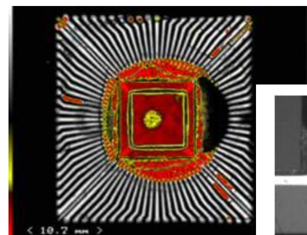
Package delamination leading to wire/bond failure



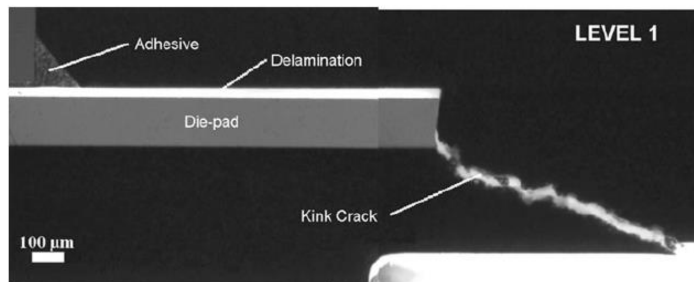
Low k delamination in flip chips



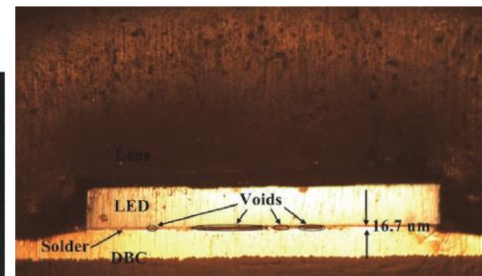
Popcorn cracking



Early SAM detection



Die-lift / die attach failures



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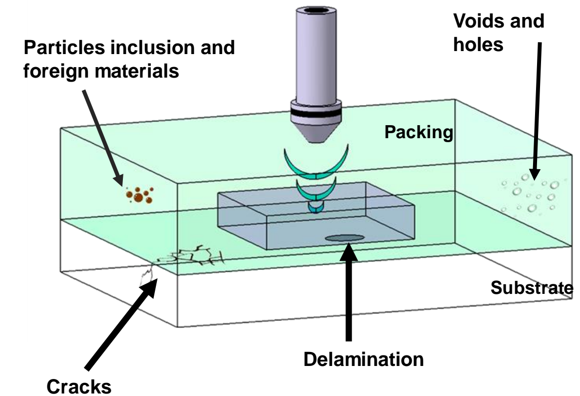

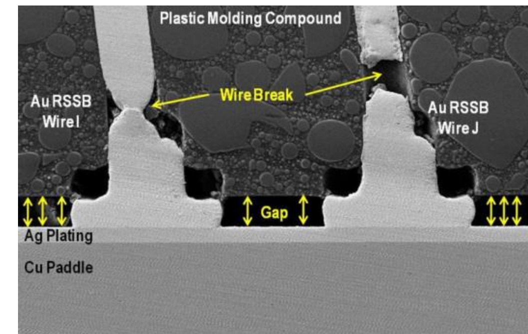

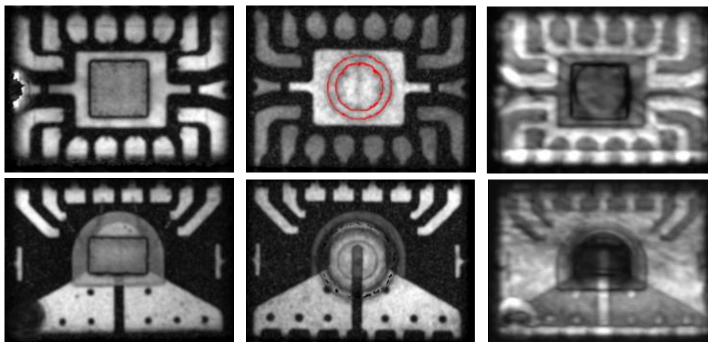

Why Scanning Acoustic Microscopy?

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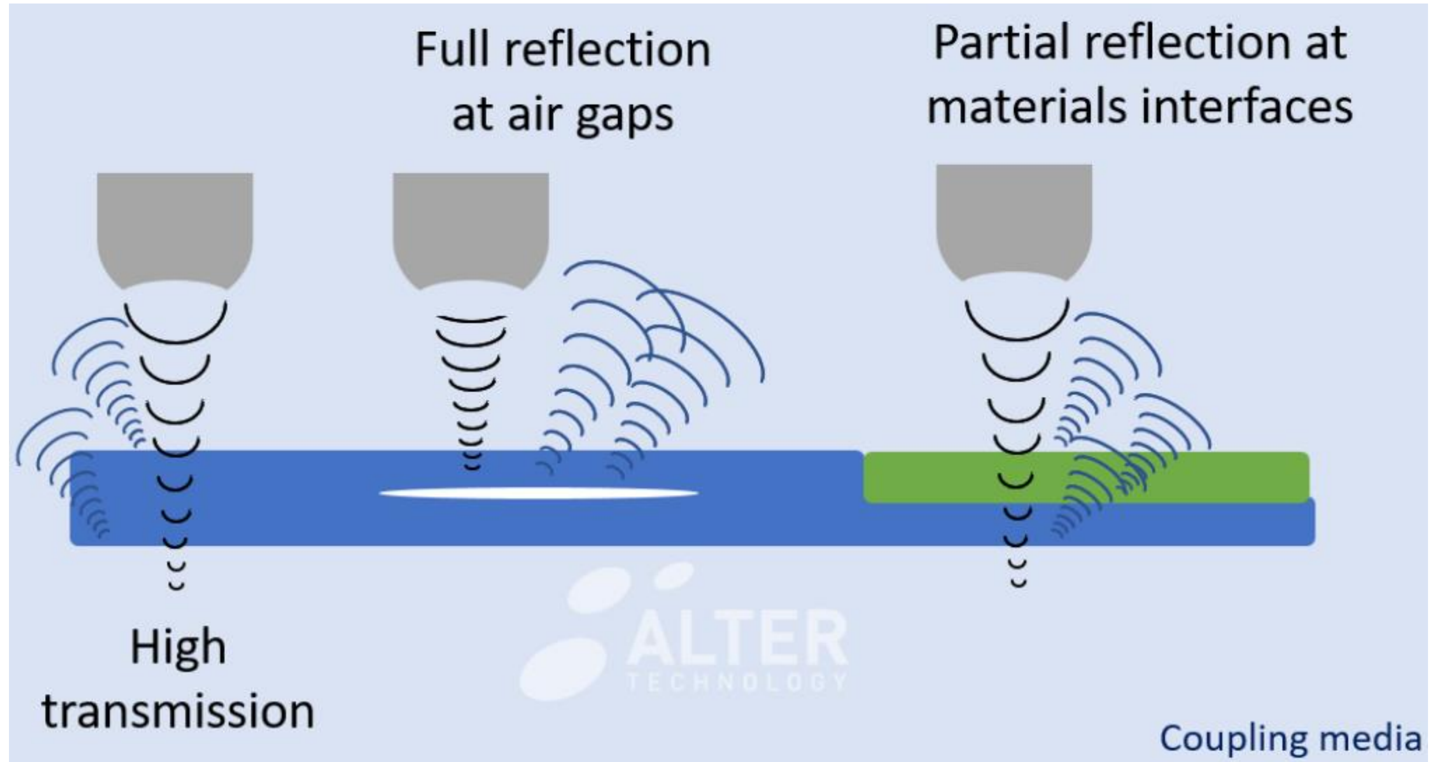
Ultrasound waves are extremely sensitive to density changes



$$\frac{I_{inc}}{I_{ref}} = R = \left(\frac{Z_1 - Z_2}{Z_1 + Z_s}\right)^2$$

The intensity of the reflected beam is used for the detection of materials interfaces

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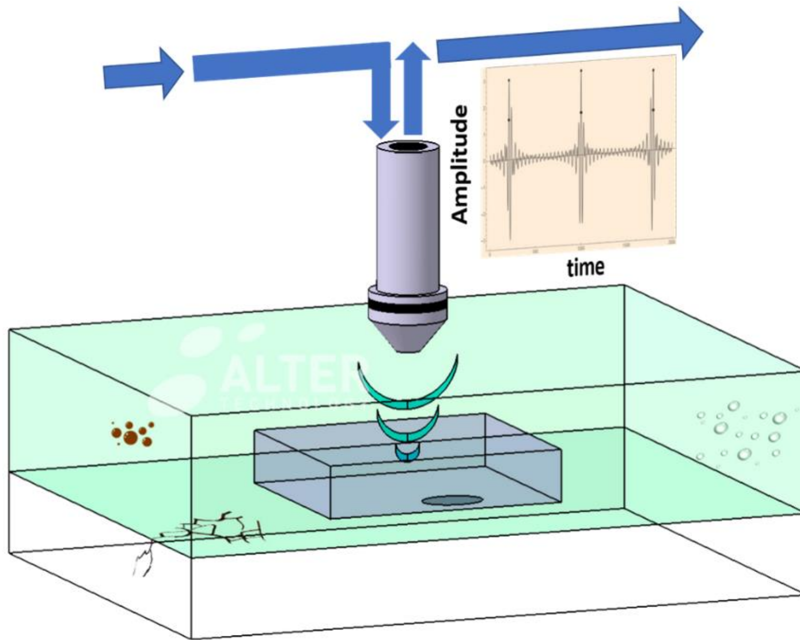
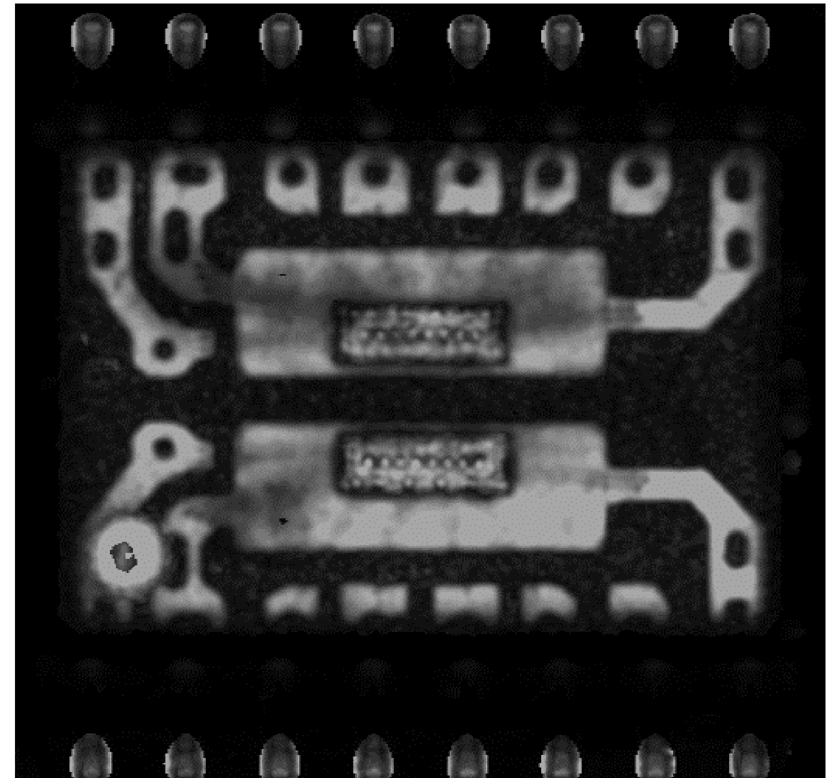
Scan modes

C-mode The intensity of the reflected beam at a given depth is analysed to reconstruct the internal structure





Imaging of internal structures with confocal resolution

Why Scanning Acoustic Microscopy?

