SAND2011-5311C

To be Presented at the Three River Technical Conference 2011, August 2-3, 2011, MN

# 3D X-Ray CT Analysis of Solder Joints in Area Array Electronic Package Assemblies

**Rajen Chanchani**
**Sandia National Labs***
**Albuquerque, NM**
**chanchr@sandia.gov**

**Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.**

# 3D X-Ray CT Analysis of Solder Joints in Area Array Electronic Package Assemblies

**The author wishes to acknowledge:**

**1. Dale Brandt and Steve Terwilliger of Sandia National labs, Albuquerque for their help in designing and fabrication of the Printed Wiring Boards and procurement of COTS PBGAs.**

**2. Tipphachane Soumphonphakdy, Javier Gallegos and Kathy Myers of Sandia National Labs , Albuquerque for helping with the logistics and sample preparation.**

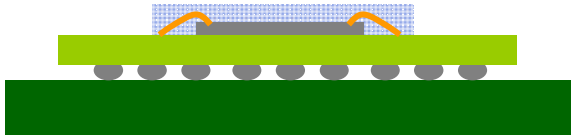
**3. Jason Edgar of Honeywell, Kansas City Plant for assembling the boards.**

Sandia National Laboratories

# Objective of the Study

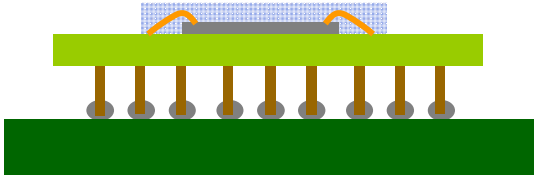
## Examples of Area Array Packaging Technologies

**Plastic BGA Assembly on a PWB.**



**Flip-Chip on Board**

**Ceramic CCGA**



## Issue:

**1. Currently we cannot reliably inspect area array I/O interconnects.**
**2. This prevents the use of the area array packaging technologies in high reliability applications.**

## Objective of this Study:

**To evaluate 3D XRay-CT Technology for area array solder joint inspection in electronic area array package assemblies.**

Sandia National Laboratories

# Outline

- **Introduction**
  - ✓ **Techniques for Area Array solder joint inspection**
  - ✓ **3D X-Ray CT Scan technology description**
- **Experimental**
  - ✓ **Plastic Ball Grid Array (PBGA)**
    - **Design, fabricate and assemble a special test vehicle with known solder joint defects**
    - **3D X-Ray Analysis**
    - **Radiation Exposure Measurements.**
  - ✓ **3D X-ray analysis of Flip-Chip Wafer-Level Chip-Scale-package.**
  - ✓ **3D X-Ray analysis of Ceramic PGA/CCGA**
- **Conclusions**

Sandia National Laboratories

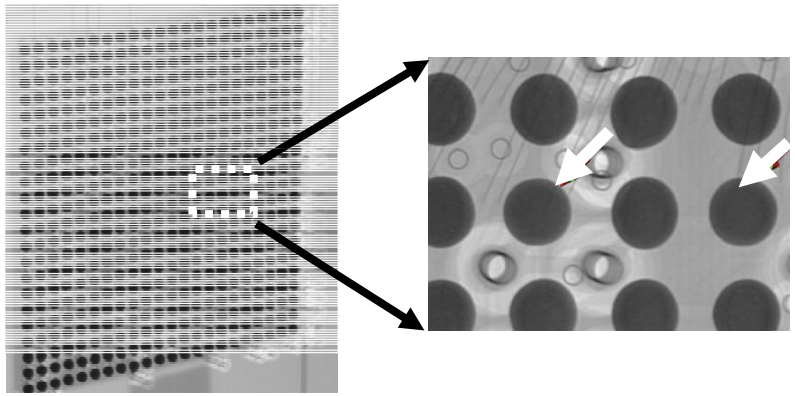
# Possible ways to inspect solder joints in Area Array Package Assemblies

## Destructive Tests

1) Cross –Sectioning and Microscopy – Very difficult to detect unknown defects.

## Non-Destructive Tests

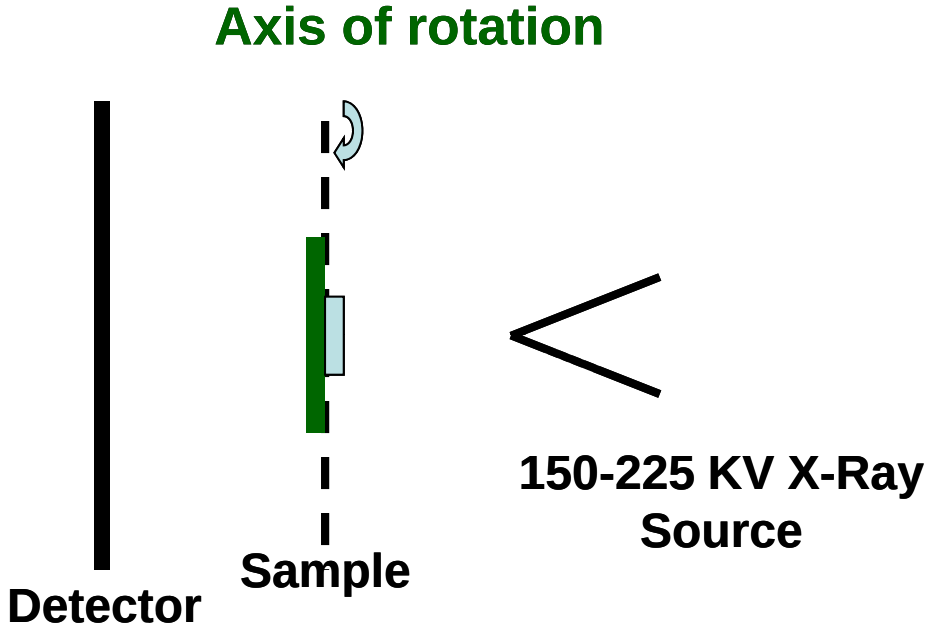
1) Electrical Functional Test – It does not tell us about how reliable the joints are.
2) CSAM (Acoustic Microscopy) – 2D image. Low resolution. Sample has to be dipped in water.
3) Visual Inspection – Only can view periphery joints.
4) 2D X-Ray Analysis – 2D Image does not show the joint in Z-dimension.



5) 3D X-Ray Analysis – Topic of this study.

