Applications of Novel High-speed In-line Automatic X-ray Inspection in High-volume Manufacturing

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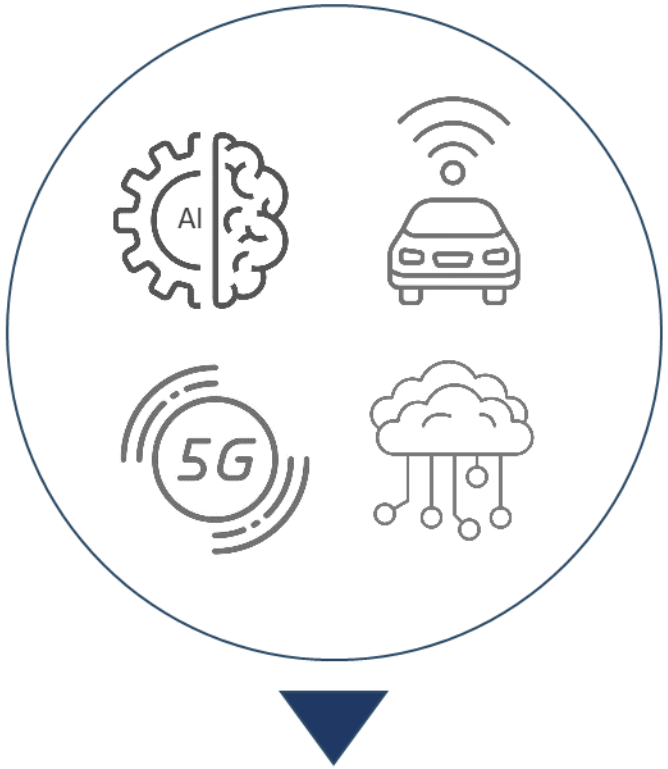
Outline

- Introduction and motivation for in-line defect inspection
- High Resolution Automated X-ray Inspection (HR-AXI)
  - Proven use-cases in high-volume manufacturing
  - Key system elements
- Conclusion

Microelectronic Device Technology Megatrends

Data Management
- 3D NAND
- HBM Memory
- 3D IC
- Stacked Die

Power Management
- PMIC
- SiP: System in package



Computing Power
- CPU/GPU
- 2.5D HPC packages

Connectivity
- Antenna (RF)
- Bluetooth
- Wireless Chip
- AiP: Antenna in Package
- RFFE: SiP

Advanced Packages Need to Deliver: Performance Reliability Complexity Scaling Density

From 2D Package to 2.5D/3D Advanced Package

The variety of new package styles and configurations:

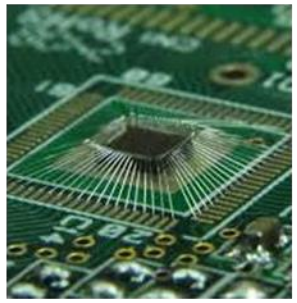
- Small form factor
- Lightweight technology
- Low profile technology
- Improved thermal management
- High speed technology
- High reliability
- High pin-count technology

More and more heterogeneous elements.

2D Package

Hundreds of Connections

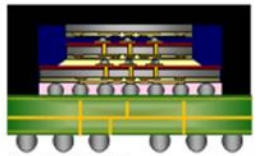
Wire Bond



Thousands of Connections

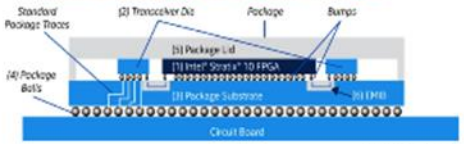
2.5D/3D Package

3DIC



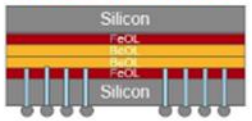
Source: Samsung.

Embedded Silicon Bridge



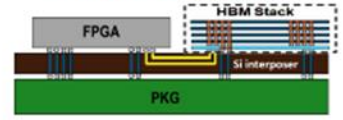
Source: Intel.

Wafer-on-Wafer



Source: TSMC.

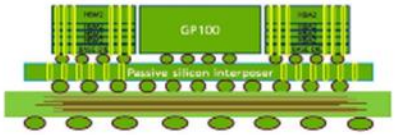
Silicon Interposer



Source: Xilinx.

Fan-Out on Substrate

Source: ASE Group



Source: Nvidia.

Millions of Connections

Resource: TechSearch and Yole Développement

Increasing Demands for Zero Defects

- Cost of a defective component can increase dramatically
  - Defect ruins a device = 1X
  - Defect ruins a board = 100X
  - Defect causes a recall = 1,000,000X
  - Defect results in human liability = 1,000,000,000X

Audi

7,000 semi devices per car + **1ppm** failure rate + **4,000** cars each day = **24** cars a day

BMW

3,500 semi devices per car + **1ppm** failure rate + **10,000** cars each day = **54** cars a day

Source: Audi Semicon 2015 and BMW AEC 2017

Increasing Demands for Zero Defects

SEMICONDUCTOR ENGINEERING

While quality over time has come under intensive scrutiny in automotive, where German carmakers require chips to last 18 years with zero defects, it isn't the only market demanding extended reliability. Smartphone makers now demand that chips work for a minimum of four years, versus the previous two-year lifecycle. And in some industrial and IoT applications, where replacing sensors is difficult, some chips need to last 20 years or more. (full article)

Extended reliability

ASSEMBLY

– Statistical Process Control. SPC is a powerful tool to measure and monitor process capability. It identifies how a process is performing and if the process is changing. This is particularly valuable to understand if continuous improvements are producing better processes. SPC allows us to analyze random samples of parts to determine if we are likely producing good parts.

