# A Brief Comparison of Computed Laminography versus 3D X-ray Microscopy

## for Electronics Failure Analysis

Seeing beyond

# A Brief Comparison of Computed Laminography versus 3D X-ray Microscopy
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X-ray techniques have been crucial imaging and analysis tools in semiconductor and electronics failure analysis because it is not required to cut a device open to visualize internal structures and defects. The efficacy and efficiency of defect root cause determination strongly depend on the data fidelity and image resolution on faulty regions. In this paper, we will describe two distinctive X-ray imaging methods – computed laminography (CL) and X-ray microscopy (XRM). We will provide a brief comparison of several semiconductor package examples analyzed by these two X-ray techniques.

### Computed Laminography

3D computed tomography (CT) has become the preferred technique for non-destructive failure analysis over 2D X-ray imaging techniques because it provides rich volumetric information on a sample. In a typical circular CT system, a sample rotates by 180 (±fan angle) or 360 degrees, and a set of projection images are acquired with equal angular intervals. These 2D projections are mathematically reconstructed to 3D data. Because each projection carries specific X-ray absorption information at an angle, it is generally required to acquire projections covering the range of more than 180 degrees for adequate reconstruction. However, the CT technique has two major limits – image resolution and photon starvation – when imaging a flat, dense sample. Firstly, as X-ray penetrates the long-axis of a planar device and long-view projections are acquired, image resolution degrades dramatically due to relatively large source-to-sample distance. Secondly, increased beam hardening and photon starvation occur in long-axis view (long-view) projections due to beam paths being significantly longer. Consequently, reconstructed images are prone to various under-sampling and noise artifacts.

An alternative approach, computed laminography (CL) has been proposed to avoid long-view projections for imaging high-aspect-ratio samples [1-2]. Figure 1a shows the two instrumentation setups used to acquire CL images. In the first setup shown in the blue scheme, a rotary detector is used to collect a series of projections over an angular range, typically 140 degrees.

This setup allows an object to be placed close to the source, possibly achieving high geometric magnifications, and avoiding the photon starvation problem because no long-view projection is acquired. In the second CL setup in the orange scheme, the sample is tilted at ψ degree, rotates by 360 degrees, and a stationary detector collects projection images with equal angular intervals.