Sandia National Laboratories

# 3D X-Ray CT Scan Technique



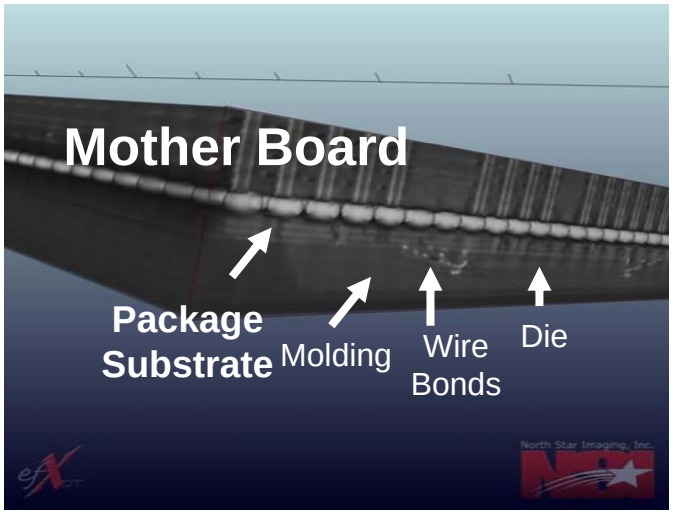

## 3D- X-Ray Technique

1. Large number of 2D X-Ray images (e.g. 1440) are taken while the sample is rotated on an axis.
2. The computer processes the 2D images to output 3d images.

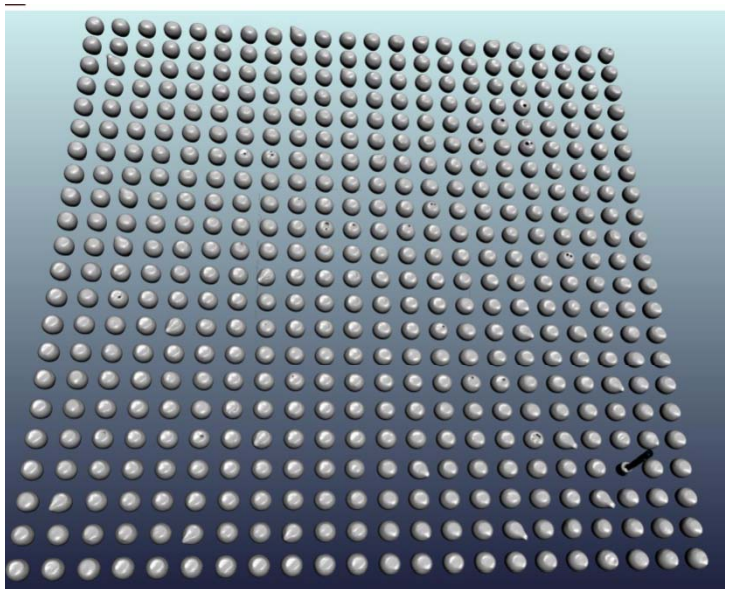
Sandia National Laboratories

# 3D X-Ray CT Scan Technique

- **Traditionally have been used in medical diagnosis.**
- **Recently, this technology has advanced to get better resolution, lower cost and smaller size.**




**Look thru materials**



**This technique is specially suited for inspection of high density materials like solders and metals**

Sandia National Laboratories

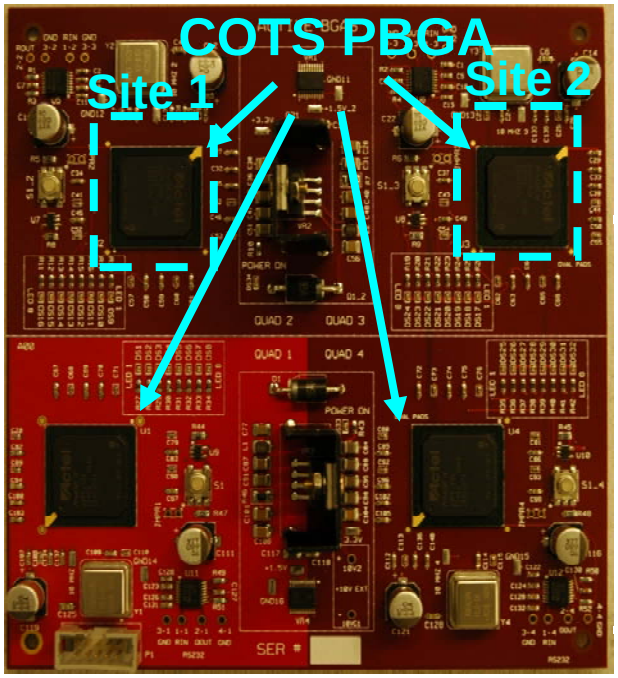
# Experimental Approach

1. **Design, fabricate and assemble a special test vehicle with known solder joint defects**
   a. **Plastic Ball grid Array (PBGA) assembled on Polyimide-Glass mother board.**
2. **Investigate if 3D X-Ray CT technique can detect all defects.**
3. **Measure X-ray dosages exposure on the packages.**
4. **Look at other Area Array technologies by 3D X-Ray :**
   a. **Flip-chip WLCSP on MCM-L substrate**
   b. **Ceramic PGA or CGA**

Sandia National Laboratories

# Design, Fabricate and Assemble PBGA Boards

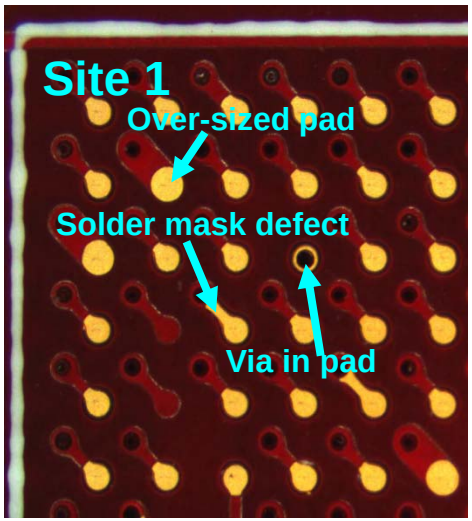
## PBGA used - COTS Actel 484 I/O BGA

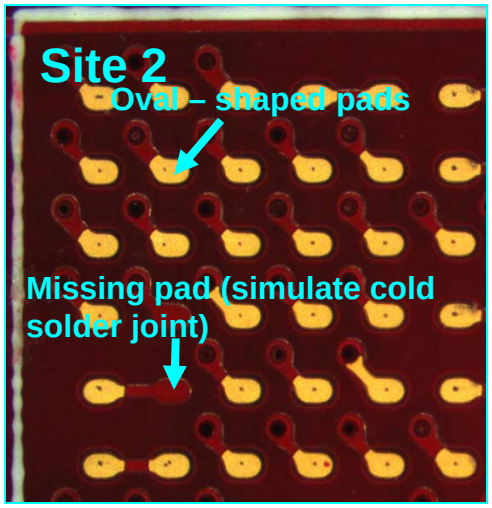



Completed board assembly

(a)

