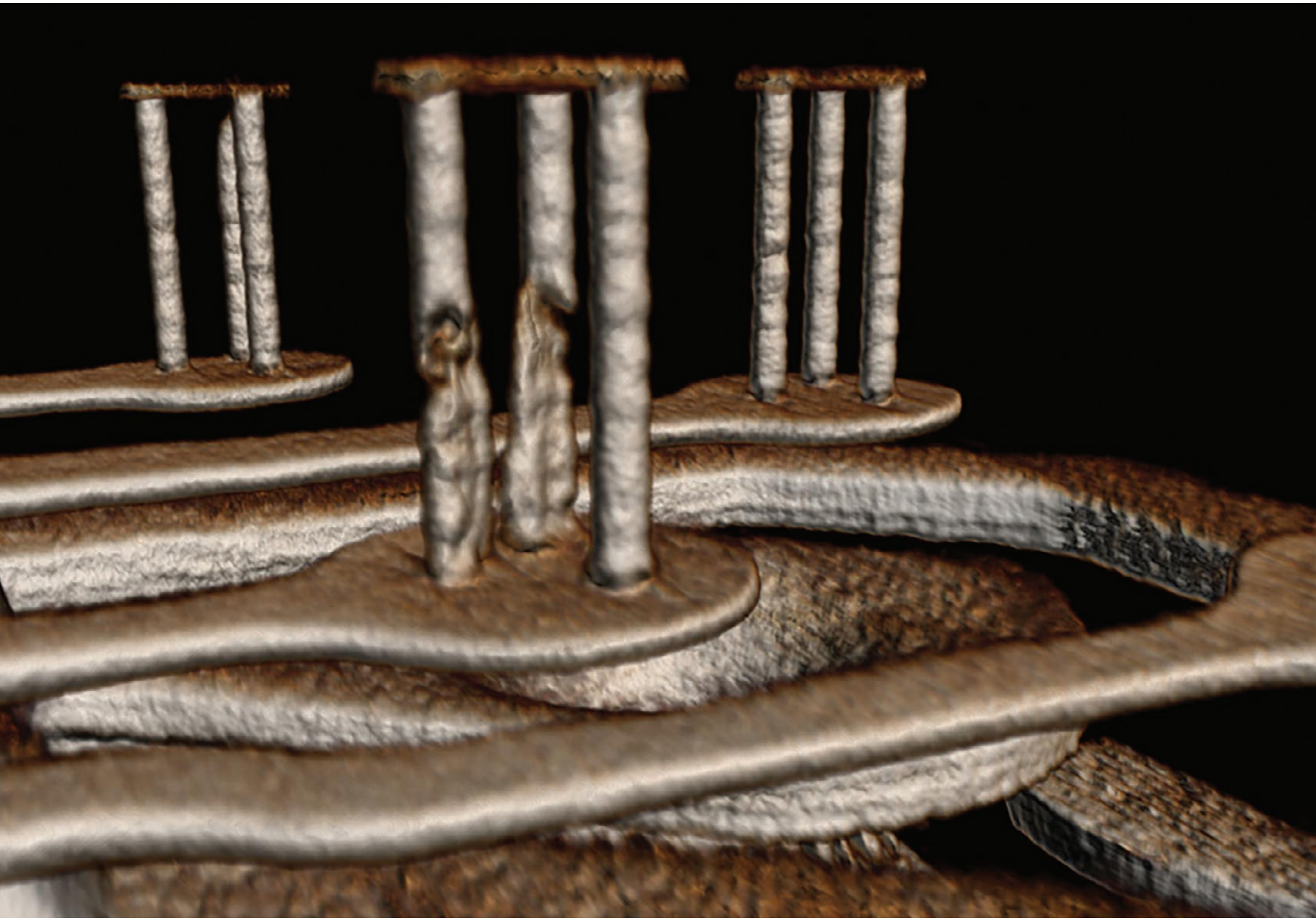

Package Optimization and Failure Analysis
with 3D X-ray Microscopy

We make it visible.

Package Optimization and Failure Analysis
with 3D X-ray Microscopy

Author: *Carl Zeiss X-ray Microscopy*
Pleasanton, California

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As the semiconductor industry approaches the limits of CMOS scaling, traditional planar methods can no longer keep pace with Moore's Law. To continue innovating ever-smaller, ever-faster devices with low power requirements, the industry has turned to package innovation through 3D stacking of chips and novel packaging formats, a trend labeled "More than Moore."

This focus on 3D system integration and the introduction of new materials such as lead-free solder and low-K dielectrics have combined to produce new manufacturing challenges and increased failure risks. Furthermore, since the physical location of failures will likely be buried within the 3D structure, new 3D characterization capability is required to isolate and determine the root cause. ZEISS Xradia 3D X-ray microscopes (XRM) provide an effective solution to the critical need for non-destructive sub-micron imaging of defects buried within intact 3D packages.

Developments driving new requirements for characterization in the semiconductor industry include the following.