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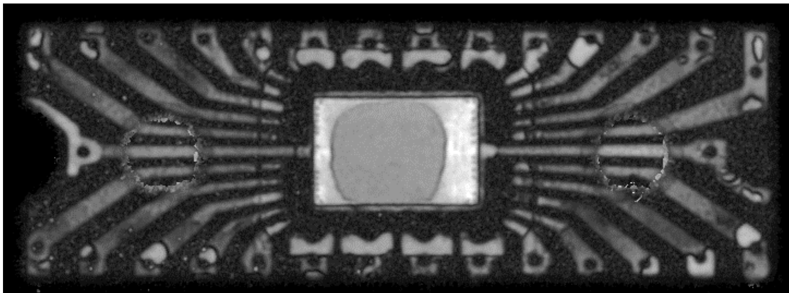
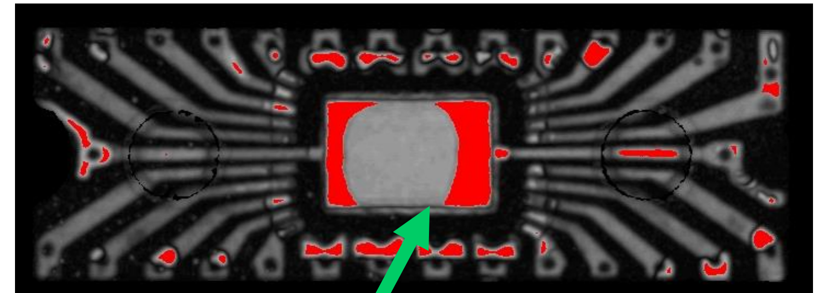
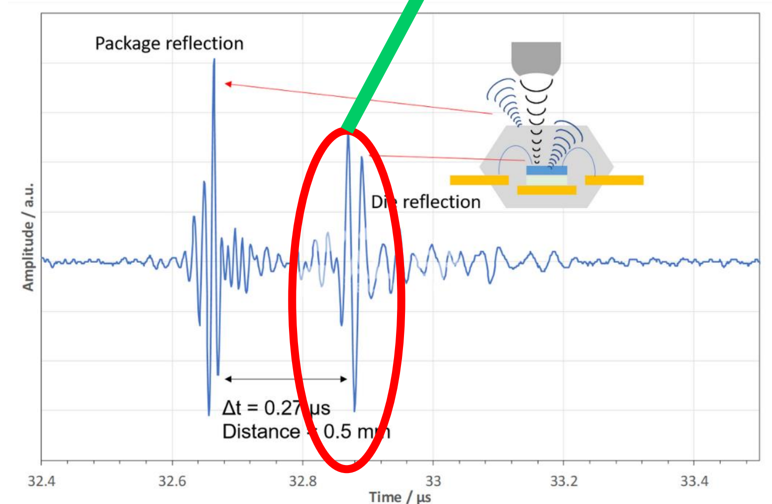
Peak amplitude analyses are used for the detection of interfaces between different materials/media

Phase analyses are used for the identification of air flaws (delimitations)





A-scan



Detailed analysis of the A-scan provides the most reliable results for the detection of delaminated areas

Why Scanning Acoustic Microscopy?

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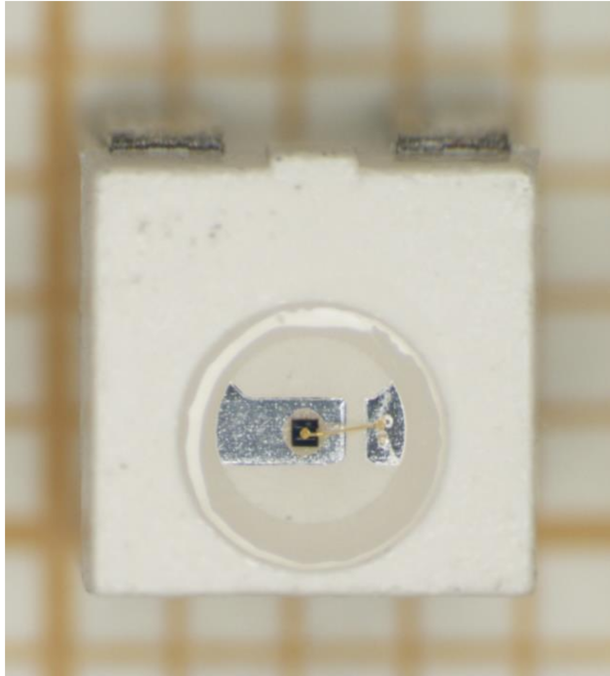
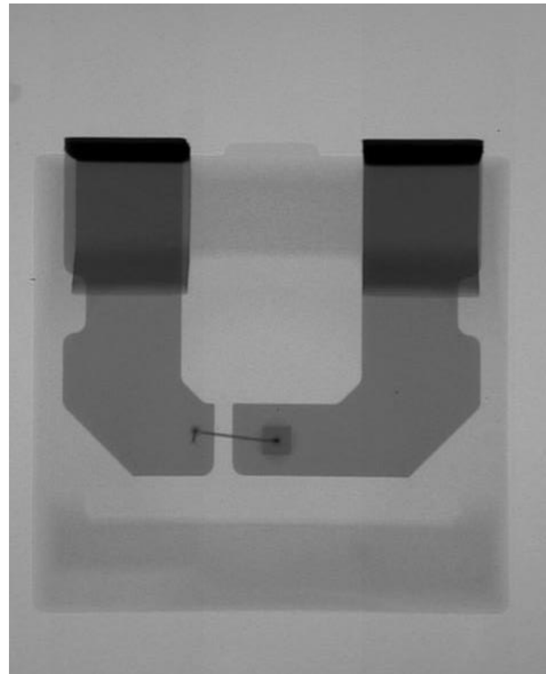
SAM non-destructive approach the early detection of critical failures in plastic encapsulated systems

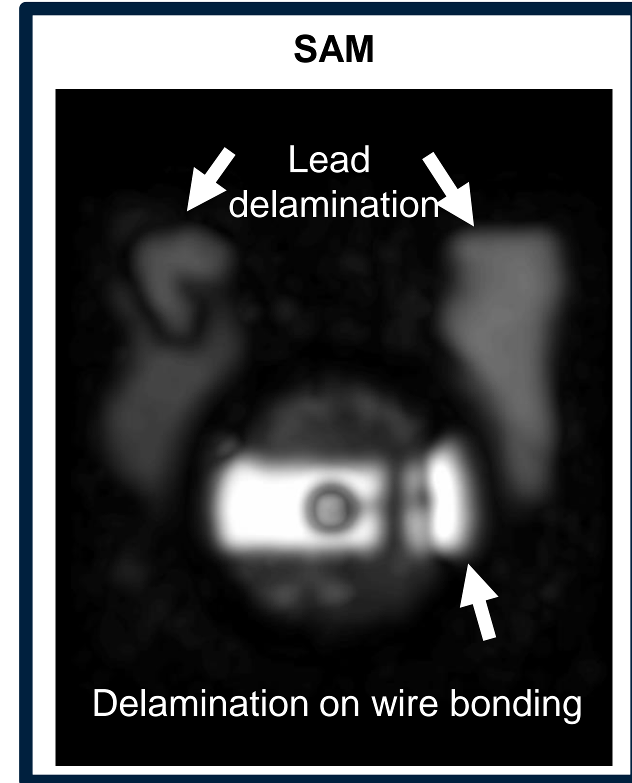
External

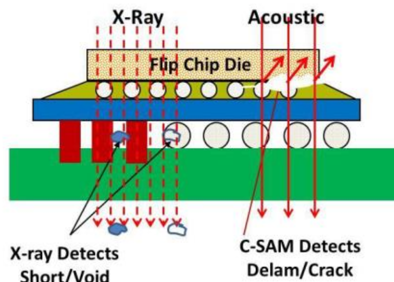


X-Ray



SAM





High lateral resolution
- Wire deformation
- Voids
- …

High sensitivity to air gaps
- Delamination
- Cracks
- Voids

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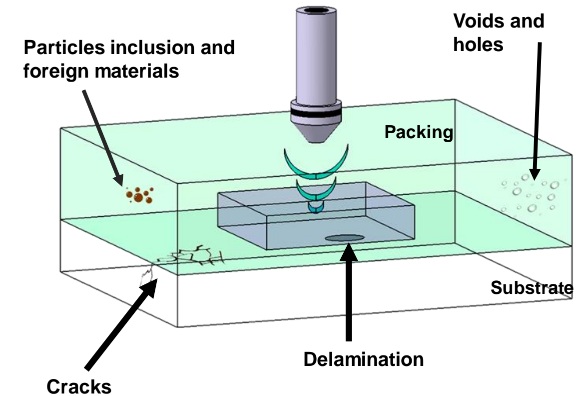

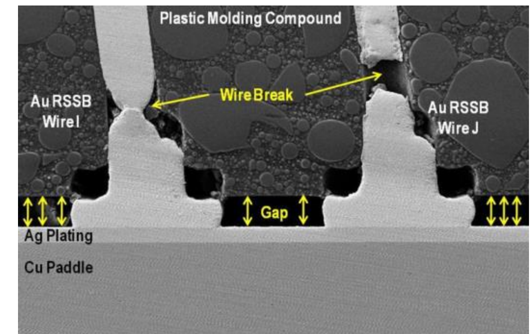

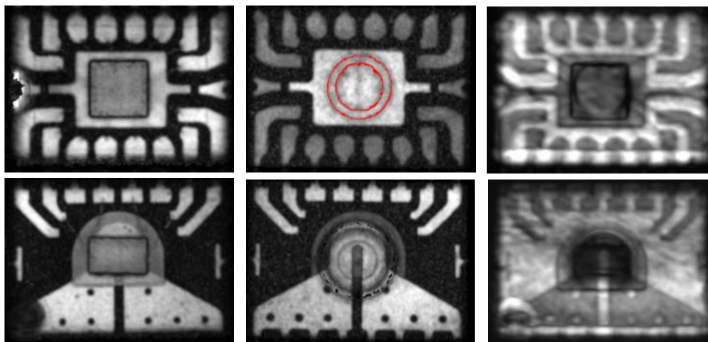

Test methods

J-STD-020E Moisture/Reflow Sensitivity Classification for Non-hermetic Surface Mount Devices

PEM-INST-001

Instructions for
Plastic Encapsulated Microcircuit
(PEM)
Selection, Screening, and
Qualification

PEM-INST-001 Instructions for Plastic Encapsulated Microcircuit (PEM) Selection, Screening, and Qualification

ESCC 25200 Application of Scanning Acoustic Microscopy to Plastic Encapsulated Devices

DEPARTMENT OF DEFENSE TEST METHOD STANDARD

MIL-STD-883
Test Method 2030
Ultrasonic Inspection of Die Attach

MIL-STD-1580
Paragraph 16.5.1.3
Acoustic Microscopy

Critical delamination sites in leaded packages

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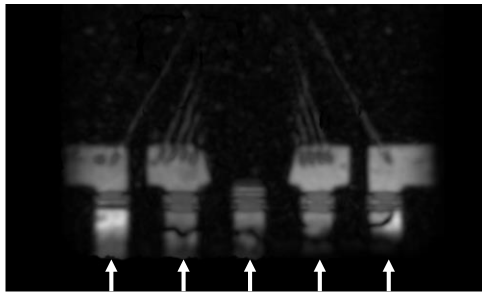
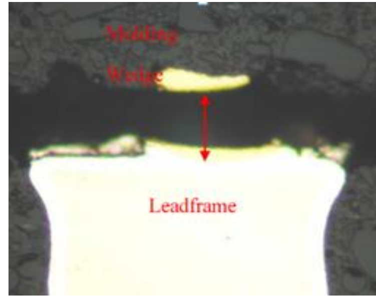
Surface breaking part