## Intentionally designed solder defects




Magnified view of sites 1 and 2 showing the intentional defects

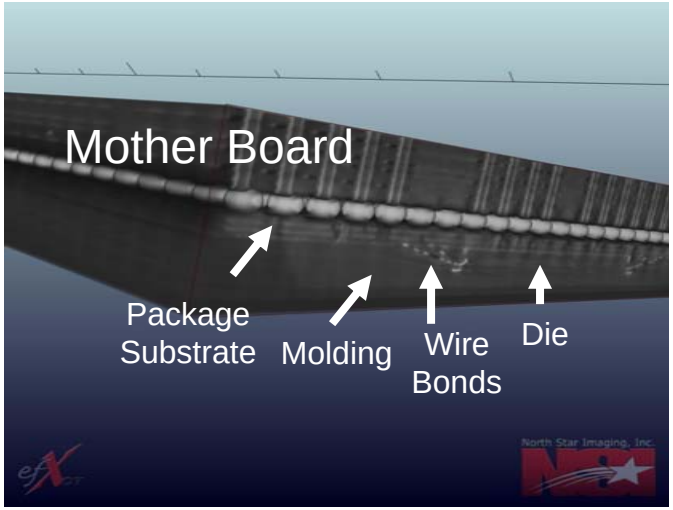
(b)