However, SPC does NOT provide any assurance that every part produced is a good part. In fact, by the very nature and requirements of the mathematics behind SPC, bad parts will be produced. (full article)

SPC cannot achieve zero defects

Increasing Demands for Zero Defects

SEMICONDUCTOR ENGINEERING

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Extended reliability

ASSEMBLY

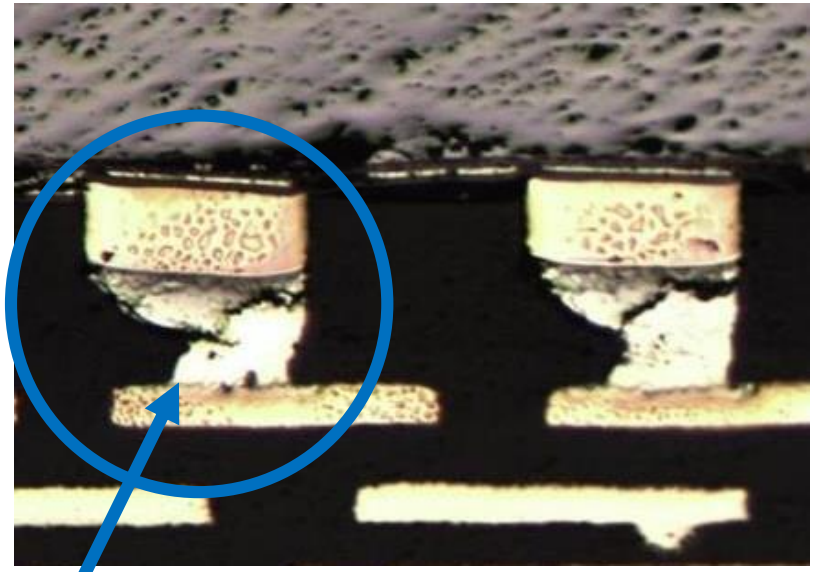
– Statistical Process Control. SPC is a powerful tool to measure and monitor process capability.

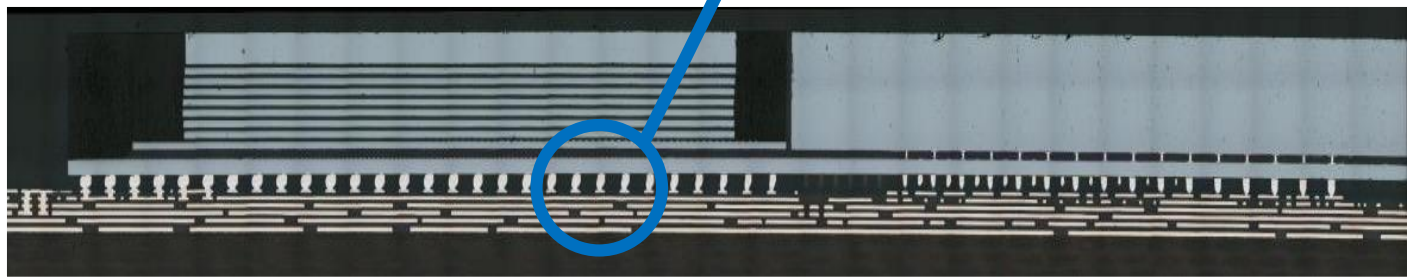
Achieving zero defects requires 100% in-line defect inspection

produced. (full article)

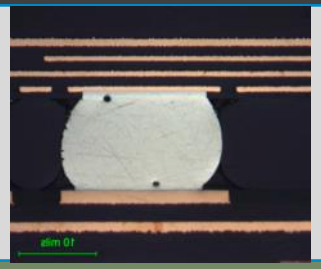
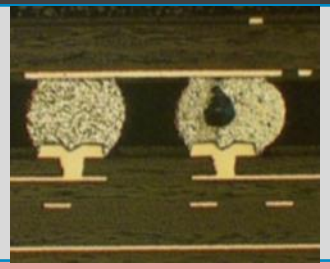
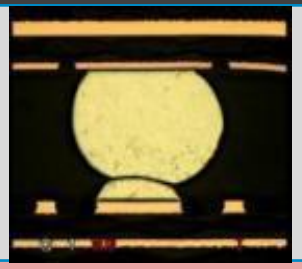
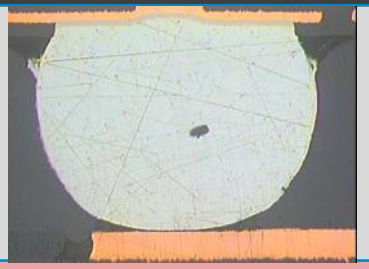
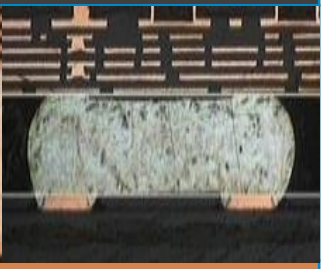
Reliability Defects

"Walking Wounded": Defects that are NOT caught during manufacturing today





"Walking Wounded" Defects are NOT Caught Today

Description	Good solder connection	Void Intermittent reliability defect	Head-on-Pillow Intermittent reliability defect	Non-wet Intermittent reliability defect	Non-contact open	Bridge/Short
Defect						
Electrical Test	Y	N	N	N	--	--
Optical Inspection	N	N	N	N	N	N

What is Missing?

- The essentials
  - Non-destructive
  - Fast
  - Transmissive
  - High resolution
  - Automated

High Resolution Automated X-ray Inspection (HR-AXI)

The Only In-line X-ray Inspection System for 3DICs

100X Faster

than other X-ray systems using proprietary X-ray source and detector

AI-based

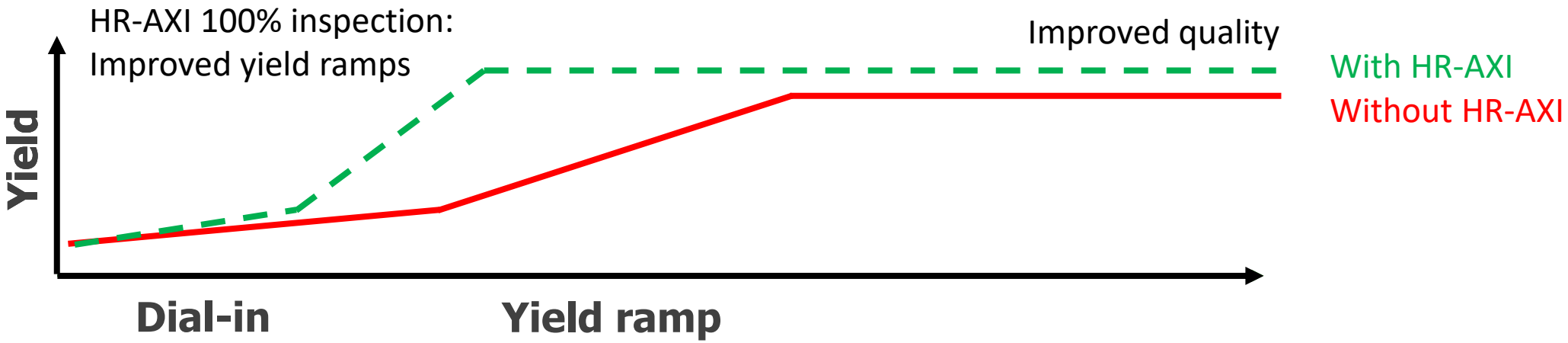
image processing for 100% in-line process control and defect detection that improves over time