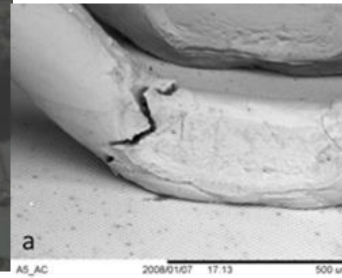
Lead finger

Bonding areas

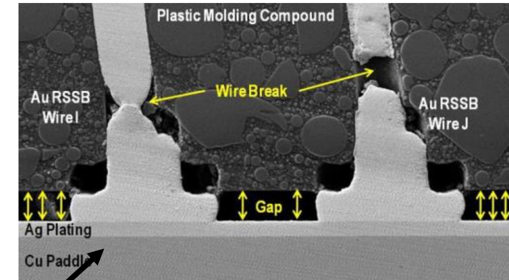
Disbonding

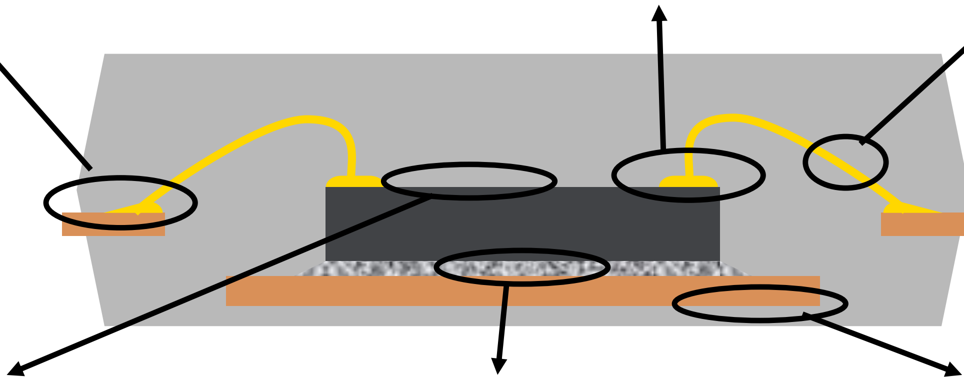


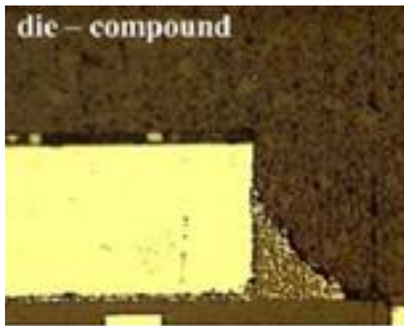
Heel crack



Bond wires

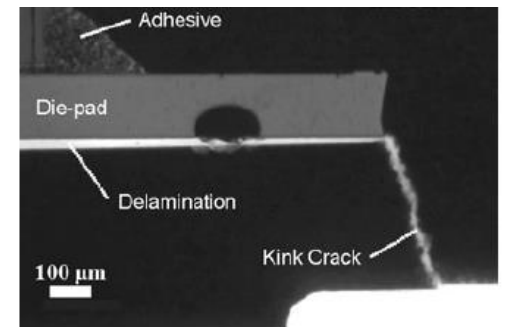






Die surface

Die attach



Die paddle

Failure examples

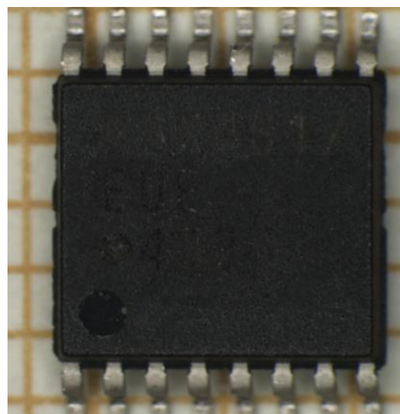
Delamination on bonding areas

Main reliability issues

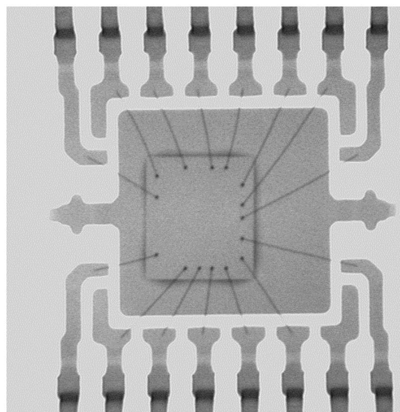
- ❑ Shear stress over wire bonds
- Disbonding
- Heel cracking
- Stitch crack in wires
- Bonding corrosion

CMOS multiplexer (16-TSSOP)

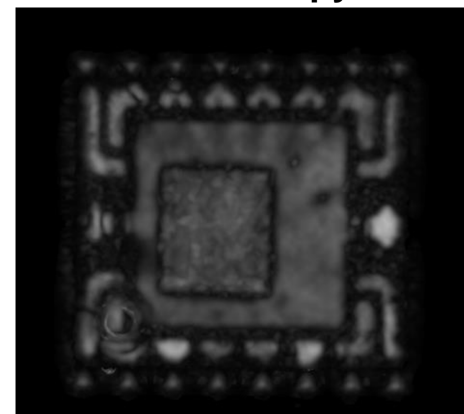
External



X-ray



Scanning acoustic microscopy



C-mode

Lead-finger delamination

T-mode

Failure examples

ALTER TECHNOLOGY GROUP

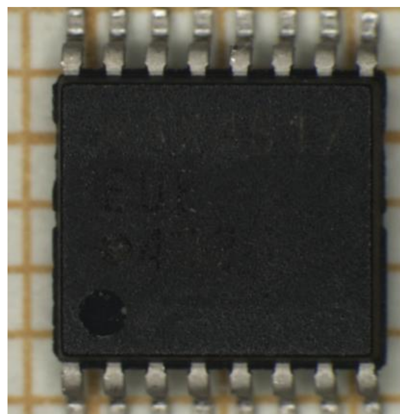
Delamination on bonding areas

Main reliability issues

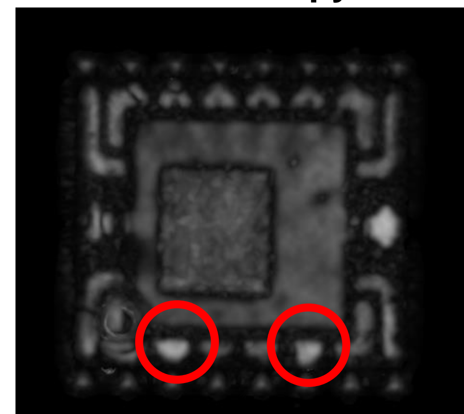
- ❑ Shear stress over wire bonds
  - Disbonding
  - Heel cracking
  - Stitch crack in wires
  - Bonding corrosion

CMOS multiplexer (16-TSSOP)

External



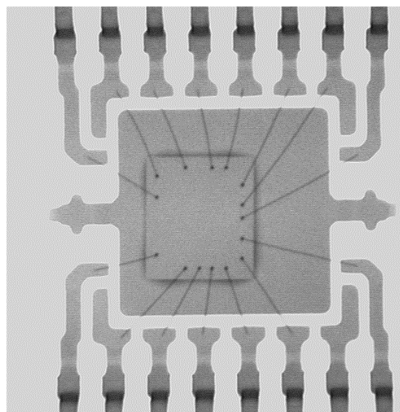
Scanning acoustic microscopy



C-mode

Lead-finger delamination

X-ray



T-mode

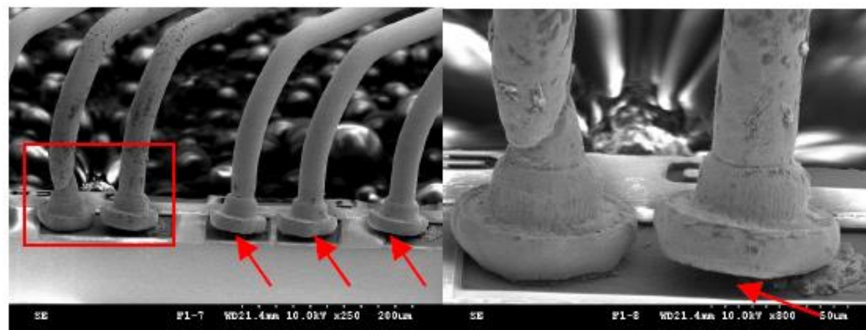
ALTER TECHNOLOGY GROUP

Delamination on bonding areas

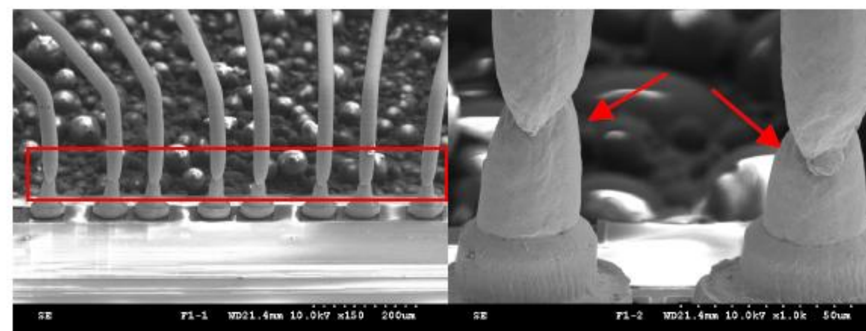
Main reliability issues

- ❑ Shear stress over wire bonds
  - Disbonding
  - Stitch crack in wires
  - Heel cracking
  - Bonding corrosion

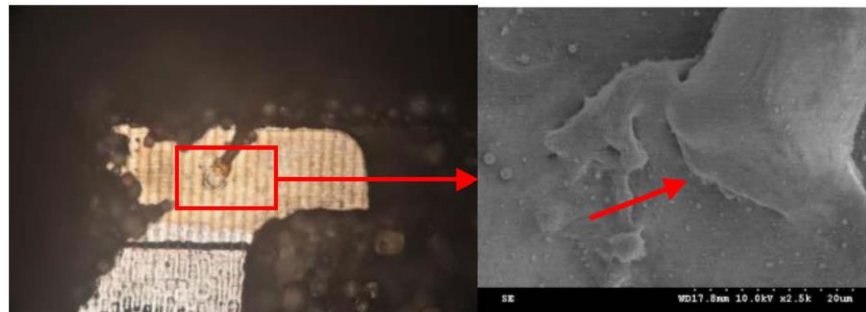
Disbonding and bond shifting



Stitch cracks



Heel cracks



H. Wu et al. 2014 International Conference on Reliability, Maintainability and Safety (ICRMS)

J. Cai et al. 17th International Conference on Electronic Packaging Technology 978-1-5090-1396-8/16/$31.00 ©20161EEE

Failure examples

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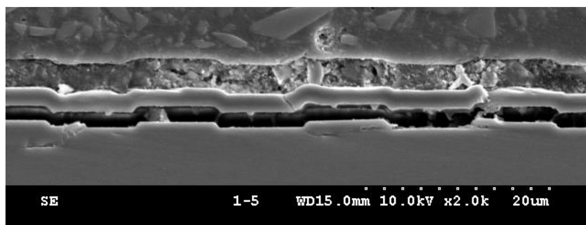
Delamination of die surface

