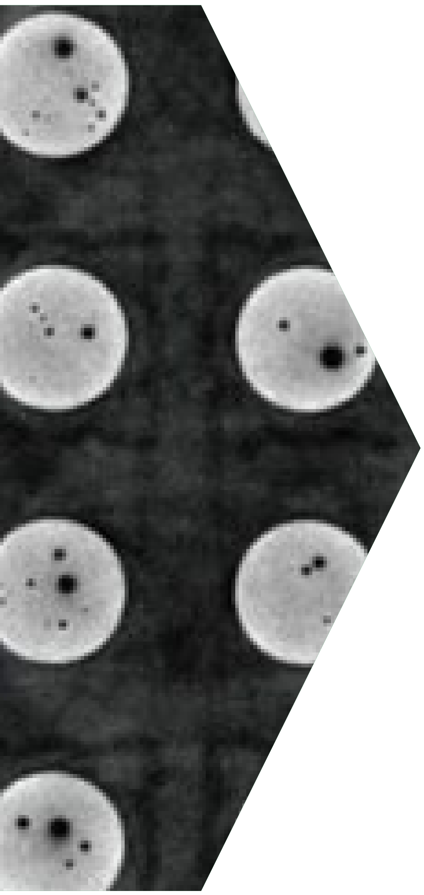

Rapid 3D X-ray of Intact Graphics Card PCB at 1µm

Non-destructive 3D X-ray has become the gold standard approach for semiconductor failure analysis (FA). Imaging large samples at sub-micron (<1µm) resolutions and at reasonable throughput is a major challenge for all conventional 3D x-ray microscopes. Sigray's patent-pending Apex XCT system removes this barrier, achieving <15 minute scans of large samples such as PCBs and wafers at spatial resolutions down to 0.5 µm.

This white paper will review semiconductor applications of the Apex XCT

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Rapid 3D X-ray of Intact Graphics Card PCB at 1µm

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Background:

3D X-ray through micro computed tomography (microCT, also called 3D X-ray Microscopy) has soared in popularity as a failure analysis approach in recent years, due to its inherent advantages that include:

- high-penetrating power of X-rays for identifying buried defects,
- non-destructive nature allowing follow-on analysis, and
- the ability to identify submicron defects in three dimensions.

The approach of microCT has advanced and matured considerably since the early 2000s but is approaching its physics-bound performance limits. A well-known limitation is that big samples such as large packages (e.g., PCBs) or wafers result in exponentially longer acquisition times for high resolution images due to the inverse square law. Such samples are particularly difficult when the regions of interest are located at the sample's center. Furthermore, tomographies of these samples can suffer from significant imaging artifacts (e.g., beam hardening, streaking, curtaining, etc.).

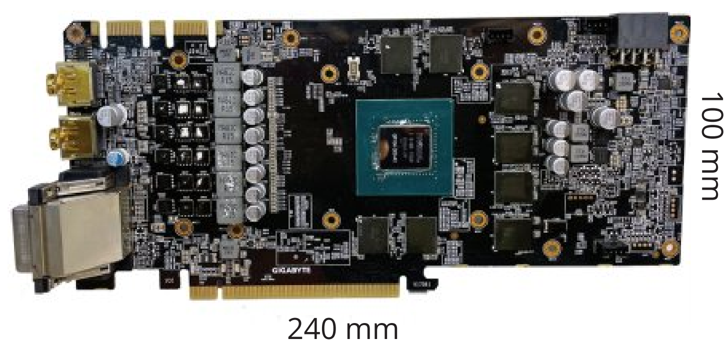

Figure 1: *Graphic Proccessing Unit (GPU) chip on a Printed Circuit Board (Gigabyte GeForce GTX 1070 Ti graphics card). Dimensions of the board are 9.5 x 4 inches (240 x 100 cm).*

Novel Approach: Sigray Apex XCT

Apex XCT is a breakthrough system that utilizes a novel, patent-pending approach that resolves the challenges such as long acquisition times and artifacts facing microCT. Unlike microCT, spatial resolutions of 0.5 µm can be quickly achieved in any region (including the center) on samples such as large packages, PCBs, and wafers. Furthermore, the Apex XCT approach removes or minimizes many of the artifacts present in microCT reconstructions of semiconductor samples.

In this applications note, we apply the Apex XCT to an intact Printed Circuit Board (PCB). Printed circuit boards (PCBs) are a common sample type in a typical semiconductor failure analysis laboratory and are production parts that ultimately end up directly in the hands of consumers. Identifying and mitigating defects provides critical insight behind failure mechanisms that can limit the device's success. However, **intact** PCBs generally are not possible using microCT, necessitating time-consuming destructive removal and isolation of suspected components.