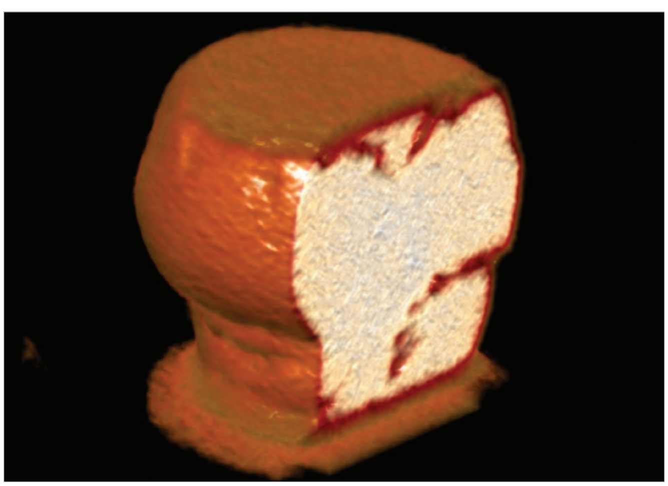

Figure 1: Cracking in solder bump (subset of image of intact package) – Xradia Versa

Complex Packaging with Finer Bumps and Smaller Features

- Trend drives demand for higher resolution imaging techniques

- Wire bonds and solder bumps continue to decrease in size. As features shrink, formerly benign small defects begin to significantly impact reliability. At the same time, requirements to use lead-free solder have increased delamination and crack risk.

Higher Number of interfaces

- Non-destructive techniques capable of visualizing buried features in stacks with many layers are now required

- Interfaces in 3D packages, either in the interposer and fan-out layers, or in number of dice within a stack, have grown in number, which obscures the visibility of defects below the surface for conventional non-destructive techniques

Through Silicon Vias (TSV)

- TSV vertically connect chips or devices and are considered one of the key enabling technologies for 3D architectures. Fabrication is not yet mature for TSV and significant defects can occur, especially in developing smaller TSV (1-5 µm). Such failures include voids during metallization, or die cracking induced by the large thermal expansion mismatch between silicon and conducting via material, or as reliability failures during stress testing.

The new package geometries created by these developments provide significant challenges for traditional analysis techniques such as electrical, acoustic, terahertz, and confocal imaging. Furthermore, conventional cross-sectioning techniques are destructive and provide limited sampling volume.

ZEISS Xradia Versa and Xradia Ultra families of 3D X-ray microscopes provide the highest resolution and contrast capabilities for computed tomography, beyond traditional micro-CT. These instruments solve emerging imaging challenges for next generation semiconductor packaging. Both system families also enable *in situ* studies, which allow progressive testing and observation of failure evolution in devices under relevant environments like heating, cooling, electrical load, and mechanical load.

ZEISS Xradia Versa provide failure analysts with non-destructive imaging capabilities at submicron resolution for large intact packages without de-packaging, which could otherwise alter defects. This solution has proven to have valuable applications in process optimization and failure analysis, from identifying cracks in solder balls to delamination and voids in current package TSV.

ZEISS Xradia Ultra offer the highest resolution of all laboratory 3D X-ray inspection tools, reaching 20 nm pixel (50 nm spatial) resolution for imaging that supports advanced device development, such as imaging multiple cutting-edge sub-10 µm TSV to provide high value statistics for new TSV production processes. Xradia Ultra also enable automatic quantification of measurements such as TSV void volume.