Main reliability issues

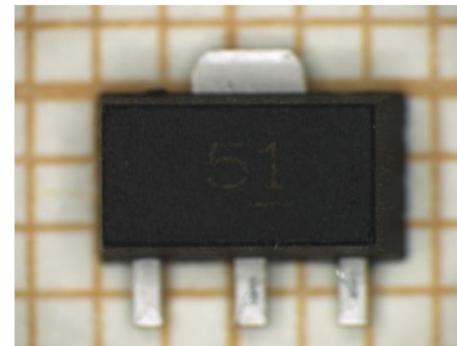
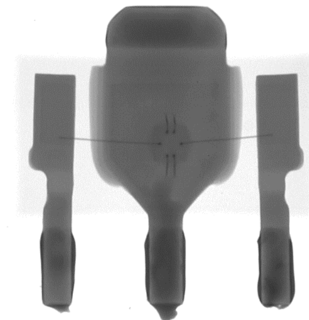
- ❑ Shear stress on die surface and bondings
- Cracks at the passivation layer
- Damaged metallization
- Degradation of the contact bridges

Delamination of the metallization layer



Y. Chen et al 2011 International Conference on Quality, Reliability, Risk, Maintenance, and Safety Engineering

MW amplifier SOT-89

C-mode	T-mode	
		Paddle+ die delamination
		Reference (no delamination)
		

Failure examples

Voids in die attach

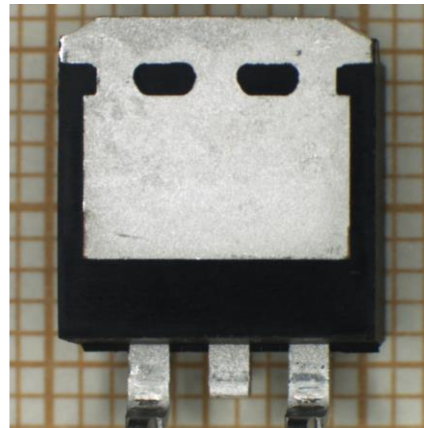
ALTER TECHNOLOGY GROUP

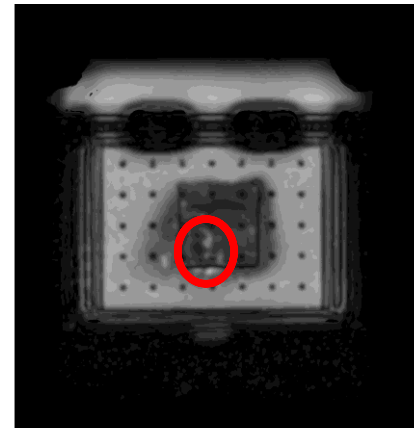
Silicon power transistor (D2PAK)

Acceptable Voids at the die attach

Main reliability issues

- Poor mechanical stability
- Inefficient heat dissipation





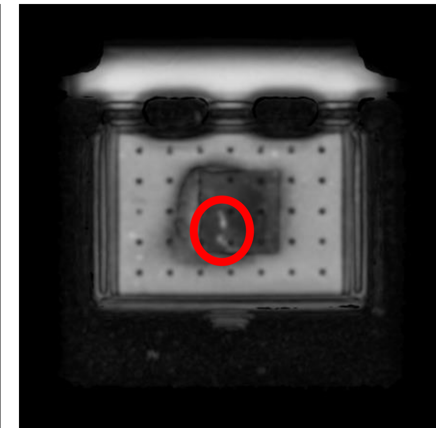


Table 2: Thermal resistance of LED packaged with different bonding pressure.

Void fraction	Thickness of die-attach layer (μm)	Thermal resistance of material (calculated) (°C/W)	Thermal resistance of die-attach layer (experiment) (°C/W)	Thermal resistance caused by voids in die-attach layer (calculated) (°C/W)
62.45%	38.8	0.45	2.37	1.95
52.60%	29	0.34	1.63	1.29
39.67%	16.7	0.19	1.12	0.93
29.76%	14.6	0.17	0.81	0.64
16.53%	8.4	0.1	0.41	0.31

P. He et al. Advances in Materials Science and Engineering, 8658164, 2017

ALTER TECHNOLOGY GROUP

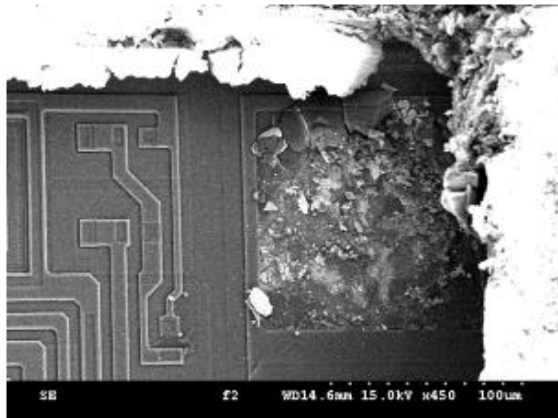
Delamination of surface breaking parts

Low dropout regulator (TO-263)

Reliability issues

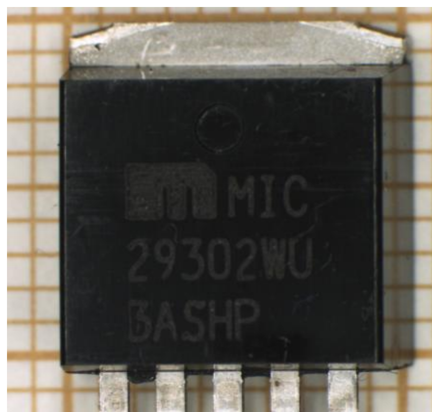
- Path for moisture and contamination
- Secondary cracking phenomena
- Corrosion at active area

Pad corrosion due to lead finger delamination

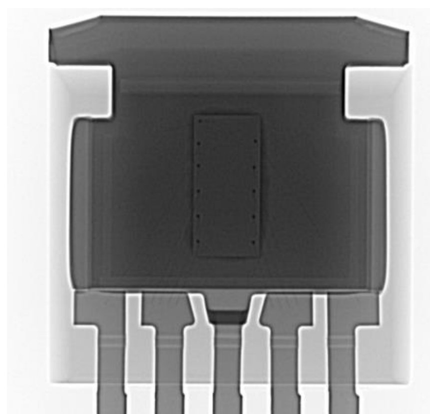


H. Wu et al. 2014 International Conference on Reliability, Maintainability and Safety (ICRMS)

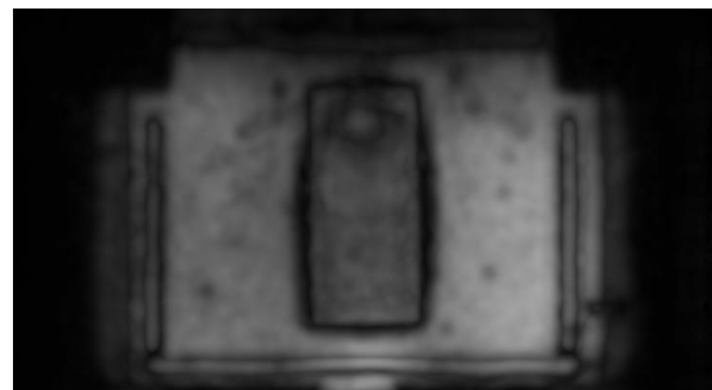
External

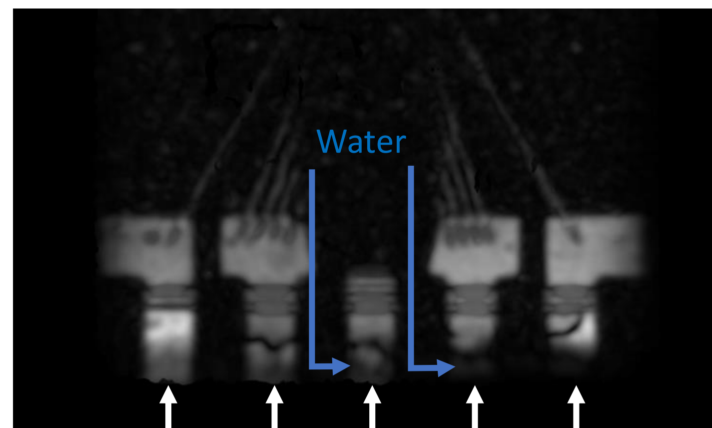


X-Ray



Confocal Scanning acoustic microscopy





Lead finger delamination

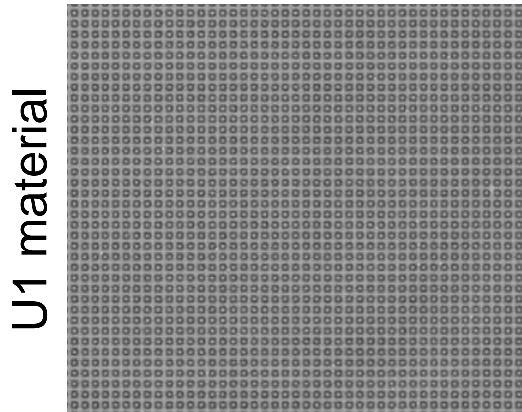
Detection of latent failures

ALTER TECHNOLOGY GROUP

SAM is used for the early detection of latent critical failures

SAM inspection underfill interface

U1 material



U2 material

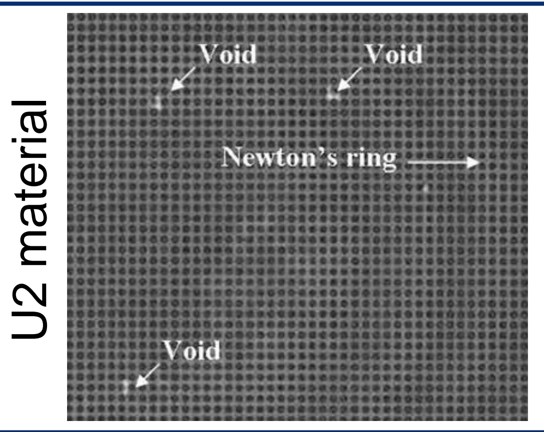


Table 3
Results of reliability tests

Test item	Condition	Result of U1 (Fail/Total)	U2 (Fail/Total)
TCT	−55 to 125 °C, 1000 cycles, Dwell time = 5 min	PASS	1/15 (530 cycles) 2/15 (600 cycles) 3/15 (643 cycles) 5/15 (800 cycles) 7/15 (1000 cycles)
TST	−55 to 125 °C, 1000 cycles, Dwell time = 5 min	1/15 + 3 (100 cycles) 1/15 + 3 (1000 cycles)	1/15 (500 cycles) 5/15 (750 cycles) 6/15 (1000 cycles)
PCT	121 °C/100% RH, 2 atm for 168 h	n/a	0/15 (72 h) 2/15 (168 h)
HAST	130 °C/85% RH, 33.3 psi for 264 h	PASS	n/a
HTST	150 °C for 1000 h	PASS	PASS
HTS	85 °C/85% RH for 1000 h	PASS	PASS