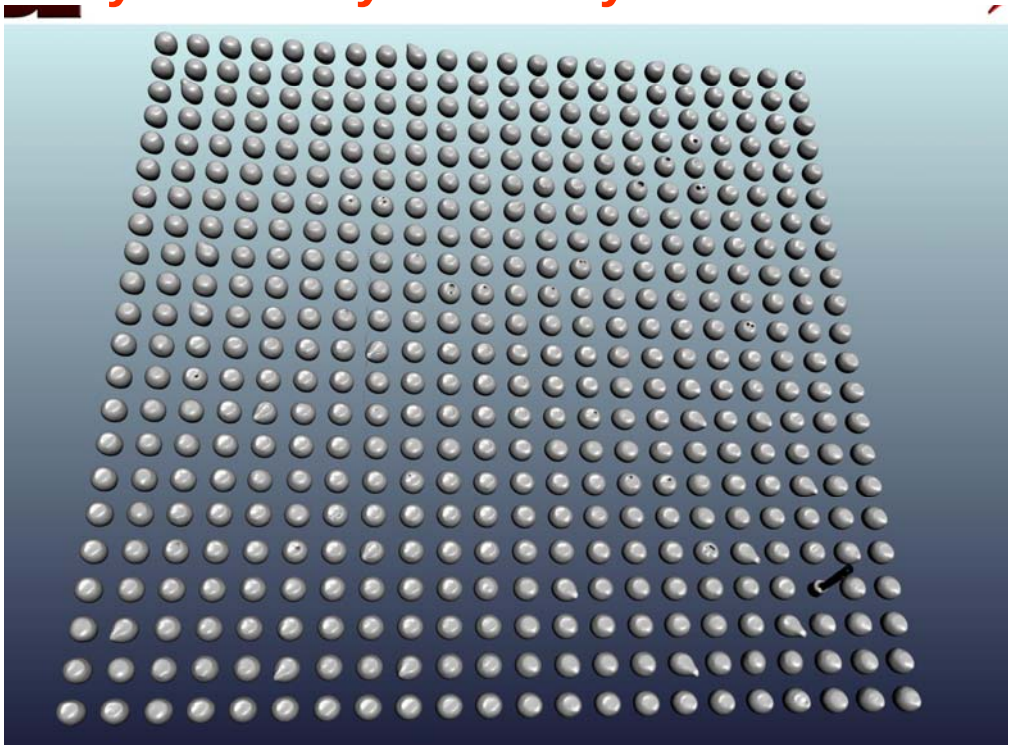
Sandia National Laboratories

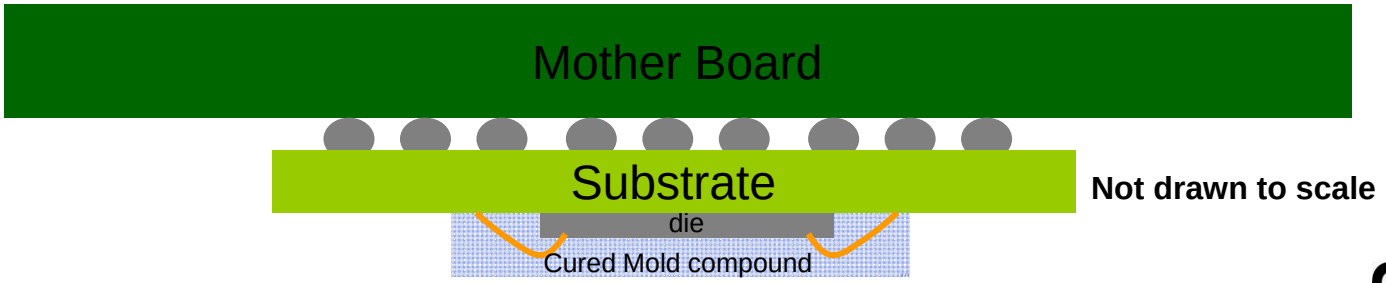
# 3D X-ray Image

## 484 I/Os COTS PBGA assembled on a Mother Board

**All intentional anomalies and defects introduced in boards were picked up as solder defects by 3D X-Ray CT Analysis.**



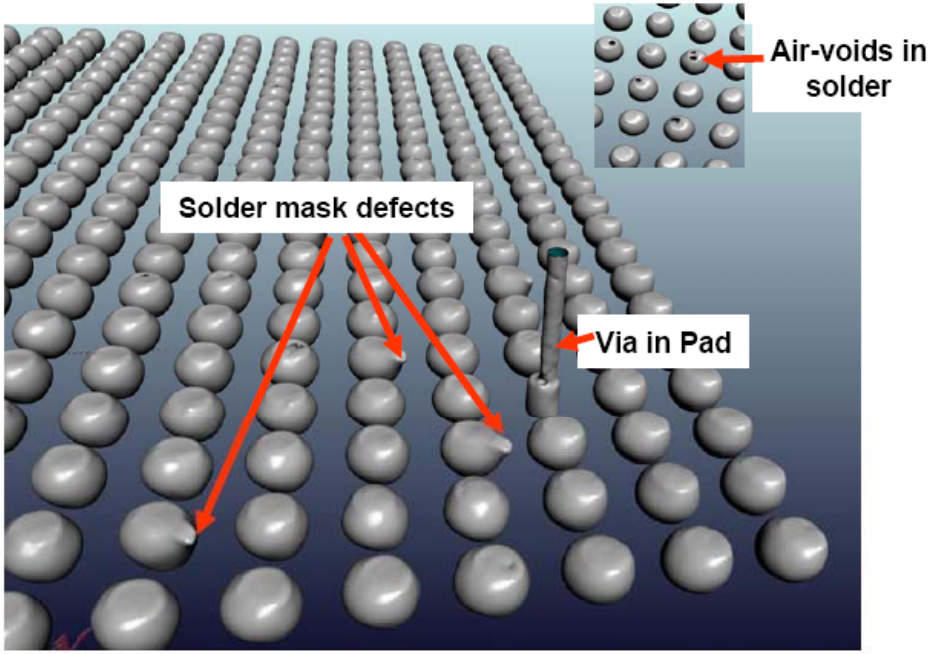



**Not drawn to scale**

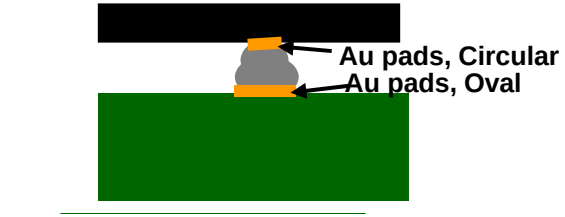
Sandia National Laboratories

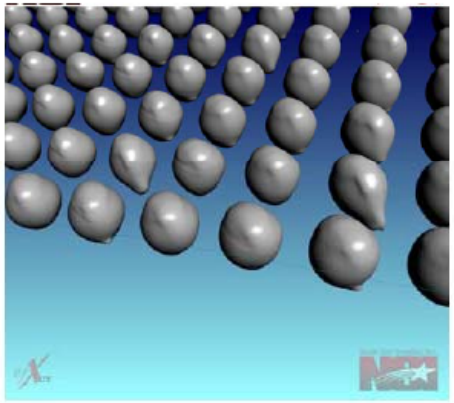
# 3D X-ray Image

## Solder Defects/shapes in 3D X-Ray Analysis




(a)



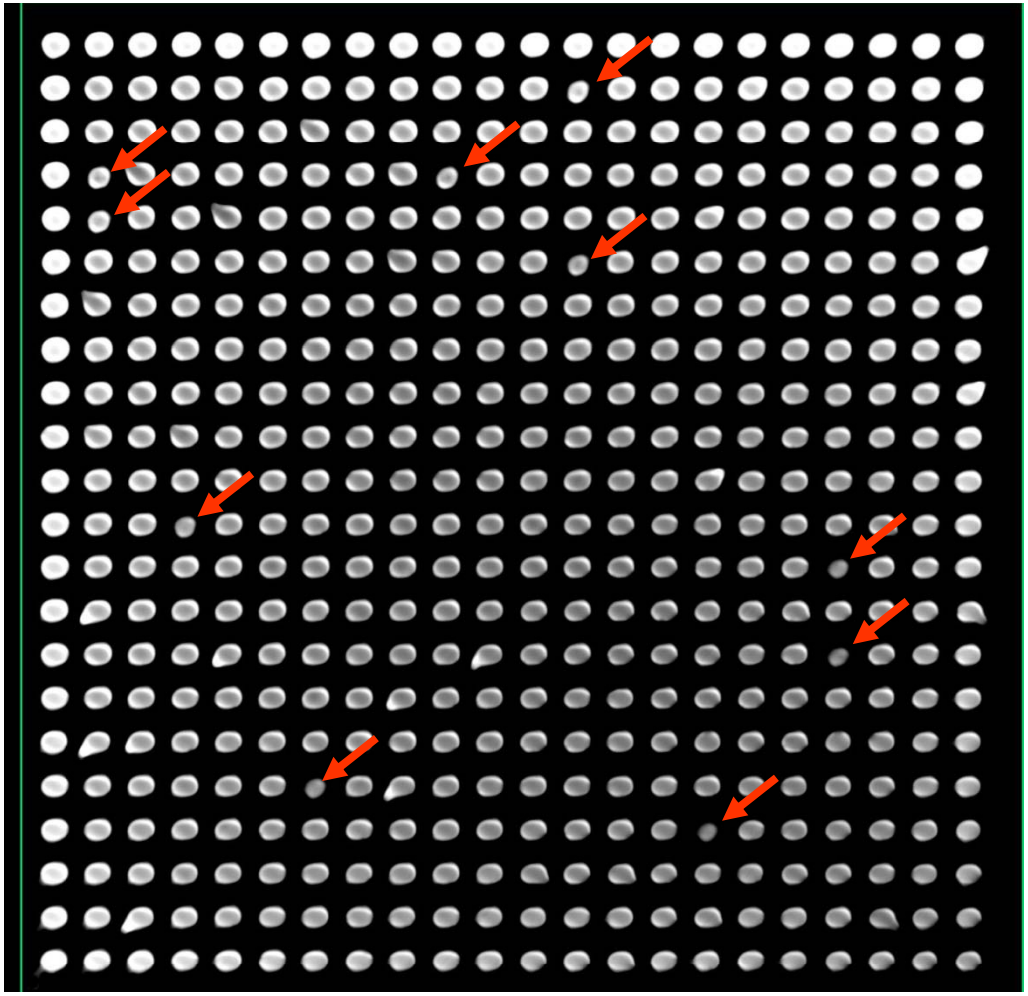



(b)

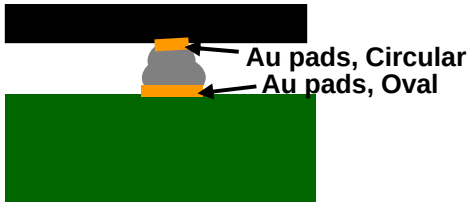
Sandia National Laboratories

# 3D X-ray Image

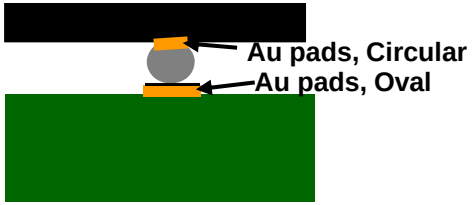
## No-contact solder joint (e.g. cold joint)