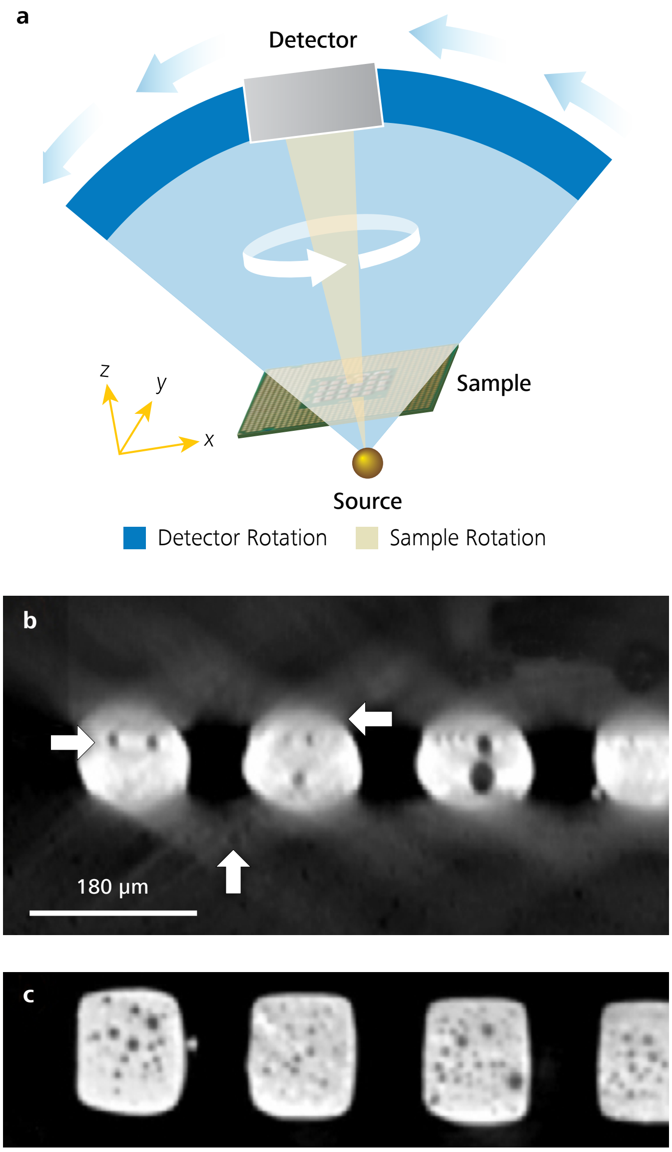

***Figure 1*** *a) Schematics of a 2.5D computed laminography setup, b) reconstructed XZ slice showed the distorted structures and voids at the solder interfaces. The streak artifacts appeared in the low-absorbing areas. c) reconstructed planar view XY.*

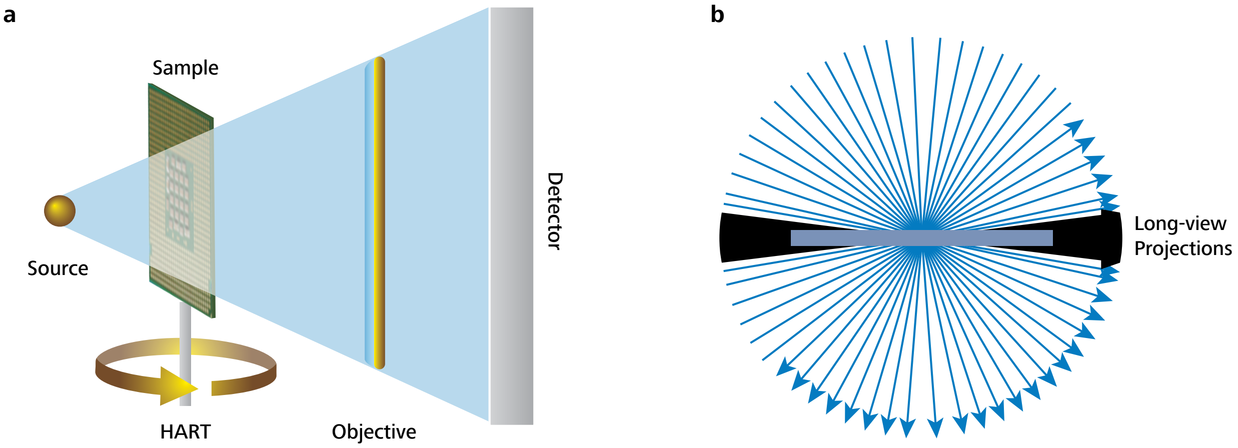

*Figure 2* a) ZEISS X-ray microscope setup with the optical objectives allows high-resolution full angular coverage tomographic scans for flat semiconductor packages, and b) high-aspect-ratio tomography (HART) automates scan angular density to minimize effects of photon starvation.

Because CL setups avoid acquiring long-view projections, critical sample information is lost. Figure 1b-c shows the results of such an example on a flip chip package acquired by using a CL system in European Synchrotron Research Facility [1]. While the planar view in Figure 1c looks artifact free, it is obvious that the voids at the solder interface were distorted in the cross-sectional slice XZ (Figure 1b). The misrepresentation of the defect may mislead the failure analyst to draw an inaccurate conclusion about the failure root cause. In addition, the streak artifacts originating from the high-absorbing solders were apparent in the low-absorbing regions of the slice. We can also observe this artifacts-prone reconstruction in a lab-based CL system [2].