SAM identifies the configuration more susceptible to fail

C-C Chuang et al. Microelectronics Reliability 48 (2008) 1875–1881

Summary

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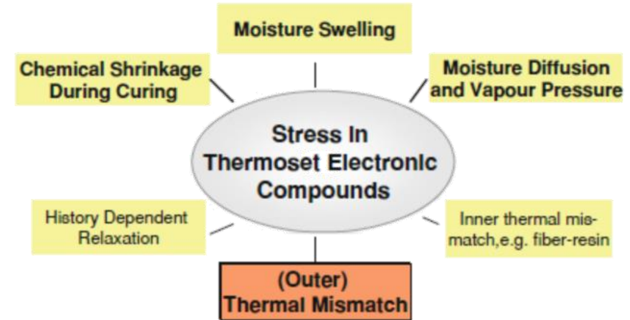
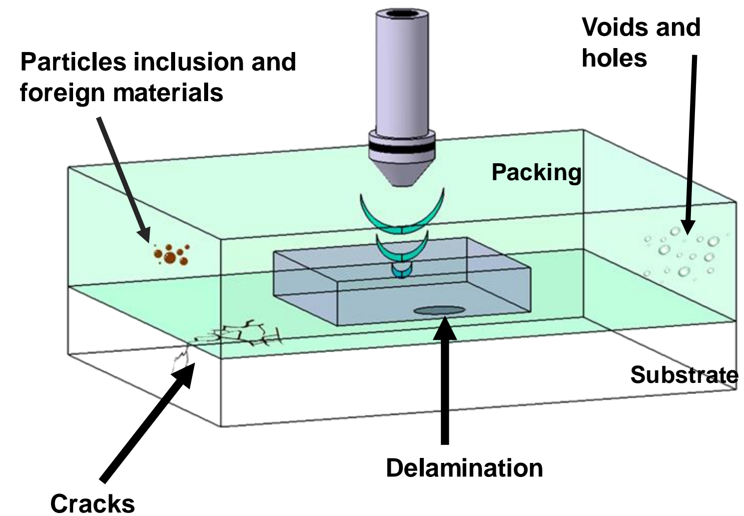
Plastic encapsulated system experience high internal stress

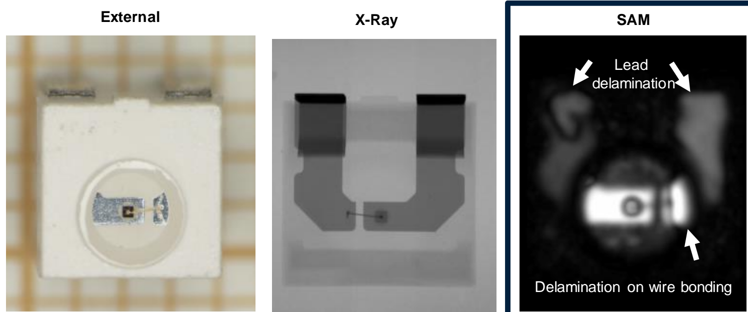


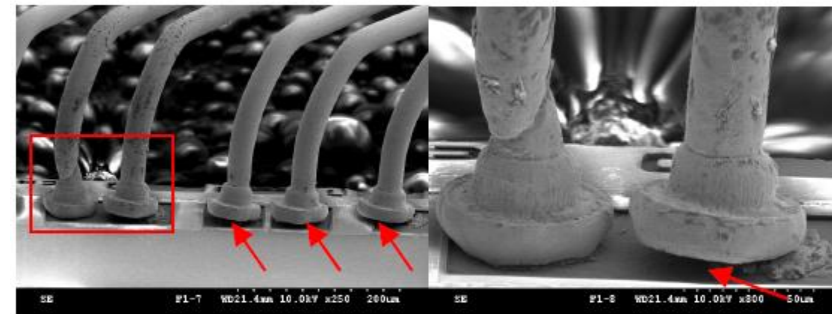
The promote the development of internal structural anomalies



They are the root case of different failures modes in ICs

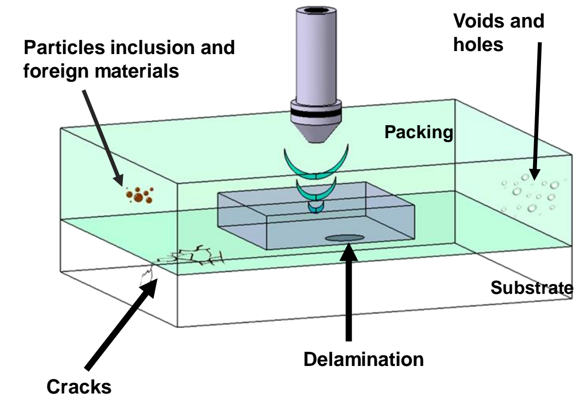
SAM is the most effective tool for the non-destructive detection and screening of such deviations

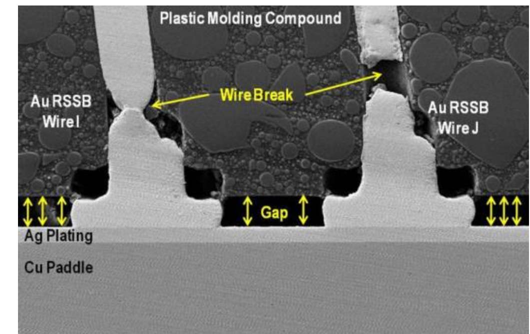


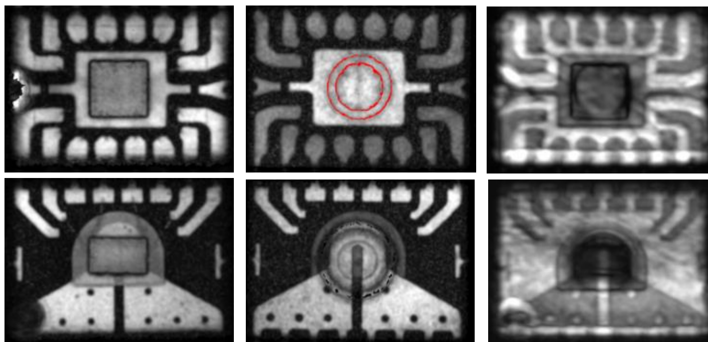


Outline

- ❑ Introduction
- ❑ The Scanning Acoustic Microscopy technique
- ❑ Inspection zones and typical failure modes
- ❑ ATN SAM capabilities







ALTER TECHNOLOGY SAM capabilities

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Scanning Acoustic Microscopy is a complex technique:

REQUIREMENTS FOR A SUITABLE INSPECTION

1. **Specialized and dedicated staff**
2. **Advanced characterisation systems** with flexible inspection capabilities adapted to the architecture of the specimen
3. **Multi-scan** based **interpretation** in case of **suspicious results**
4. **Comprehensive multi-depth inspection** of critical parts within thick packages

ALTER TECHNOLGY SERVICES

1. **Team work** formed by **Ph.D.** in Materials Science, experienced **Engineers** and **qualified technicians**
2. **Recently upgraded system** equipped with the **state of the art features**.
3. **Final result** is based on the combined assessment of **A-mode, confocal C-mode and Through-transmission scan modes**
4. **Prelaminar X-ray inspection** is systematically conducted to identify the critical focal planes **for multifocal C-SAM inspections**

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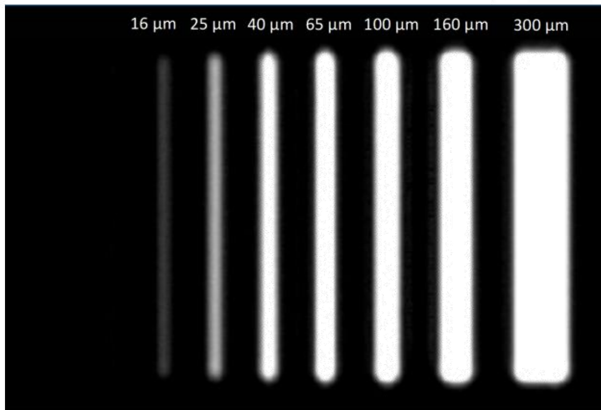
Recently upgraded capabilities
FineSatV (Hitachi)

- **Fast** inspection speed
- **High-quality** images
- Recently developed operating software with novel analysis functions.
- **Simultaneous confocal c-mode and through-transmission inspections**
- Advanced Fourier-transform data-treatment



- Wide variety of transducers (**adjustable inspection depth/lateral resolution**).
  - Maximum lateral resolution 30 µm.
  - Maximum inspection depth 5 mm or higher depending on the density

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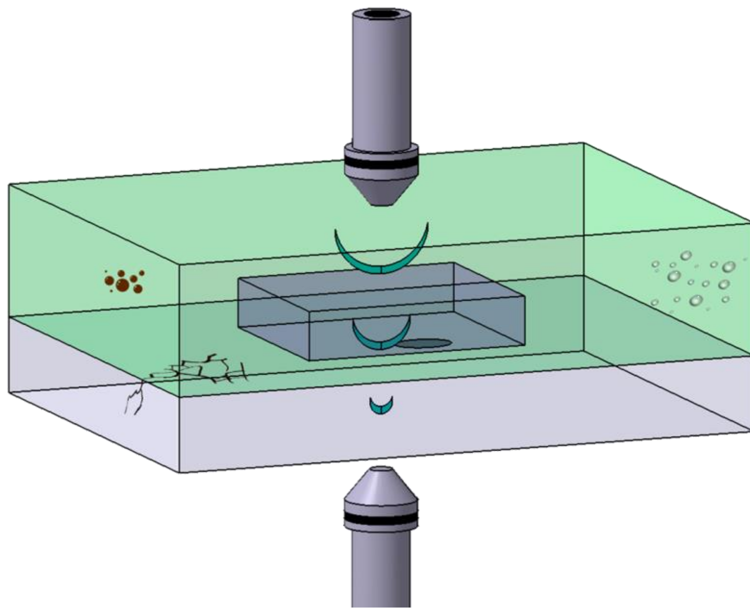
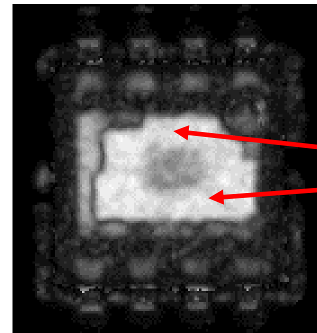
Scan modes

T-mode The intensity of the ultrasound beam transmitted by the system is used to prove the internal structure



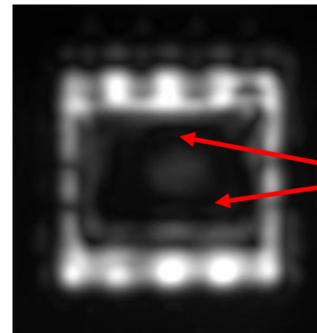
C-mode

Complementary inspections



Strong reflection

Delamination (air interface)