Non-destructive

to sensitive ICs (DRAM) due to unique system design and X-ray spectrum conditioning (link)

Improved Manufacturing Outcomes and Enhanced Quality

Find Issue **Root Cause** **Corrective Action** **Validate Solution**



Set up process windows

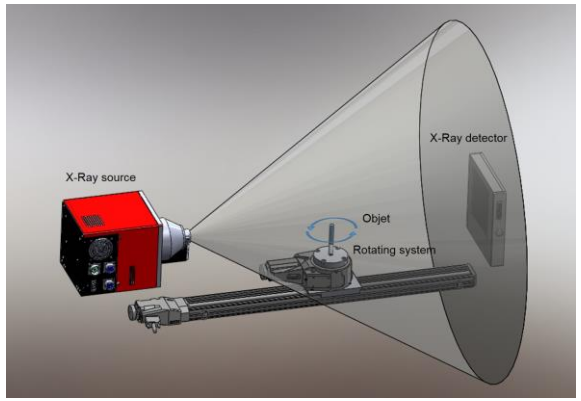
100% validation for yield ramp, continuous monitor of variability, apply process control in LVM and HVM

- Identify problems sooner
- Determine root cause faster and reduce FA
- Feedback and feedforward in process
- Continuous monitoring (NPI, HVM, OCAP)

Inspect and Review

- Inspect
  - Quickly scan entire part and locate all potential defects
    - Non-destructive
    - Fast
    - Accurate
    - Automated
- Review
  - Verify flagged defects
    - Can be destructive
    - Un-ambiguous
    - Detailed
    - Can be manual
- Inspect + Review cycle
  - Continuous improvement of AI models in HR-AXI

Inspection
HR-AXI



Review
3D-CT

Inspect and Review

- Inspect
  - Quickly scan entire part and locate all potential defects
    - Non-destructive
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    - Accurate
    - Automated
- Review
  - Verify flagged defects
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    - Un-ambiguous
    - Detailed
    - Can be manual
- Inspect + Review cycle
  - Continuous improvement of AI models in HR-AXI