**“Good” Joint**



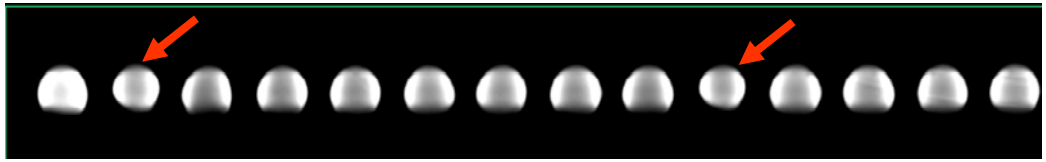

**No-Contact Joint**
**(cold solder Joint)**

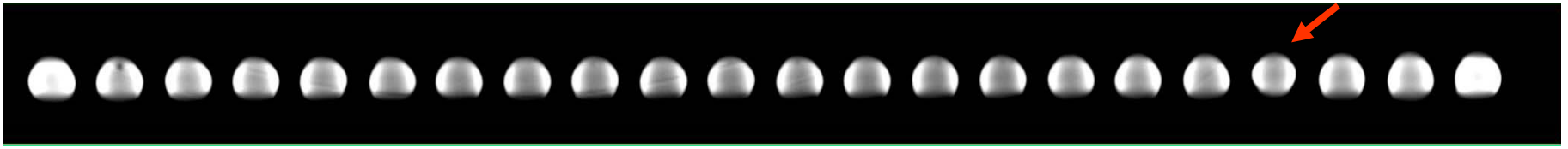


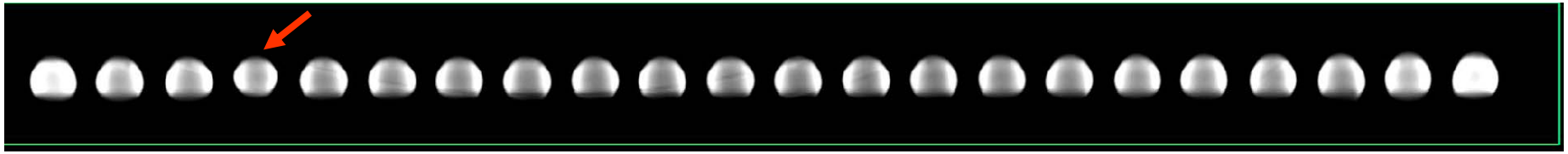

Sandia National Laboratories

# 3D X-Ray Image of solder Joint Rows

**No-Contact (e.g. cold solder joints) are pointed out.**







Sandia National Laboratories

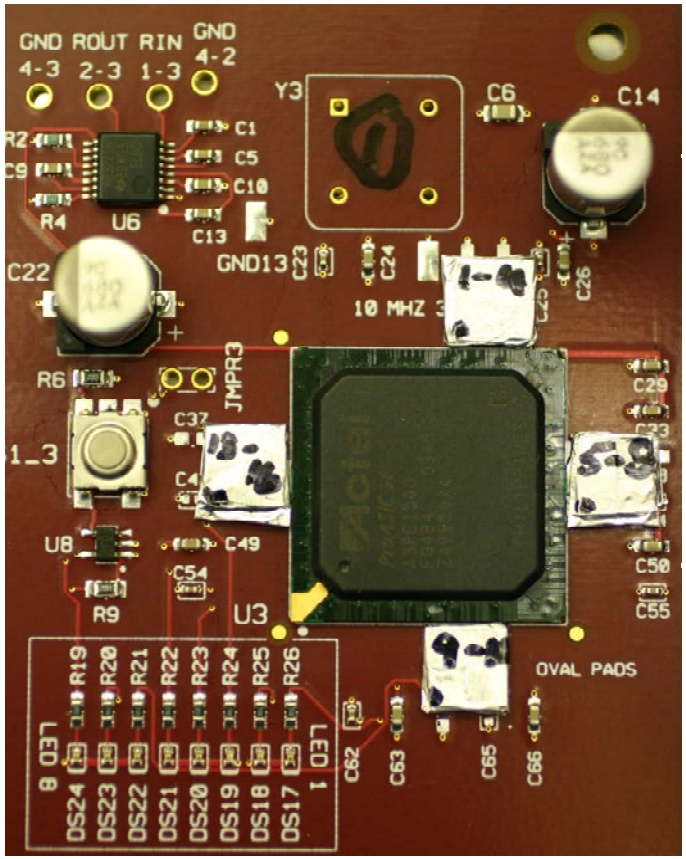
# Measurements of X-Ray Dosage Exposure

**Concern: X-Ray Radiation could affect the performance of ICs.**

**In 3D X-Ray CT Technique, the X-ray exposure is dependent on many parameters.**

1. Copper Filtering
2. Number of frames
3. Frame rates
4. Number of frames Averaged/frame
5. X-Ray source voltage

**We measured X-ray exposure using $CaF_2$ Sensors on four sides of the PBGA.**




Sandia National Laboratories

# X-Ray Dosage Data

**Effect of Copper Filtering and Number of frames on X-ray exposure.**

| | With Cu filter (Avg. Rads) | Without Cu Filter (Avg. Rads) |
|---|---|---|
| 1440 Frames Time ~ 40 mins | 1366 (images excellent) | 5738 (images excellent) |
| 720 Frames Time ~ 20 mins | 683 (images excellent) | 2869 (images excellent) |
| 360 Frames Time ~10 min | 342 | 1434 |
| Adjusting Other Instrument Parameters | 151 | |