Weak/null transmission

Trough-mode

Additional scan modes

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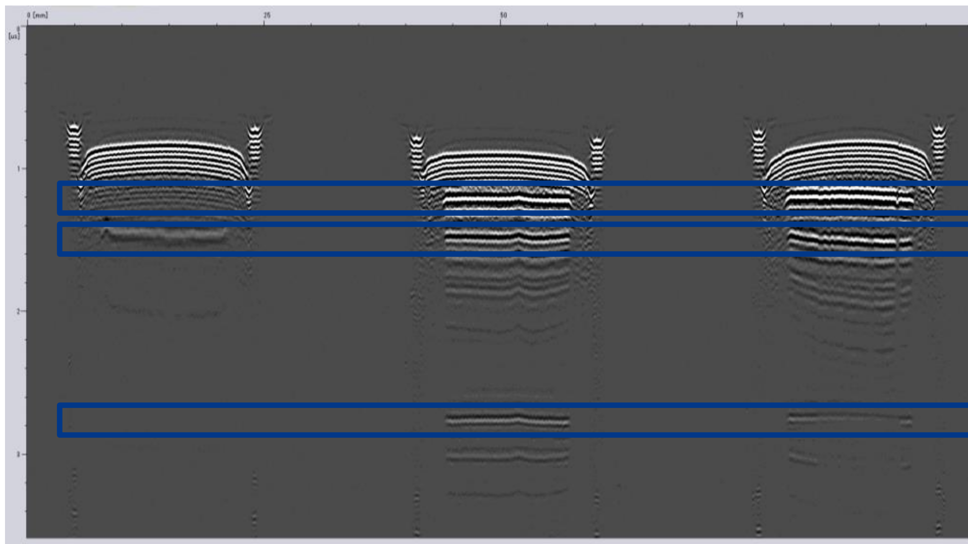
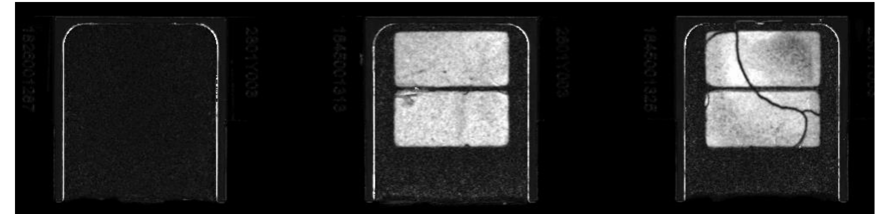
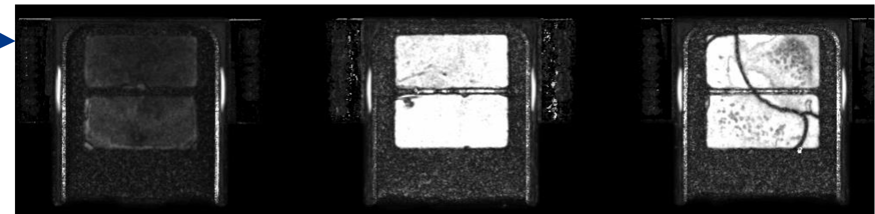
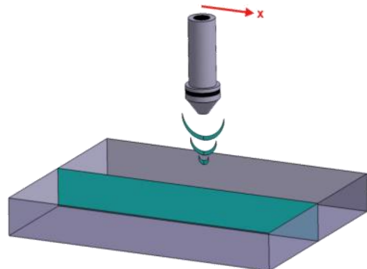
B-mode

Virtual cross sectioning









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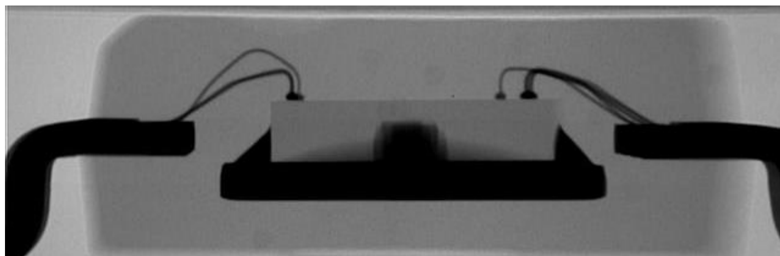
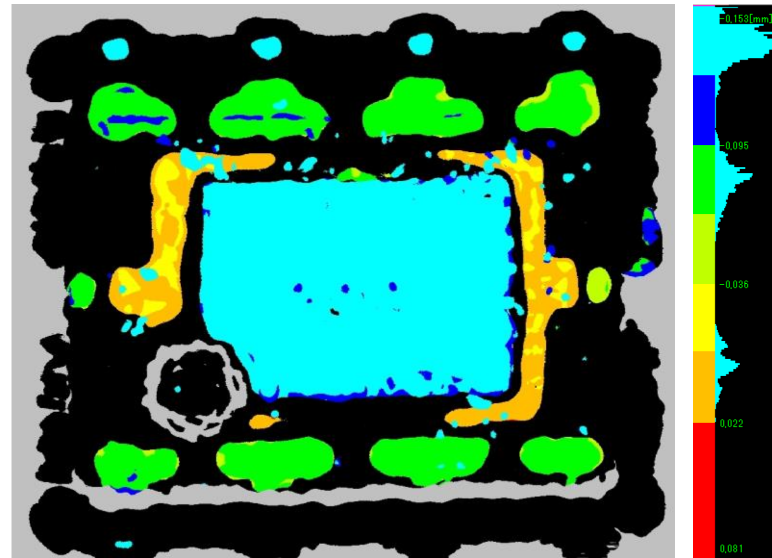
Depth mapping capabilities

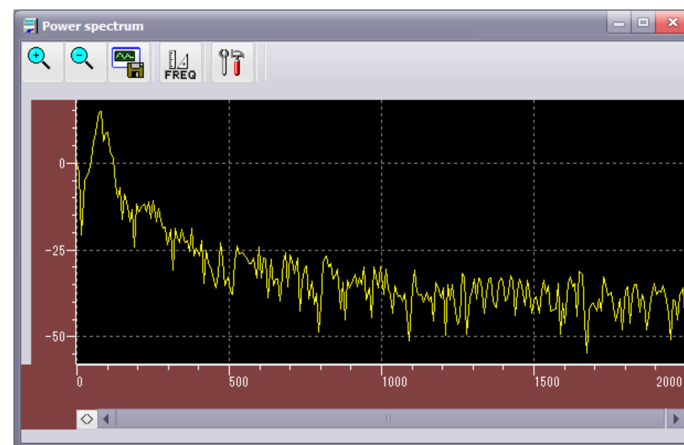
- Constructional analysis verification
- Measurements of defects location (depth).





Fourier transform data treatment

Used to improve image quality



Inspection procedure

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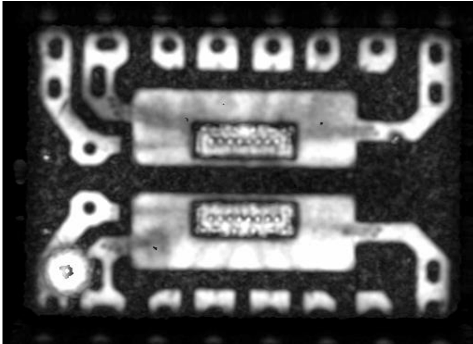
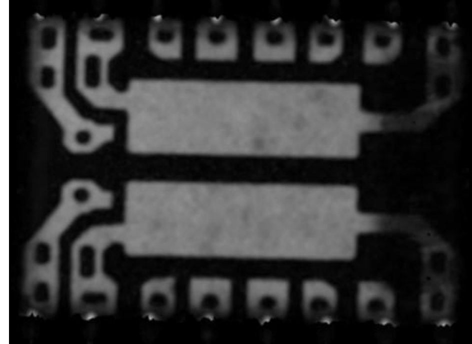
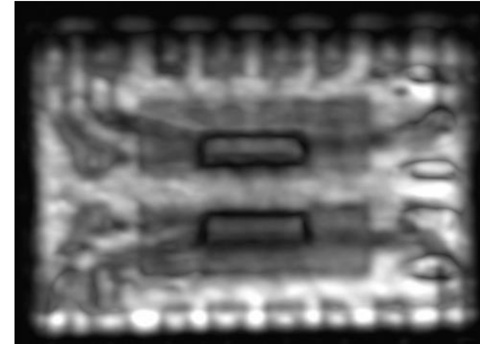
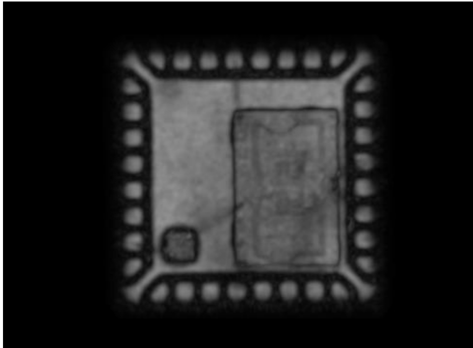
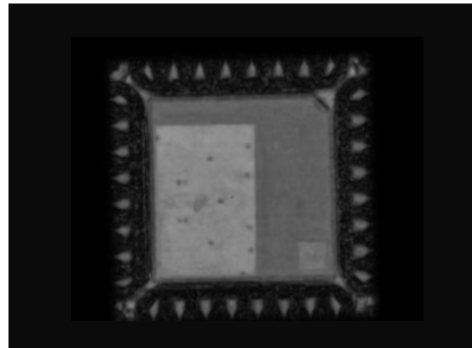
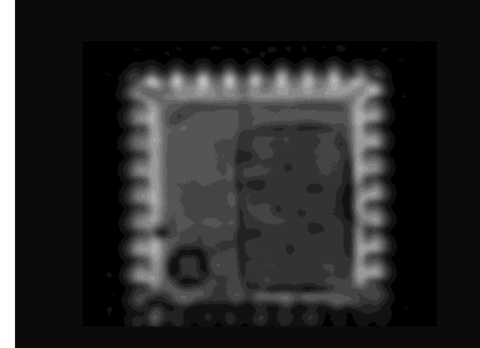
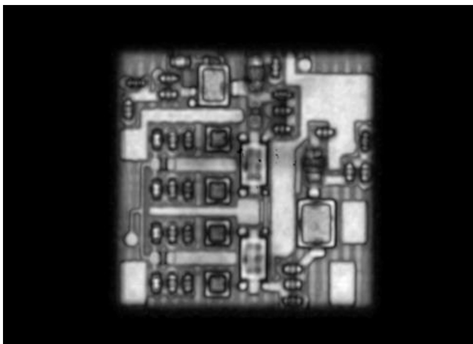
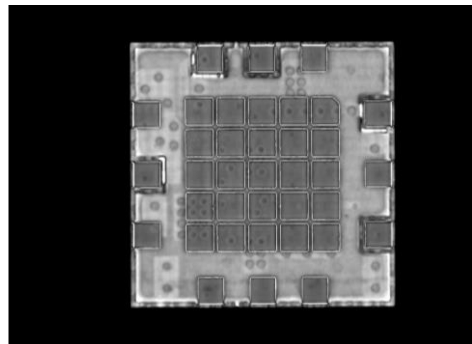
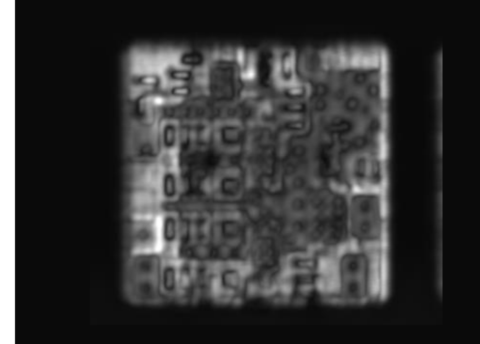
Confocal C-SAM