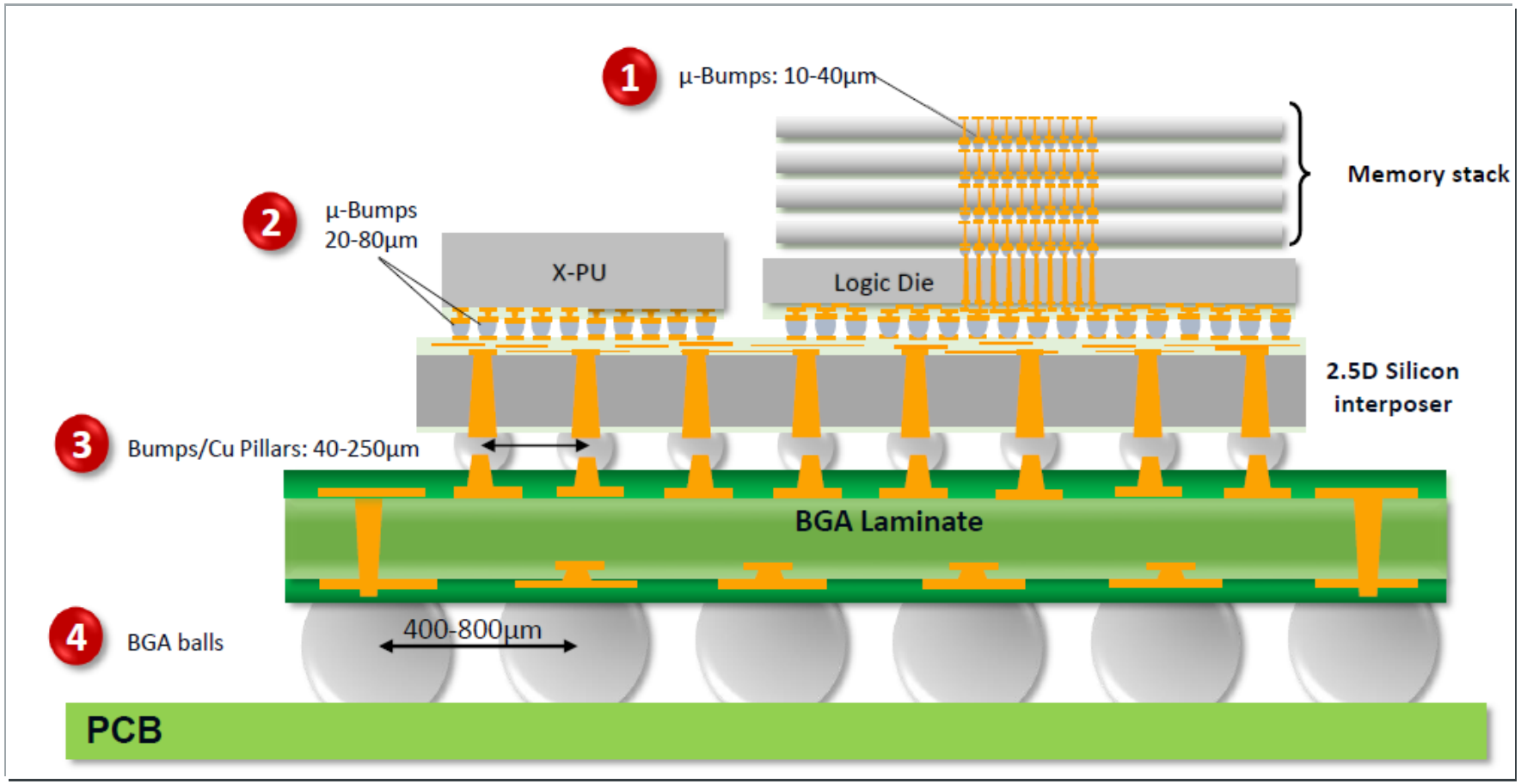
Inspection
HR-AXI

HR-AXI and 3D-CT are complementary technologies

Review
3D-CT

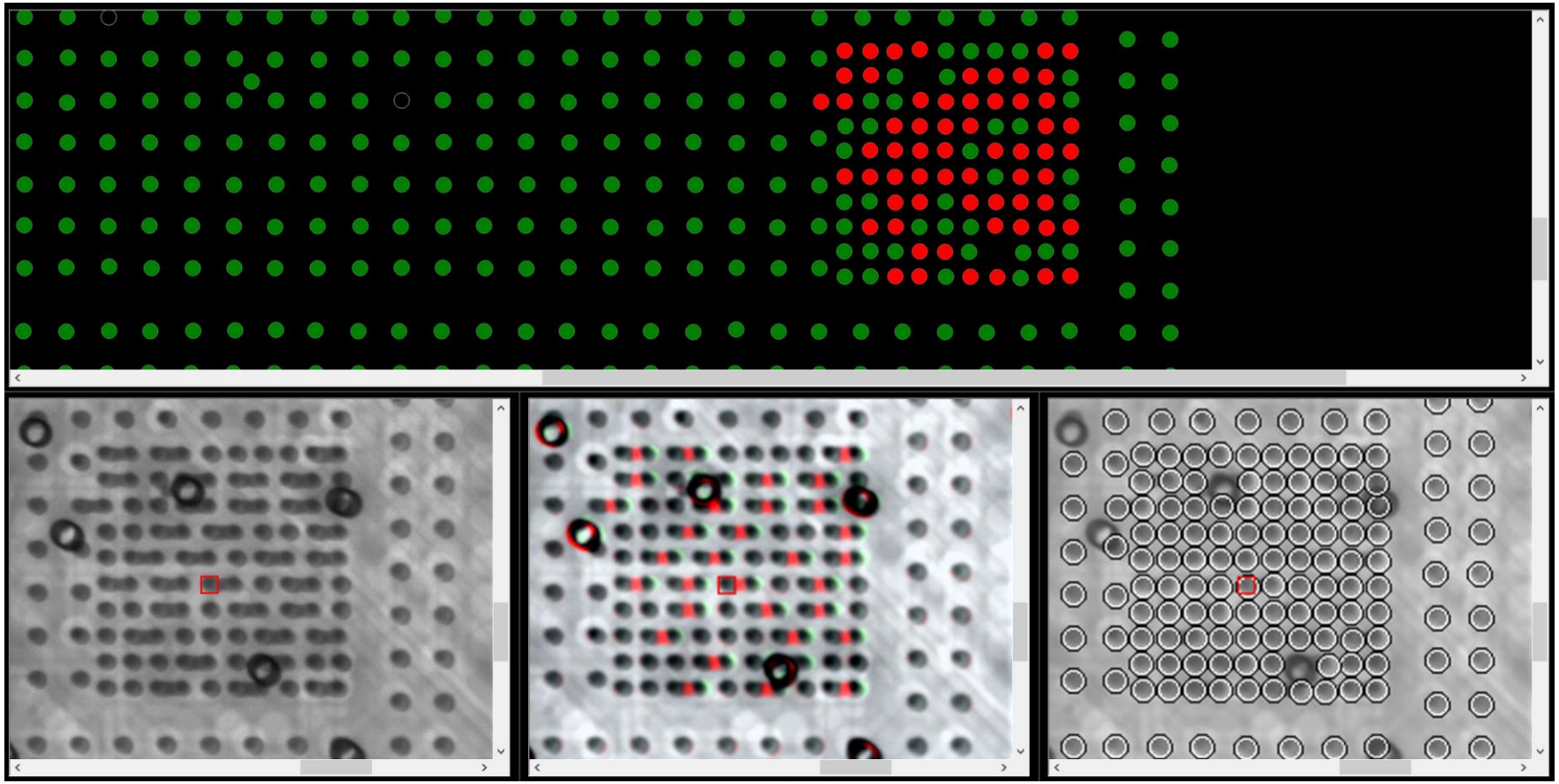
Successful Implementations in HVM

Value insertion points for in-line inspection in 2.5D packaging



Successful Implementations in HVM

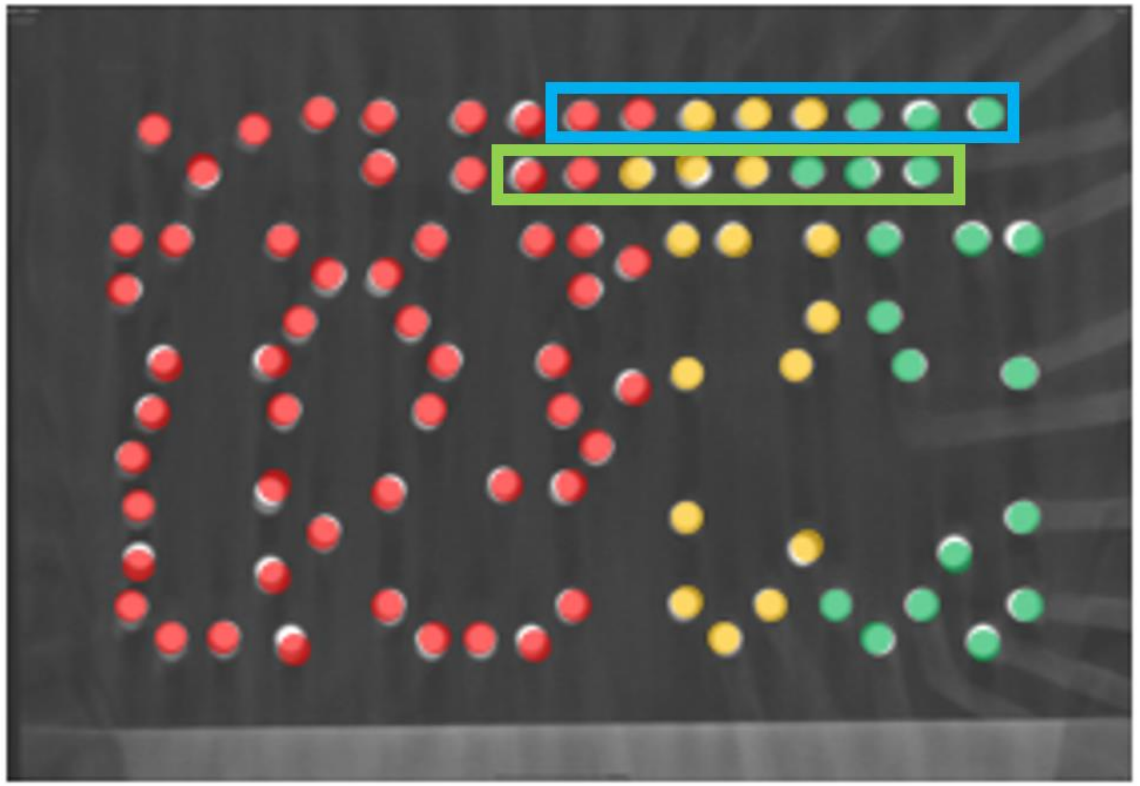
Bridge and non-wet detection in 2.5D packaging deployed in HVM