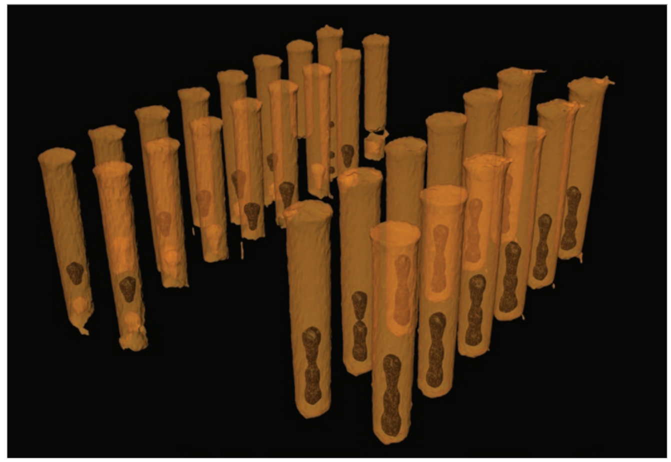

Figure 2: Voids in through silicon vias – Xradia Ultra

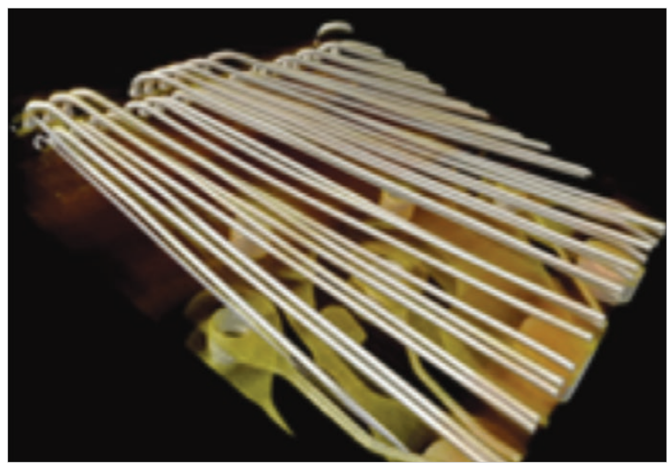

Figure 3: Wire bond, shorts open – Xradia Versa

Step-by-Step: A New Failure Analysis Workflow

The high resolution and large working distance of ZEISS Xradia Versa promote a rapid novel workflow for non-destructive failure analysis. Evolving to this process from traditional techniques will greatly enhance the precision and speed of the failure analysis process.

1. Electrical Testing *(e.g., TDR)*
   A conventional low-resolution non-destructive technique (NDT) such as electrical TDR or thermal, acoustic, or magnetometry microscopy is used to identify the approximate region within the package that contains the failure.

2. Xradia Versa Virtual Cross Section *(non-destructive)*
   Using the output of the previous step, ZEISS Xradia Versa can virtually zoom in on the region of interest within an intact package to produce high resolution, submicron images for 3D structural information, providing fine defect localization and visualization for classification. The resolution of 3D XRMs can additionally provide insight into emerging defects that have not yet degraded enough to impact performance and cannot be detected through electrical testing.

3. Progressive Characterization *(e.g. subsequent electrical,* in situ *or* ex situ *imaging on Xradia Versa, or thermal stressing)*
   Because the sample is not destroyed by Xradia Versa imaging, further testing can be done, which can:
   - Resolve any inconsistencies in defect conclusions between the low-resolution non-destructive results and Xradia Versa results (if they exist)
   - Perform *in situ* experiments with Xradia Versa to quantitatively measure the impact of stress conditions such as current or temperature on the defect and determine the failure mechanism
   - Enable further imaging with other NDT methods

4. FIB-SEM or other Cross Sectioning Techniques *(destructive)*
   Downstream, last-step electron microscopy techniques, such as mechanical cross-sectioning or focused ion beam tomography (FIB-SEM), use high-resolution fault isolation information provided by Xradia Versa to navigate to the defects and characterize them at sub-nanometer resolution. Without 3D localization information from Xradia Versa, this failure characterization technique can be time-consuming and risks destroying the defect before imaging during the ablation or cutting process.

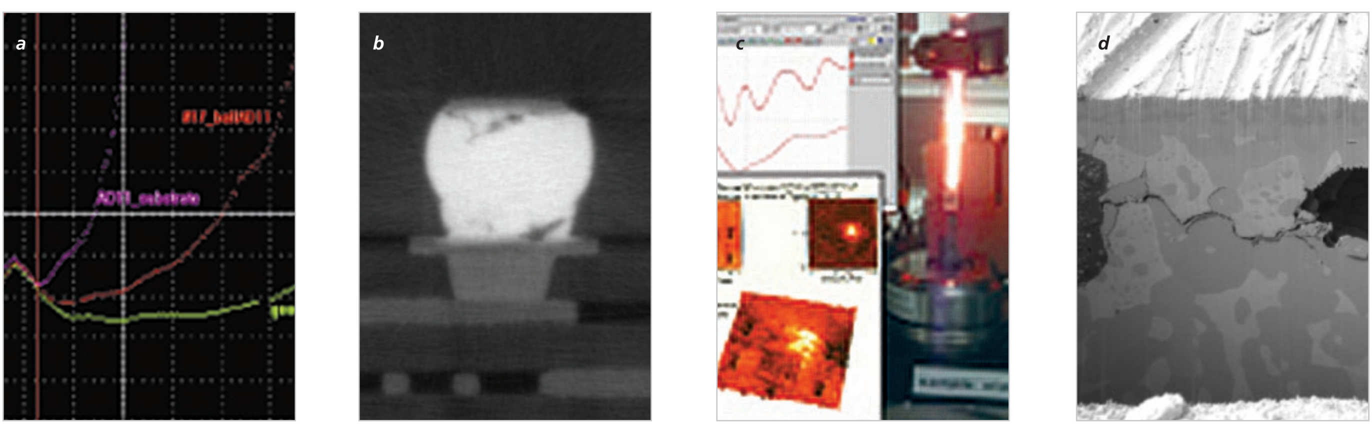

Figure 4: Images showing a new failure analysis workflow ***[a]*** *Electrical testing* ***[b]*** *Virtual cross section using Xradia Versa* ***[c]*** *Progressive characterization* ***[d]*** *destructive cross section*

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Carl Zeiss Microscopy GmbH
07745 Jena, Germany
microscopy@zeiss.com
www.zeiss.com/microscopy

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