Through-mode

Circuit side

Non-circuit side

Inspection procedure

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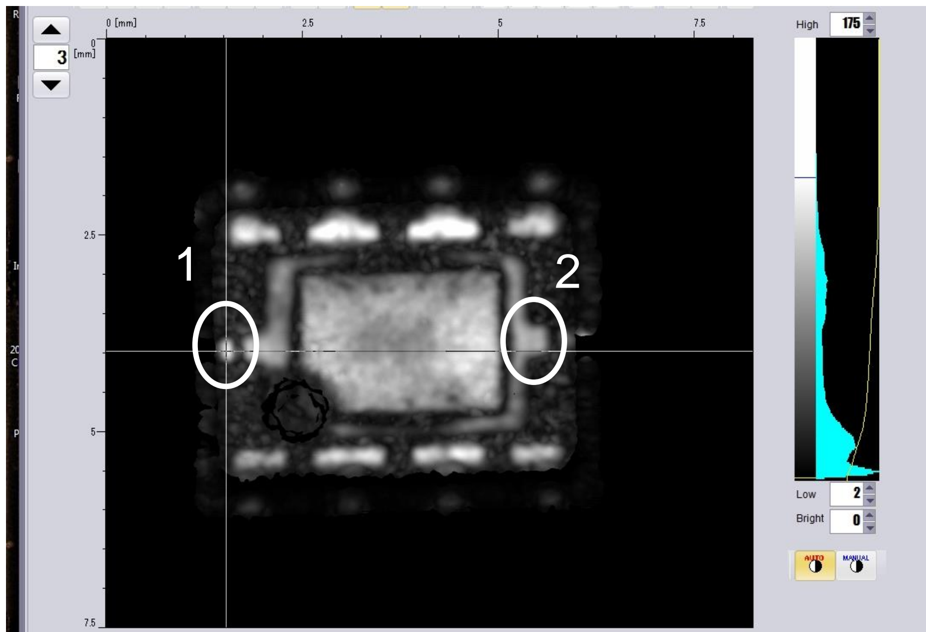
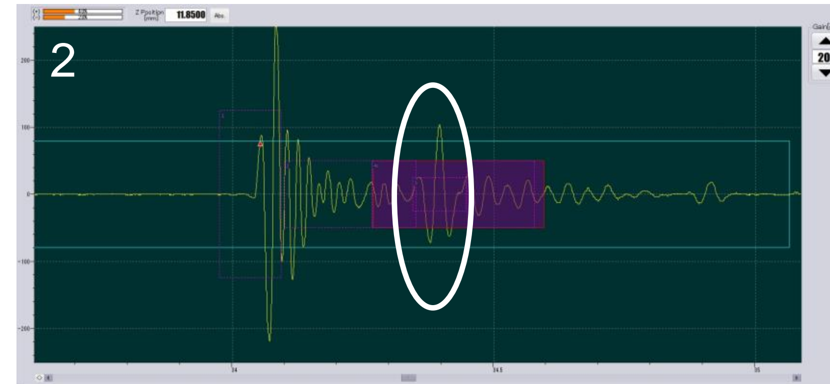
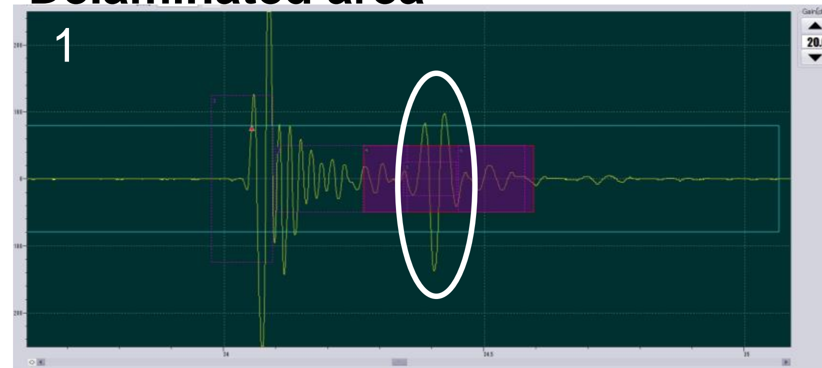
A-scan is systematically registered **along the whole sample** for all the inspected parts



Non-delaminated area



Delaminated area



Full area A-scan is available after inspection
Upon request they can be provided to the customer for the areas of interest.

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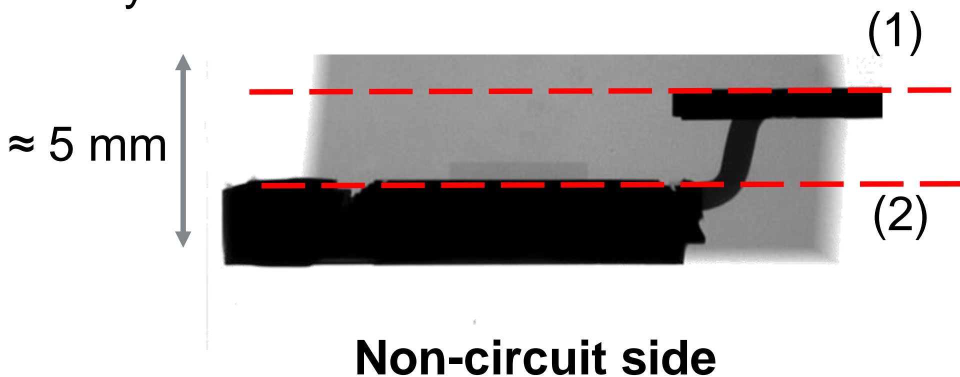
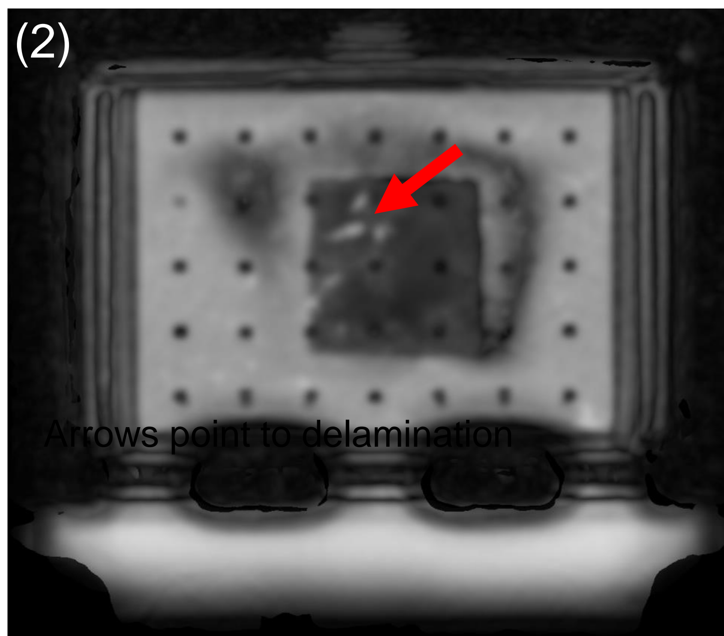
Multi-depth confocal inspection

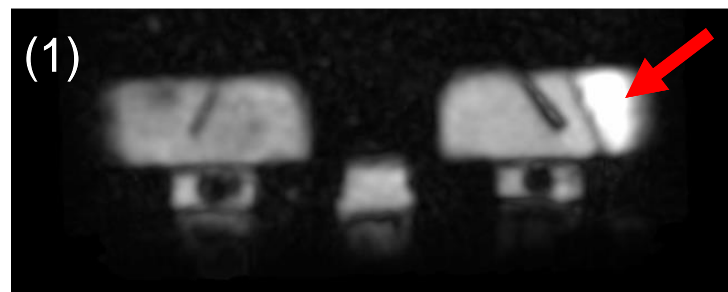
X-ray lateral view

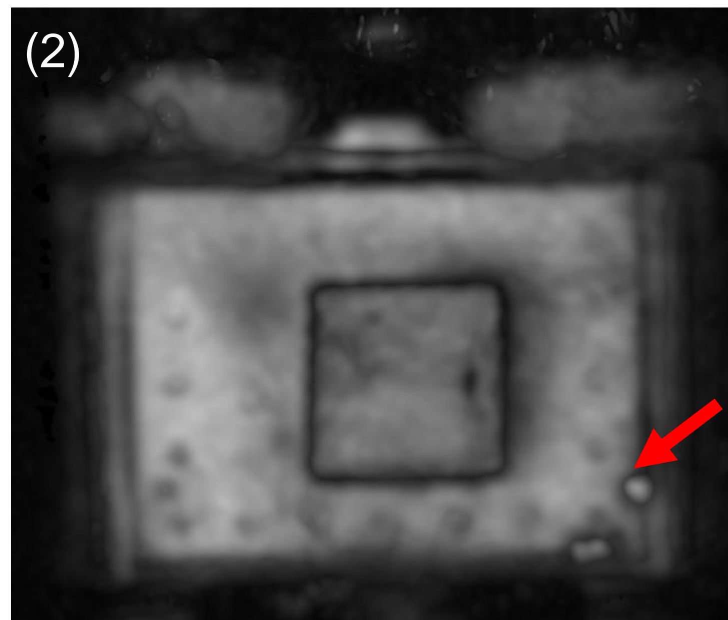


Non-circuit side



Circuit side. Two confocal inspection planes





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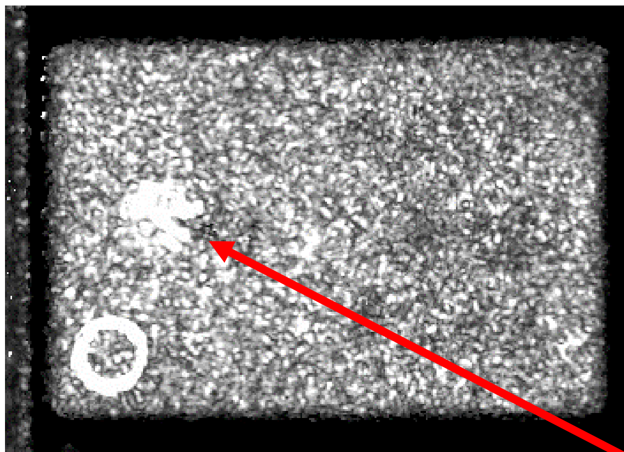
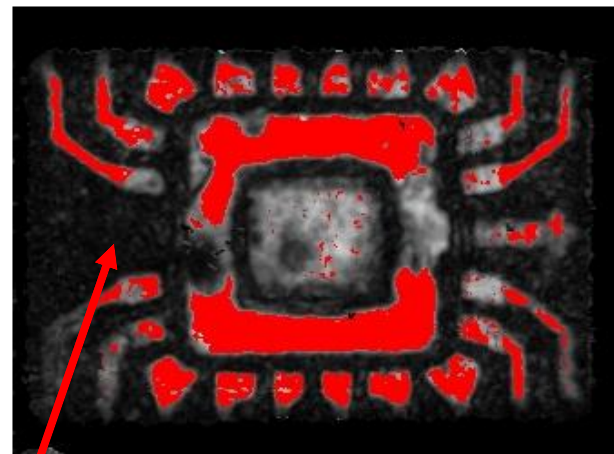
Multi-depth confocal inspection

Reliable interpretation of active part features

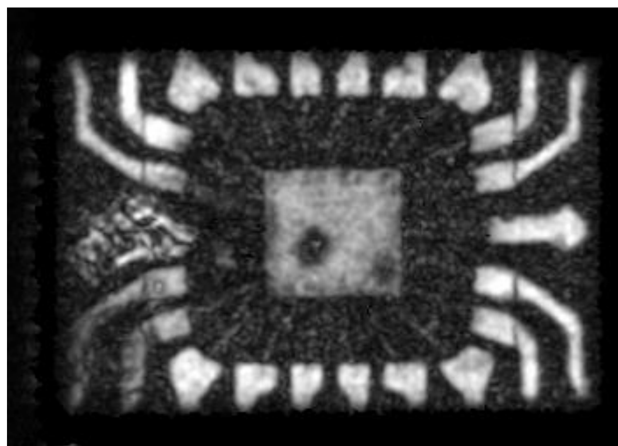
Moulding



Paddle surface



Die surface



Missed lead is an artefact due to moulding cracks

Single plane inspection leads to misleading info.