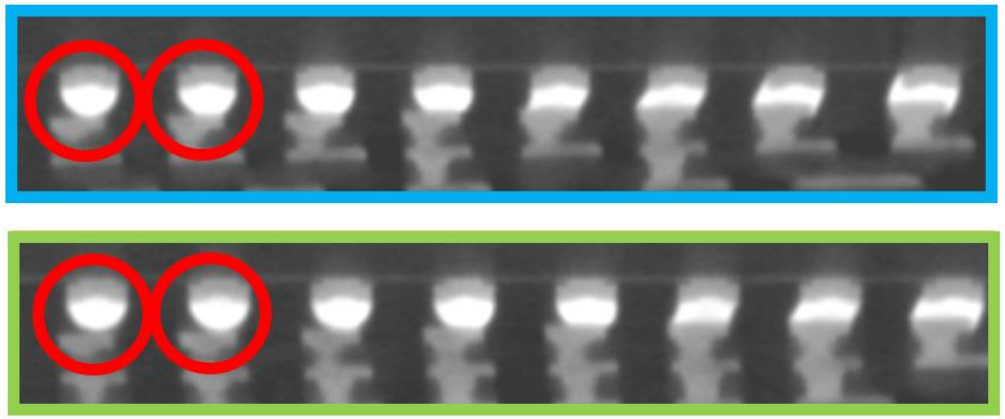
Successful Implementations in HVM

Bridge and non-wet detection in SiP deployed in HVM

HR-AXI (seconds)



3D-CT (hours)



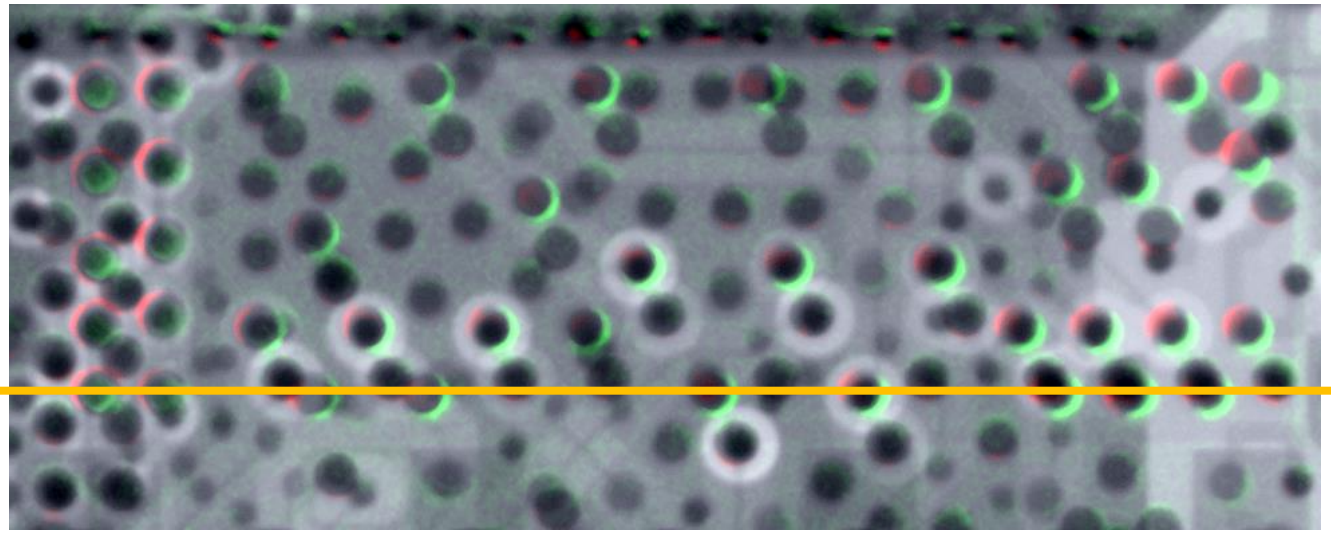
100% Non-wet

Partial Non-wet

Good Bump

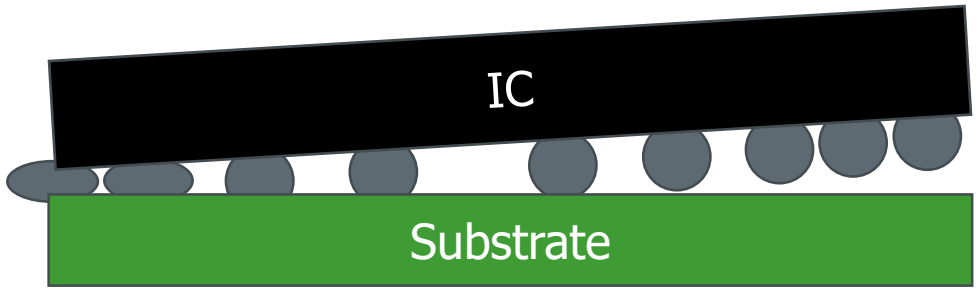
Inspection and Metrology

- Captures defects
- Provides metrology information which can identify root cause