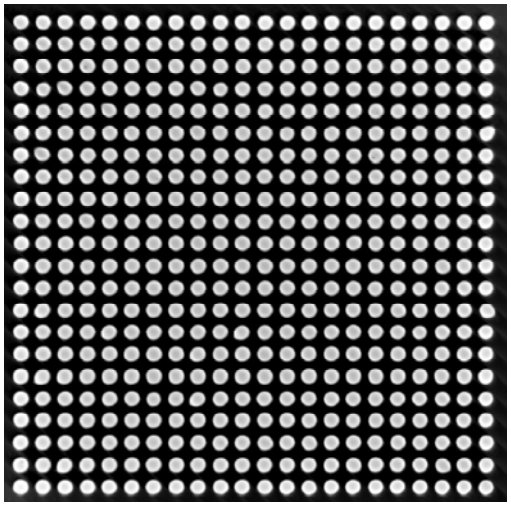
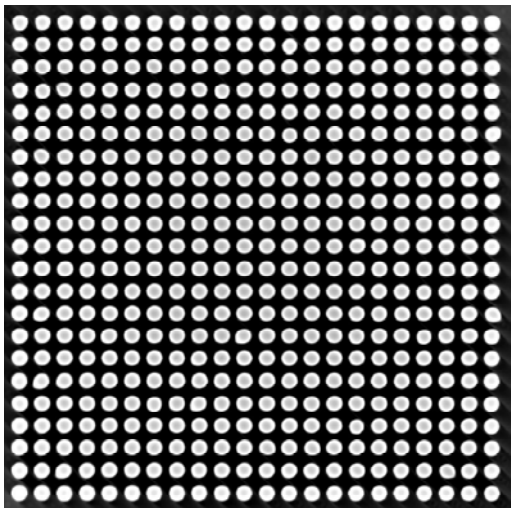
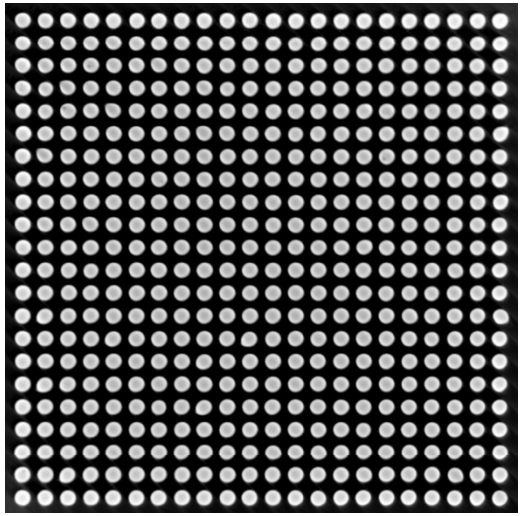
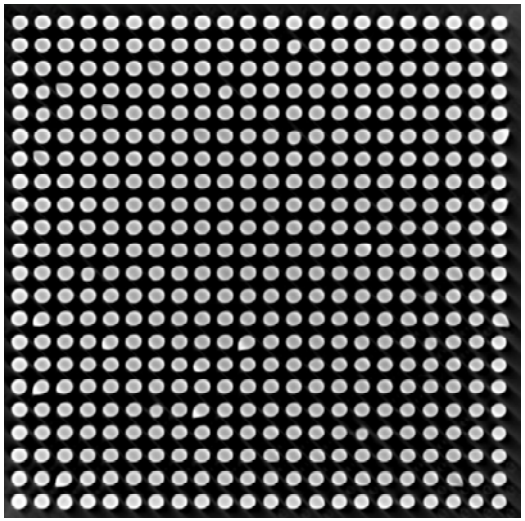
Sandia National Laboratories

# Additional X-Ray Dosage Data

| | Conditions/settings | Exposure Time (Min) | Radiation (Rads) | Image quality |
|---|---|---|---|---|
| 2 | 1440 Frames, (avg. of 3)<br>2 frames/sec, 210 KV, cu Filter, step scan | 70 min (incl. set-up time) | 2050 | Good |
| 3a. | 1440 Frames, (avg. of 2)<br>2 frames/sec, 210 KV, cu Filter, continuous | 23 | 548 | Good |
| b | 720 Frames (computed) | 12 | 274 | Good |
| 4a | 1440 Frames, (avg. of 1)<br>2 frames/sec, 210 KV, cu Filter, continuous | 10 | 301 | Good |
| b | 720 Frames (computed) | 5 | 151 | Good |

Sandia National Laboratories

# Image Quality

| | With Cu filter | Without Cu filter |
|---|---|---|
| **1440 Image Frames** |  |  |
| **720 Image Frames** |  |  |

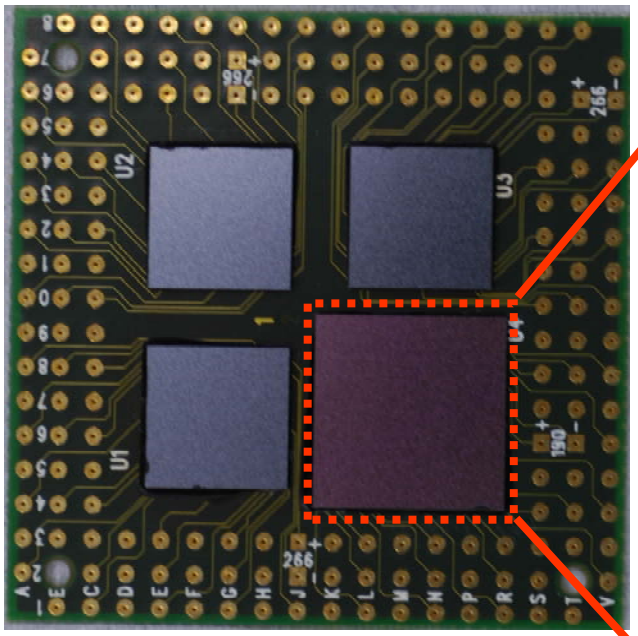
Time/frame, Frame Avg. , X-ray source = constant