## 3D X-ray Microscopy

ZEISS X-ray microscope (XRM) substantially mitigates the restraints in photon starvation and resolution when a planar sample, e.g., a semiconductor package, is imaged with full angular coverage tomographies. Firstly, the optical objective design offers the additional magnifying mechanism to the existing geometric magnification, capable of maintaining high resolution even for large and flat objects (Figure 2a). This setup allows acquisition of full angular coverage (at least 180 ±fan angle) projections, including the crucial long-view projections. It is possible to reconstruct true 3D structures with high-quality projections around the long axis of a sample. Secondly, high-aspect-ratio tomography (HART) automatically optimizes the angular density of a scan. HART substantially mitigates the photon starvation dilemma because it scans long-view projections with smaller angular intervals,effectively increasing X-ray view sampling at the angles near the sample long-axis.

Figure 3 shows a comparative study of the CL technique with XRM for imaging a 50x50 mm interposer semiconductor package which is thermally cycled according a JEDEC standard. The cross-sectional view on the left revealed true structures of metal and C4 bumps with voids and cracks, reconstructed on a high-resolution full angular coverage tomography.

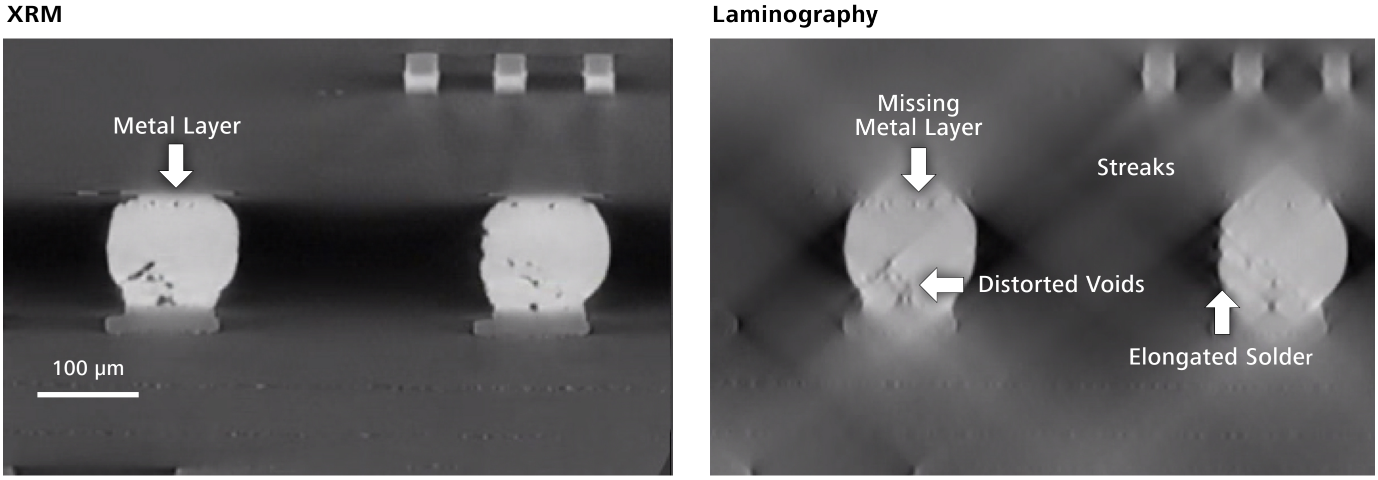

*Figure 3* Image quality comparison of XRM versus computed laminography. left) true 3D reconstruction by XRM for scanning a semiconductor package at 0.7 µm/vox, and right) the CL reconstruction shows the artifacts-prone slice with missing metal layer, distorted voids/solder pad, and elongated solder ball due to the missing long-view projections. The laminography result on the right was acquired by an in-house instrumentation setup.