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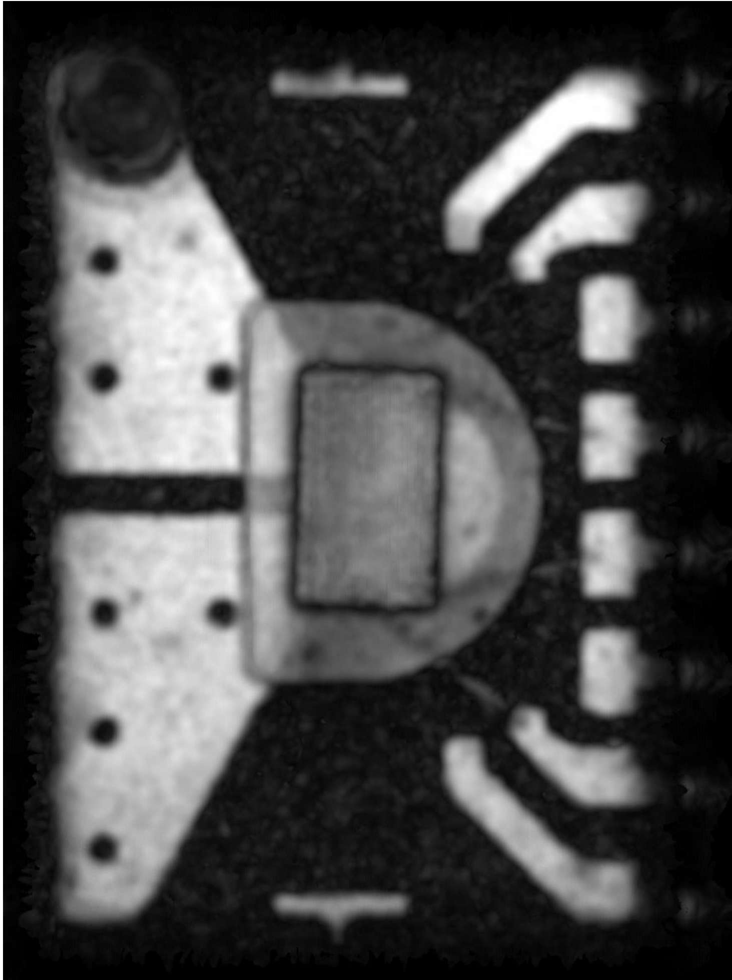
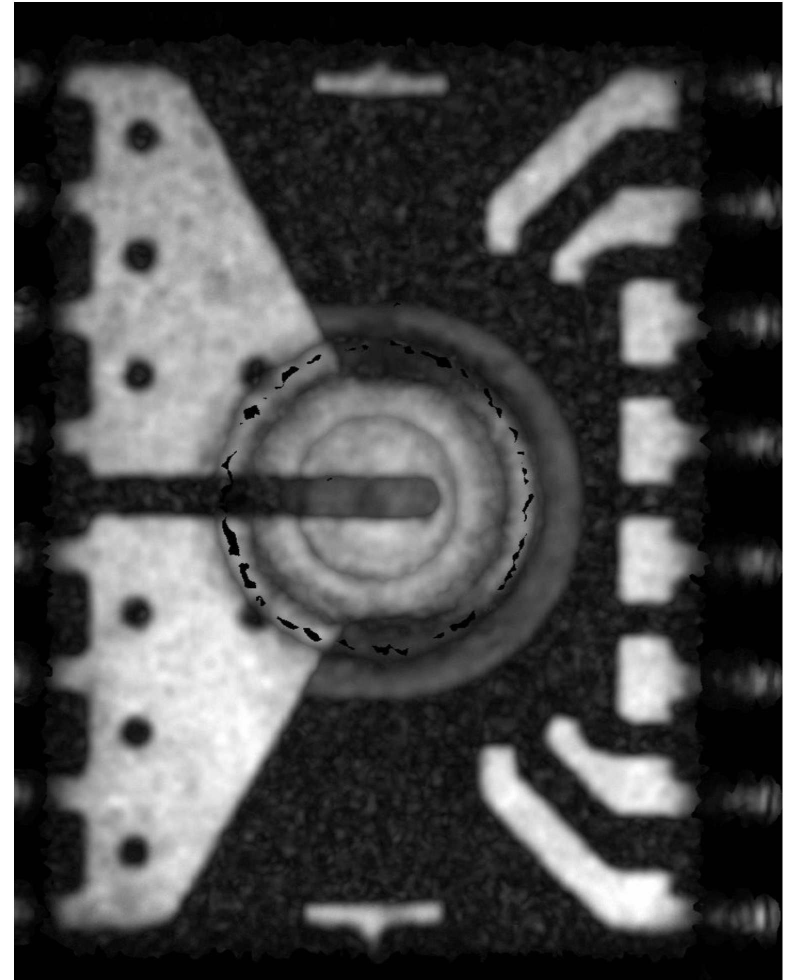
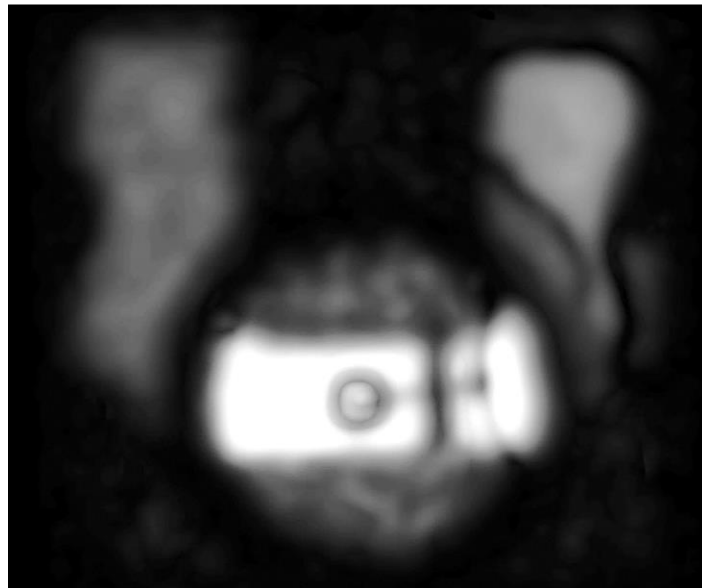
High quality images (**1500x1500 pixels resolution**) are registered for each specimen, scan mode and inspection plane



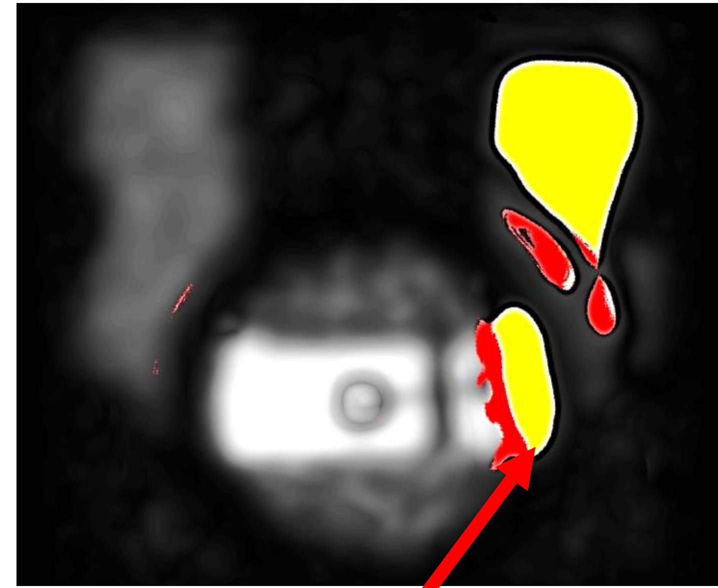


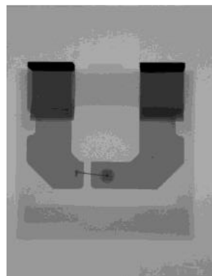
Specific **phase-inversion analysis-software** is used to **detect and mark air interfaces** and related defects

Peak amplitude image

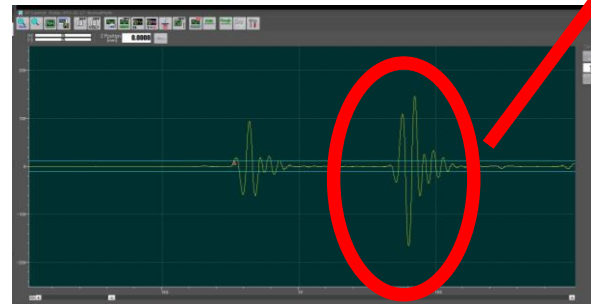


Peak phase inversion image





Verification by A-scan inspection



Delamination

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Conditioning (drying) of non-destructive samples

Inspection must be conducted in a liquid coupling media, typically water

Specifications MIL-STD-883, J-STD-020E and J-STD-033 (Handling, Packing, Shipping and use of Moisture Reflow and Process Sensitive Devices) state the procedures to remove absorbed humidity before shipping and/or soldering

Very gentle drying process agreed with the customer is used to remove moisture absorbed in the plastic package

Typical baking conditions range from 90 ºC to 125 ºC for 48 h to 24 h depending on the temperature

Complementary inspection capabilities

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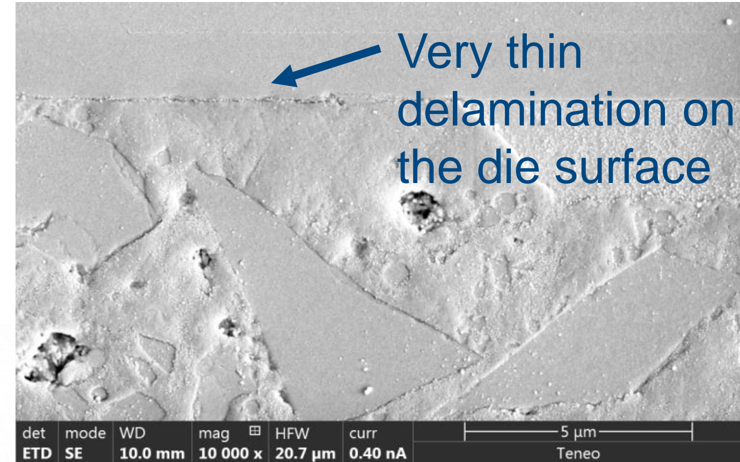
ESA recommended microsection facility

MEMO

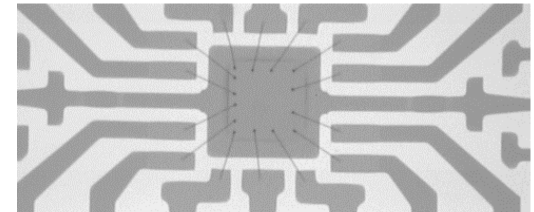
ESA-TECMSP-MO-013165

Ultra High resolution FE-SEM verification



X-ray inspection

Ideal to confirm wire-deformation findings



THANK YOU!

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