Sandia National Laboratories

# WLCSP Flip Chip area Array Joints

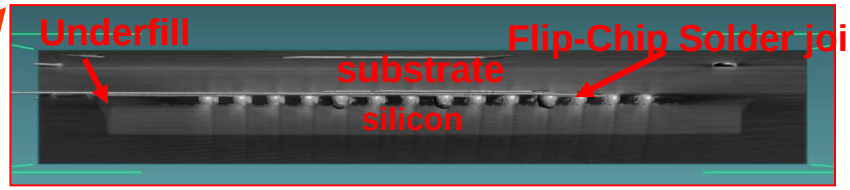
## Test vehicle

**4 Wafer-level Chip-scale-packages (WLCSP) Flip-chipped on a Polyimide-Quartz board.**

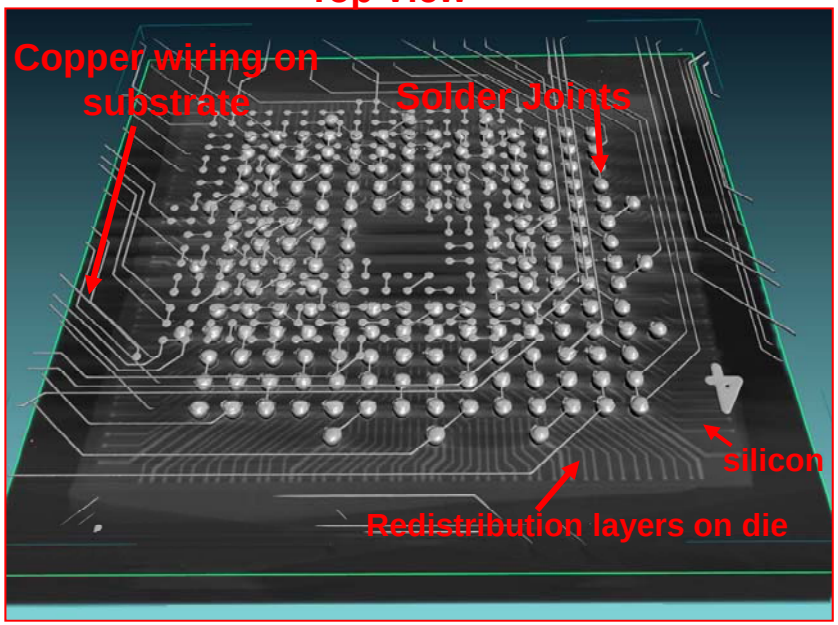



## 3D XRay Images

**Side View**

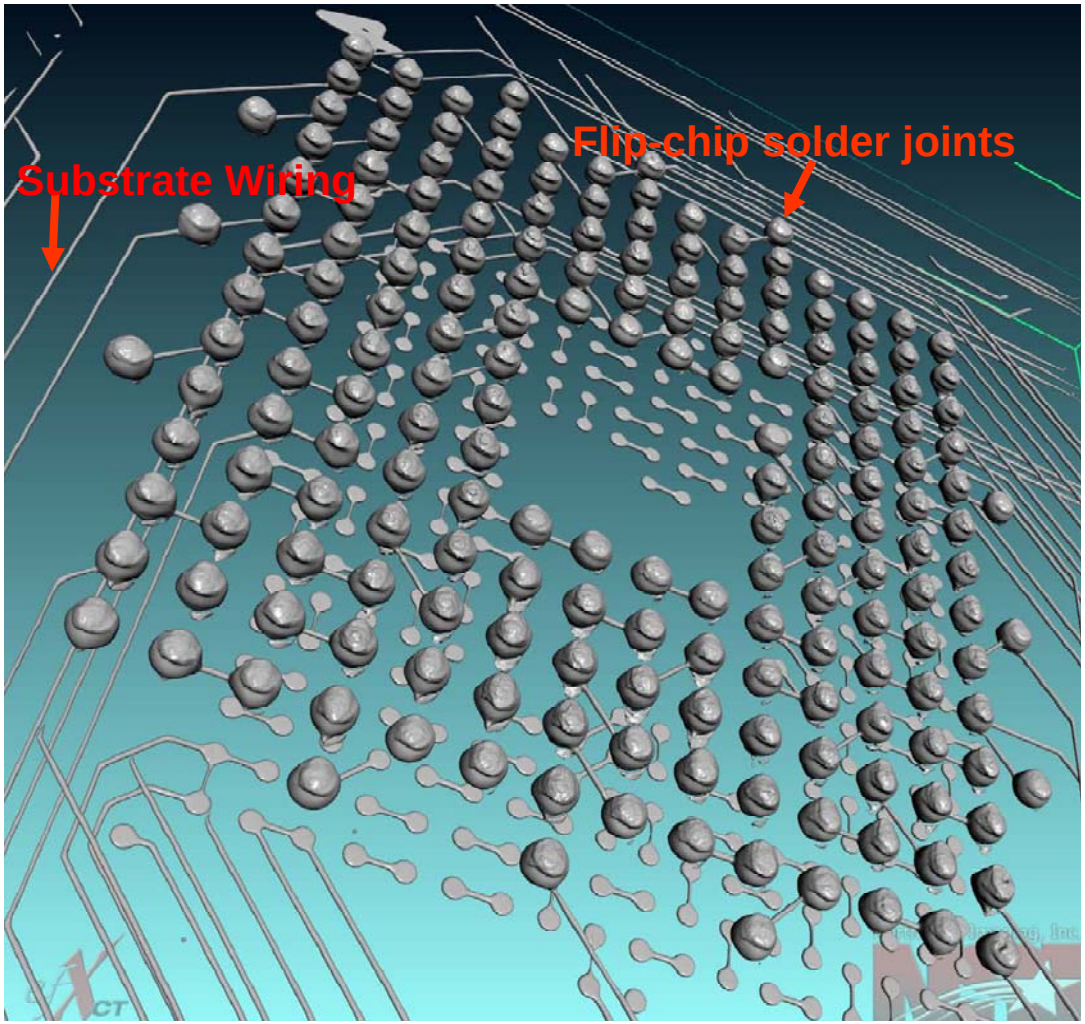



**Top View**




Sandia National Laboratories

# 3D XRay Image of Flip-Chip joints

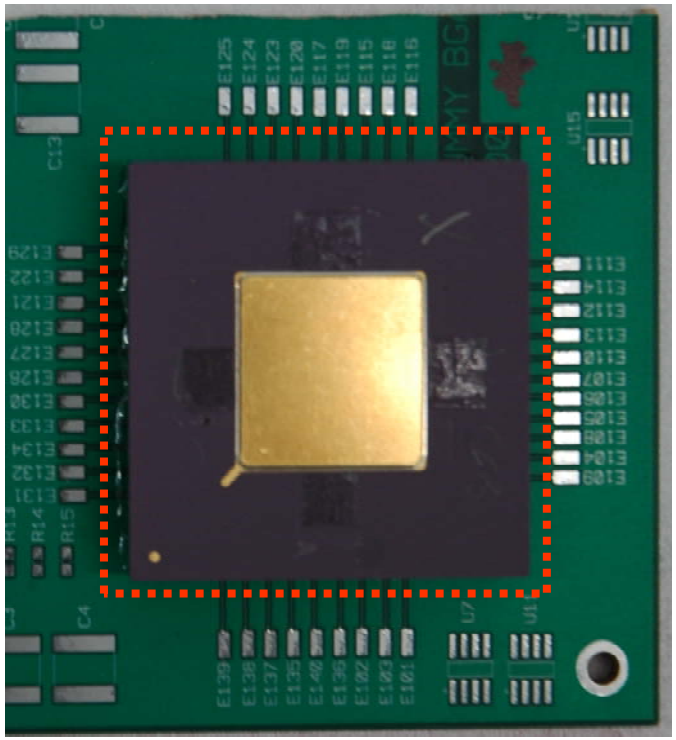



Sandia National Laboratories

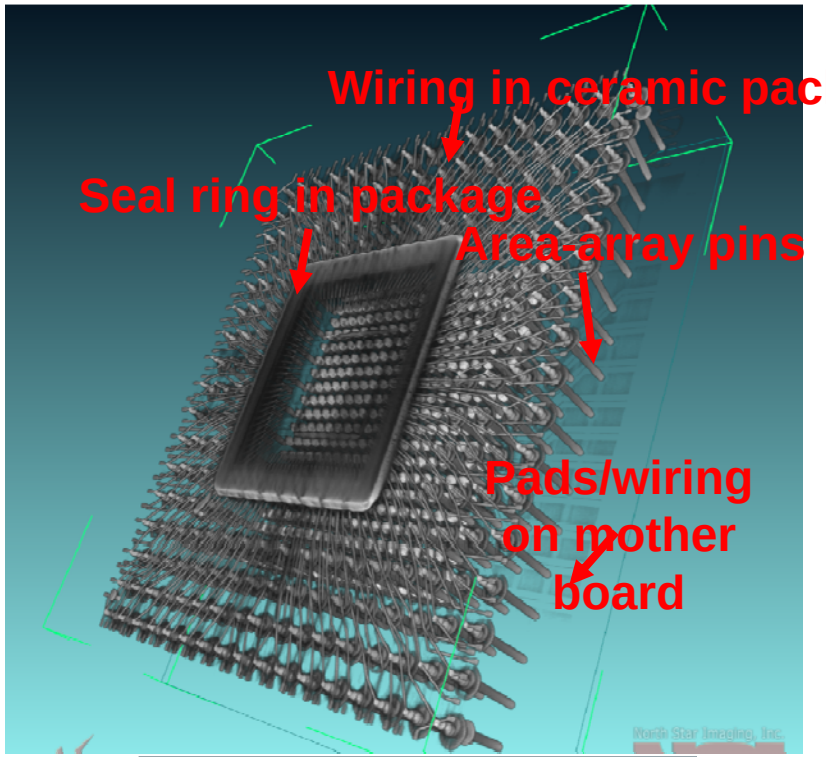
# Ceramic Pin Grid Array Joints

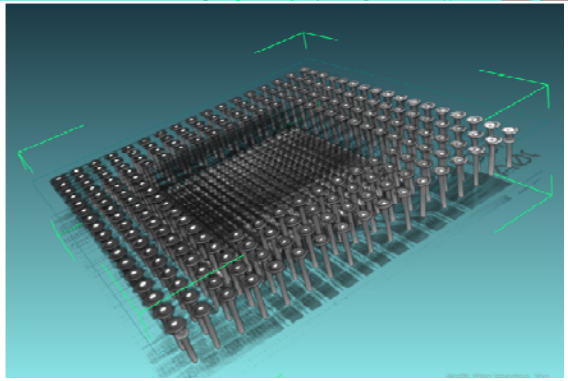
## Test vehicle

**Ceramic Pin Grid array Package Glued to Poyimide Glass Board.**



## 3D XRay Image



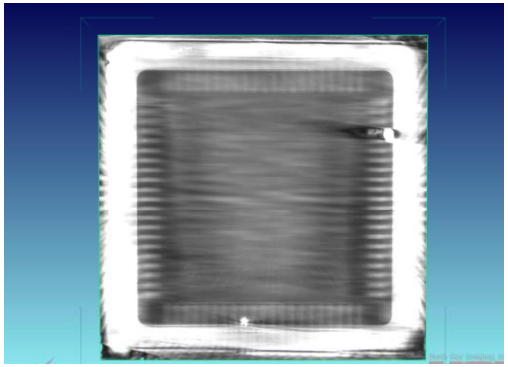
Sandia National Laboratories

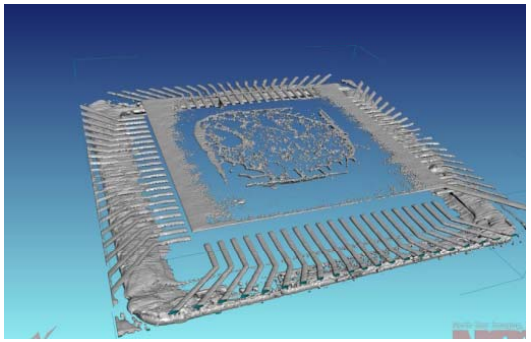