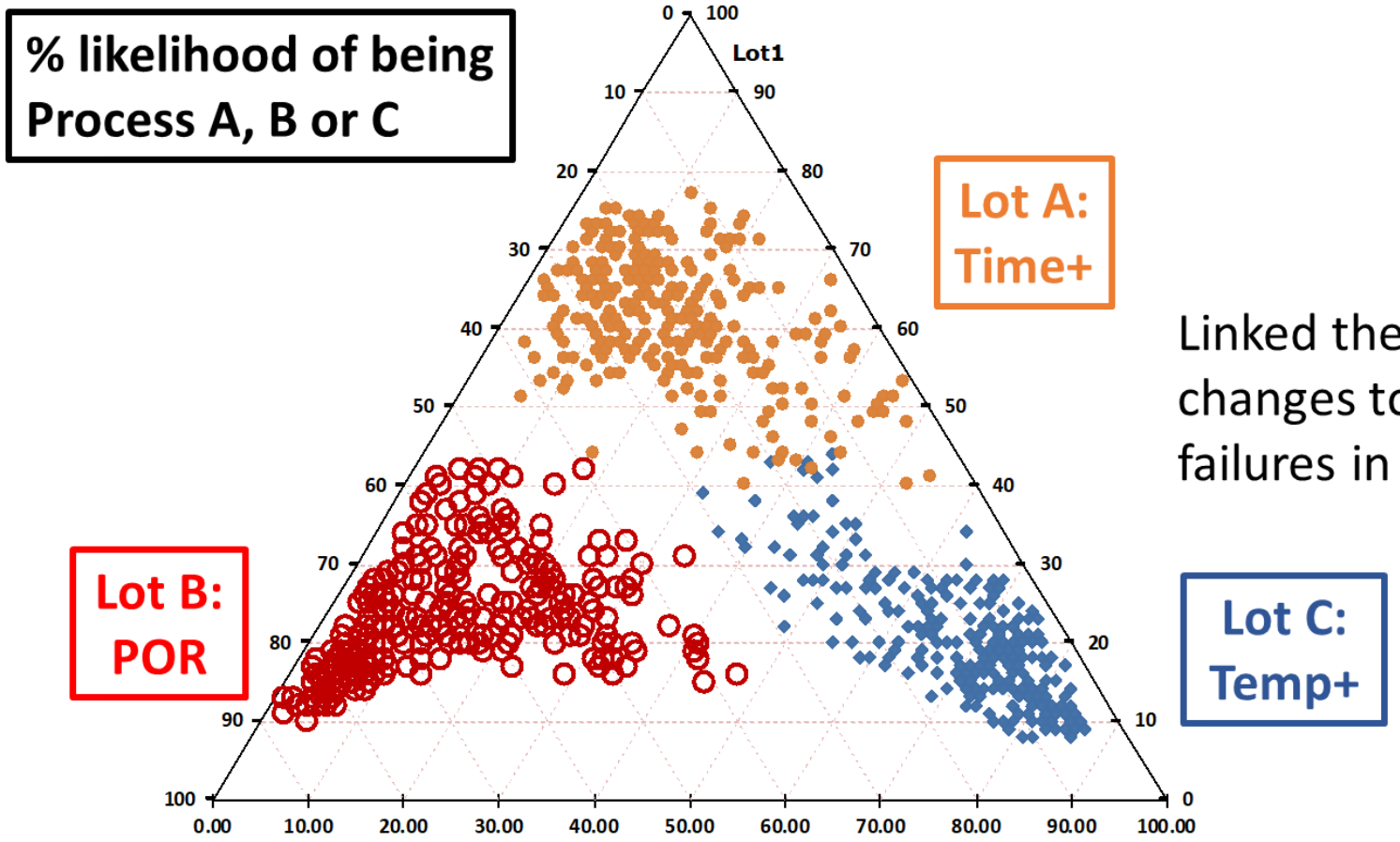
HR-AXI Top-view

Extra Solder
Missing Solder



Side-view

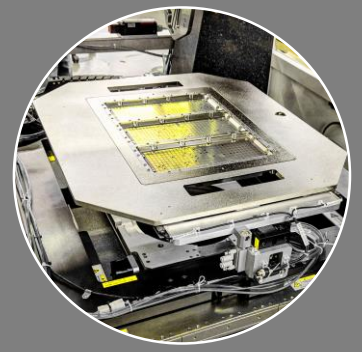
Accurate Process Monitoring



Linked these process changes to increased failures in the field.

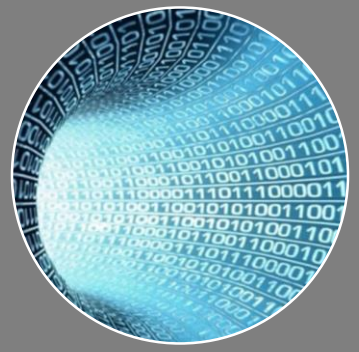
These process changes *cannot* be detected electrically
These process changes *affect reliability!*