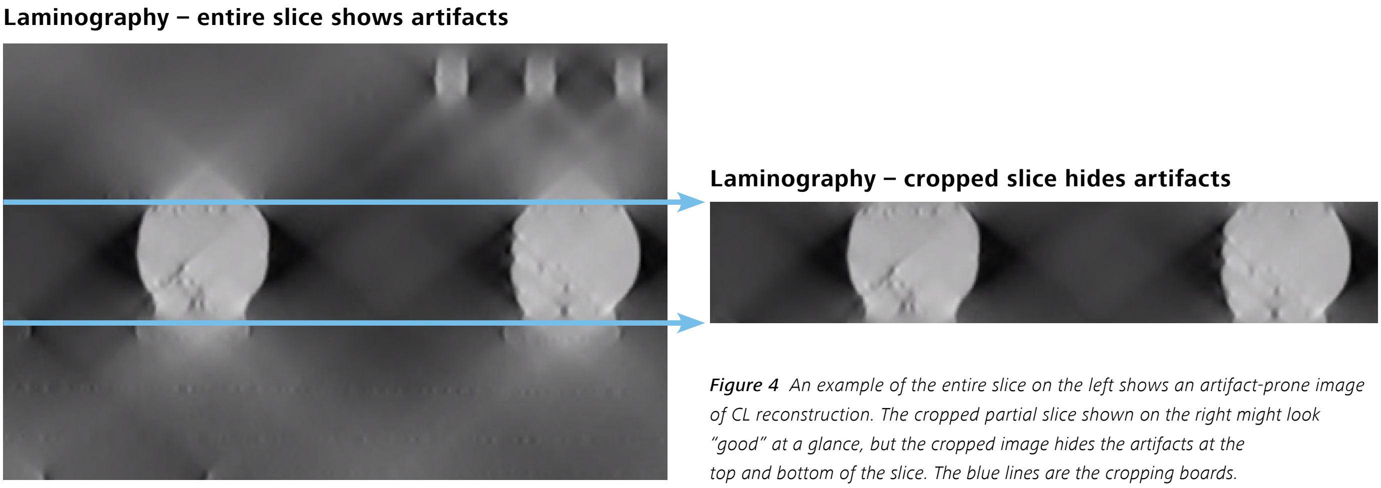

*Figure 4* An example of the entire slice on the left shows an artifact-prone image of CL reconstruction. The cropped partial slice shown on the right might look "good" at a glance, but the cropped image hides the artifacts at the top and bottom of the slice. The blue lines are the cropping boards.

By contrast, the corresponding CL slice on the right resulted in an artifacts-prone image due to the missing long-view projections. The low data fidelity is clearly shown with the missing metal layer, distorted voids, and elongated bumps in addition to the streak artifacts (Figure 4 left), although the cropped partial slice could still look "good" because it hides the artifacts at the top and bottom of the slice (Figure 4 right).

## Conclusion

X-ray failure analysis in the semiconductor industry requires high data fidelity and image resolution to pinpoint and analyze faulty regions effectively. The reconstruction accuracy of embedded defects is paramount for the success of physical failure analysis. With the increasing complexity of modern electronics packages, it is more challenging for X-ray systems to provide true 3D reconstruction solutions without losing data fidelity and resolution. Incomplete reconstruction by the computed laminography (CL) technique may result in distorted structures in artifacts-prone data due to the missing long-view projections carrying crucial sample information. While the acquisition geometry of the CL method may avoid beam hardening artifacts, these artifacts are merely replaced by limited tomography artifacts. Perhaps beam hardening artifacts are better addressed by other methods (empirical polynomial, Monte Carlo, Machine Learning, etc.), rather than introducing a method with the more severe problem of missing data. Again, it is important to differentiate between 2.5D and 3D spatial resolution, as only full angular coverage computed tomography (XRM in this case) can deliver isotropic 3D spatial resolution by having complete information for the tomographic image reconstruction.

### Reference

[1] L. Helfen et al., Appl. Phys. Lett. 86, 071915 (2005) https://www.esrf.fr/UsersAndScience/Publications/Highlights/2005/Imaging/XIO3

[2] S. L. Fisher, D. Holmes, J. S. Jorgensen, P. Gajjar, J. Behnsen, W. R. B. Lionheart, P. J. Withers, "Laminography in the lab: Imaging planar objects using a conventional x-ray CT scanner," 2019 Meas. Sci. Technol. 30 035401

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