# Gold Vs Aluminum Wire Bonds

Aluminum, being a Low Z and low density metal, cannot be detected in X-Ray like Gold wire-bonds.

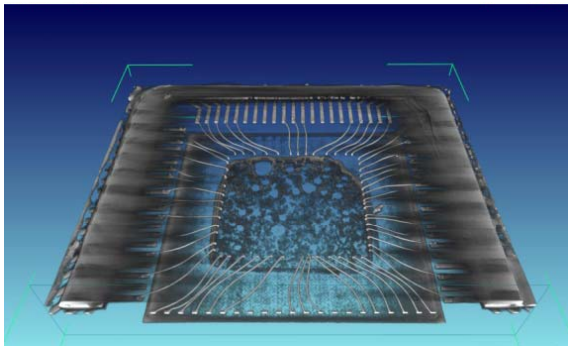
Comparison of Gold wirebond and Aluminum wire-bond inspection in 3D Xray is shown below.

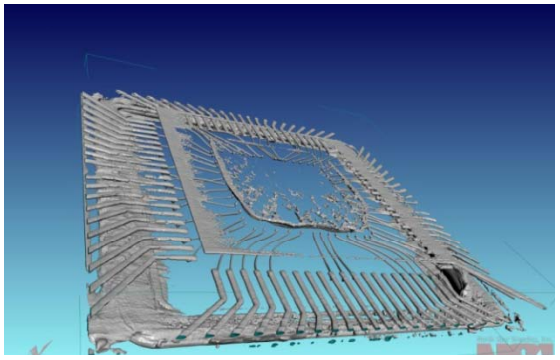
**Ceramic package with Aluminum Wire Bonds**





**Ceramic package with Gold Wire Bonds**





Sandia National Laboratories

# Conclusions

- **3D X-Ray Analysis is a viable technique for inspection and failure analysis of solder joints in area array package assemblies.**
- **The technique works with different area array technologies as was demonstrated in this study:**
  - **Plastic Ball Grid Array**
  - **Flip-Chip joints**
  - **Ceramic Pin Grid Array**
- **X-Ray exposure Dosage in preliminary work is < 700 Rads. Potentially can be significantly reduced further by optimizing the technique parameters.**

Sandia National Laboratories