Key Elements of HR-AXI



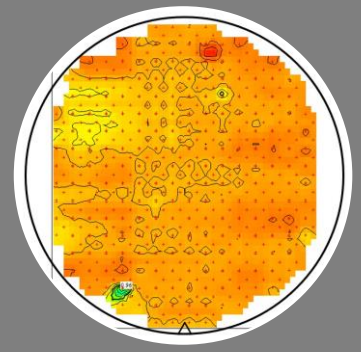
Instrument

High speed & high sensitivity data collection



Analytics

Rapid & repeatable analysis of large data sets

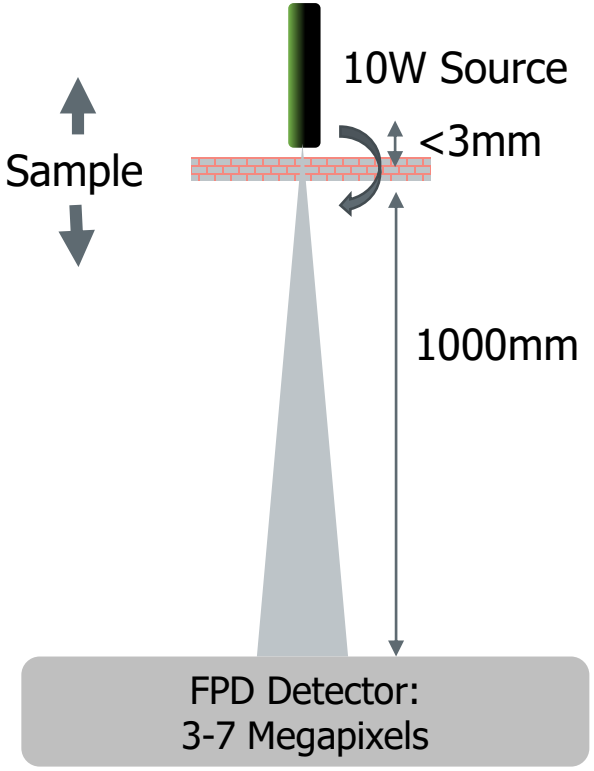


Visualization

Effective communication of information

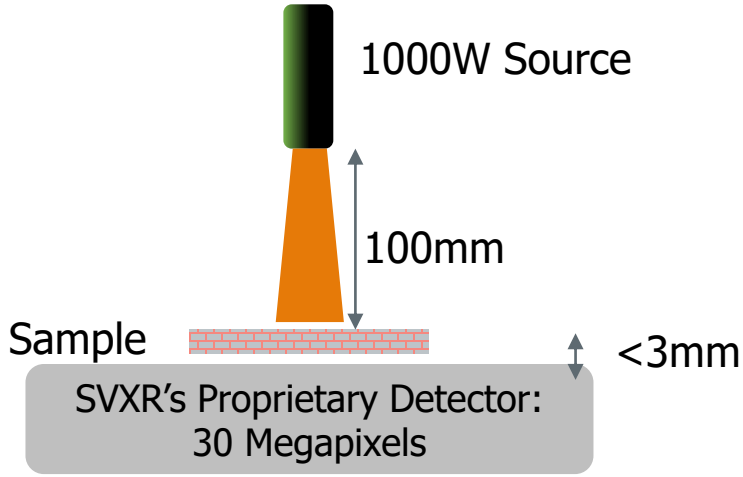
HR-AXI Designed for Speed and Sensitivity

Tradition FA X-ray



75um pixels FPD, 12Bit

SVXR HR-AXI

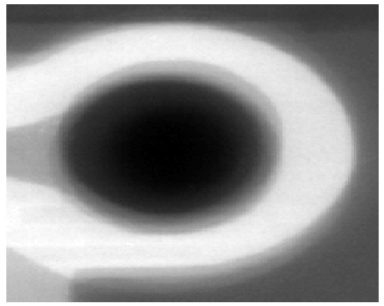


2.8um pixels CCD, 16Bit

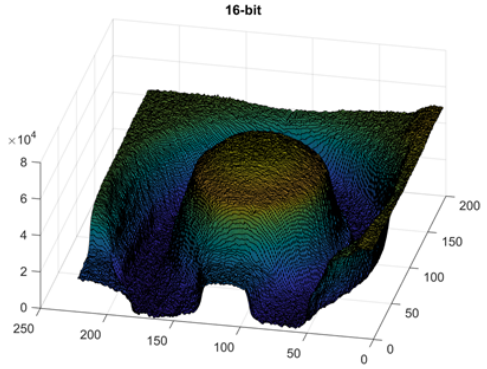
Advantages of SVXR architecture for in-line inspection and metrology

1. High speed
2. High sensitivity (dynamic range)
3. Single image defect detection
4. Large field of view with high resolution
5. Low sample dose for HBM/DRAM

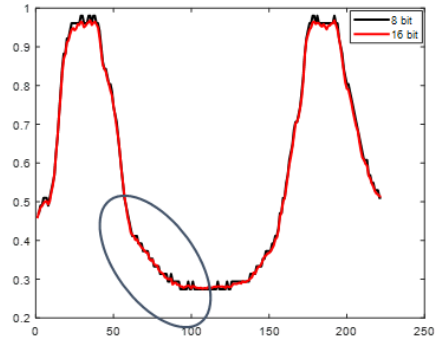
High Dynamic Range Enables Defect Detection



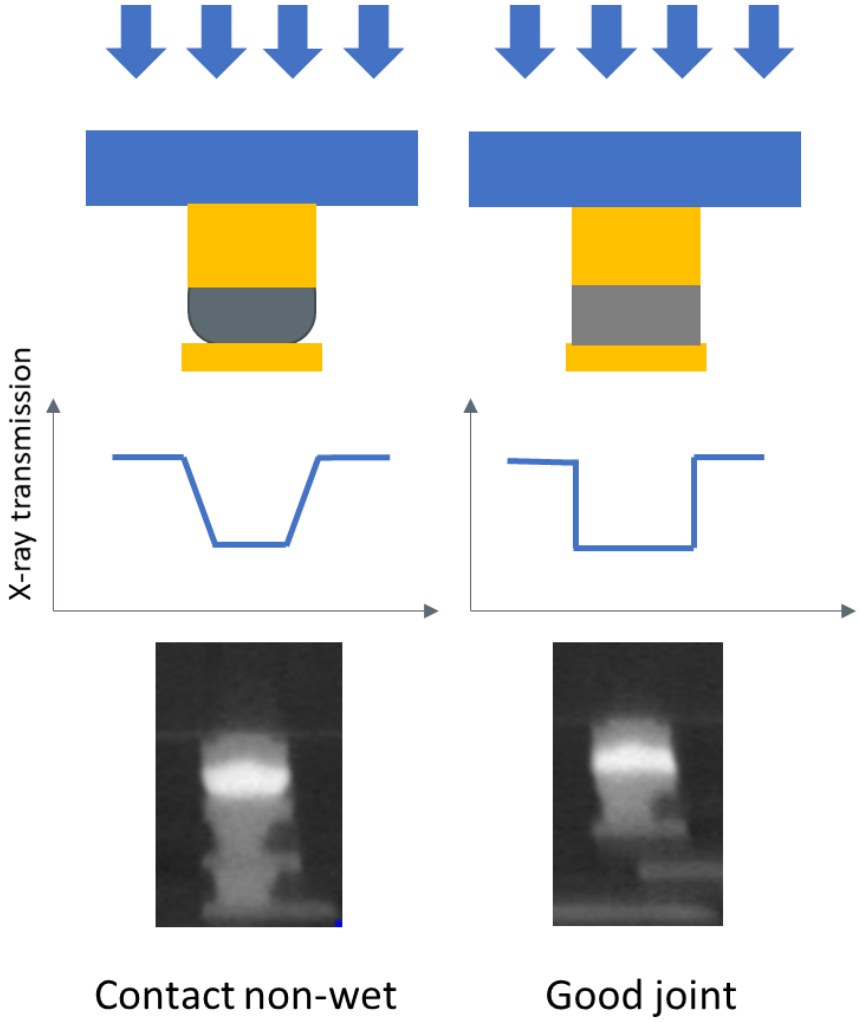
X-ray top-down image



3D plot of gray scale

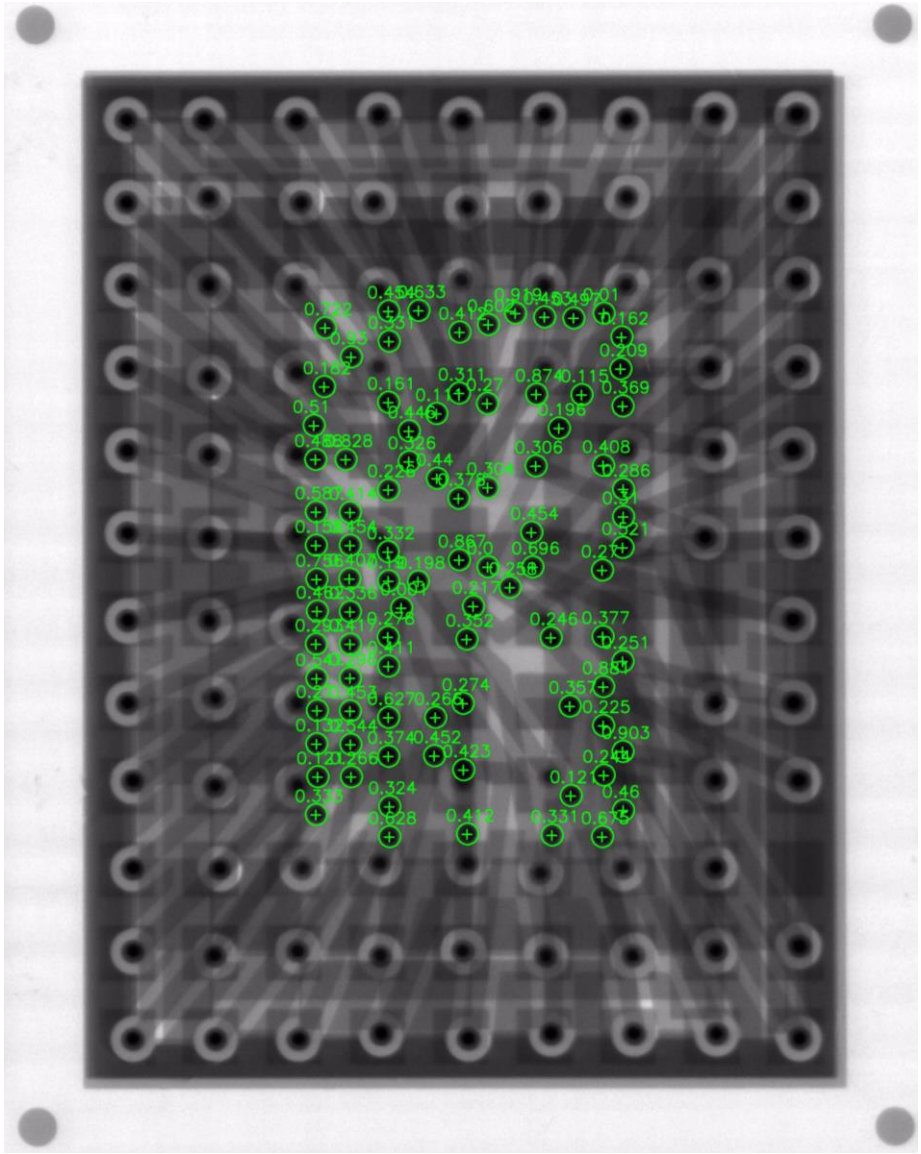


Line plot of gray scale



Analysis Software Suite

- AI and physics-based models
  - Feature generation
  - Outlier detection
  - Defect classification
- Data visualization
- Automatic reporting



Analysis Challenges

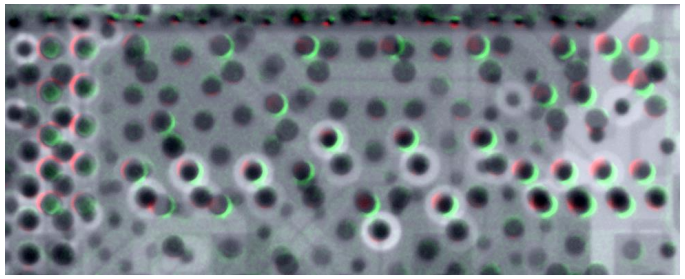
- Pattern noise
  - Alignment tolerances for vias, traces, pads, etc.
- Part-to-part variations
- Validation

Application Development Cycle

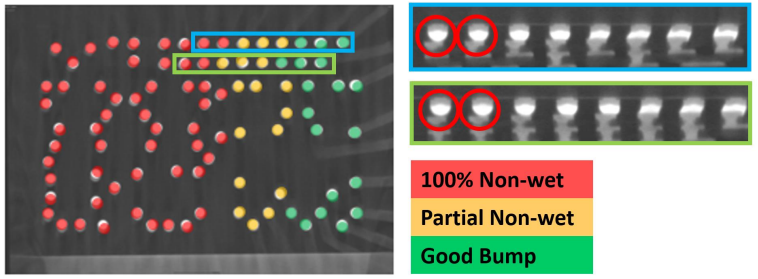
- Problem statement
  - Pain points
  - Samples (known good and known bad) with defect examples
- Imaging
  - Recipe setup (layout files to define ROIs)
- Analysis cycle
  - Identify important features to determine outliers
  - Feedback from review tool (validation/labels)
  - Improve feature generation, outlier detection, and defect classification models
- Industrialization
  - eMAP
  - Automatic handling (EFEM)
  - Data reporting
  - Continuous monitoring, feedback control loops, etc.

Conclusion

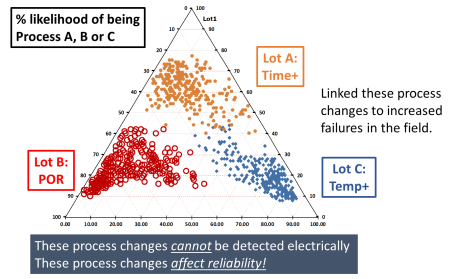
- Packaging complexity increasing going towards 3DIC
- Market tolerance for defects decreasing
- Driving towards zero defects requires in-line defect inspection
- HR-AXI is the only in-line X-ray inspection solution for 3DICs
  - 100X faster than other X-ray technologies
  - AI-based software suite automates analysis
  - Non-destructive for X-ray sensitive devices like DRAM



Inspection



Metrology



Process Monitoring

Thank You

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