Methods

Sample: Our applications lab received a GeForce 1070 Ti graphics card manufactured by Gigabyte for analysis. The PCB sample measured 24 cm x 10 cm and is a standard large-format PCI card taken directly from an operating workstation, as shown in Fig. 1. Regions of interest in the graphics processing unit (GPU) were scanned and the sample was kept intact, without sectioning out the GPU.

Acquisition Parameters:

We imaged the ROI at 8.6 μm and 1.0 μm voxel in two sequential tomographies on the Apex XCT:

Apex XCT Scan	Voxel (μm)	Accel. Voltage	Time
LFOV (Large FOV)	8.6	160 kVp	34 min
Hi-Res	1.0	140 kVp	50 min

Table 1: Parameters on Apex XCT. Scans were faster than 1 hour.

It is important to note that faster tomographies (down to single digit minutes) with good image quality for defect detection can be easily achieved on Apex XCT but for the purposes of this applications note, longer acquisition times were used to ensure print-quality images.

To baseline these results against the best performance achievable on the leading 3D X-ray approaches, two tomographies were acquired using a leading 3D X-ray Microscope.

Comparative Scan on XRM	Voxel (μm)	Accel. Voltage	Time
Flat panel	8.6	160 kVp	2.5 hours
4X Objective	1.0	160 kVp	16 hours

Because geometric constraints prevented the XRM from achieving <2.0 μm voxel using a flat panel, the high resolution scan was run using a high resolution (4X objective magnification lens-coupled) detector on the comparison tool.

Results and Discussion

GPUs have an intrinsically multi-scale architecture with a diverse set of multi-length scale features: BGAs, metallization layers, wire bonds, solder joints, TSVs, micro-bumps, etc. Figs. 2 and 3 show 3D renderings from the large FOV (8.6 μm) and high resolution (1.0 μm) scans respectively.

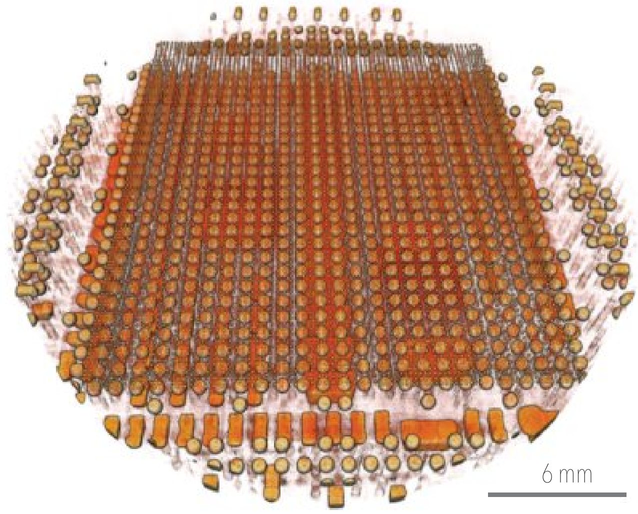

Figure 2: 3D Rendering of the GPU structure at 8.6 μm voxel (large FOV image). Acquired on Apex XCT at 160 kVp and 34 minutes.

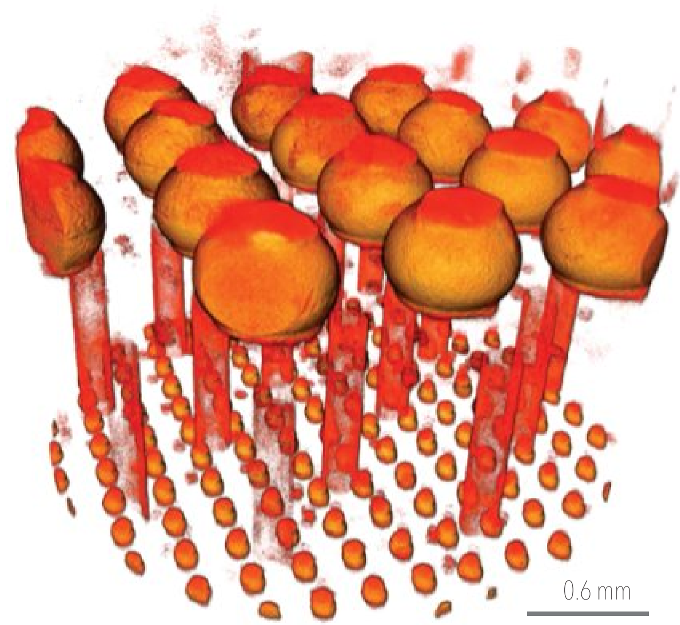

Figure 3: 3D Rendering of a region of interest (ROI) within the GPU at 1.0 μm voxel. Acquired on Apex XCT at 140 kVp and 50 minutes.

Virtual delayering of the sample with 2D cross-sections acquired by the Apex XCT revealed metal layers and defects including cracks and voids in the BGA layer (Fig. 4, left) and in the microbump layer (Fig. 7).

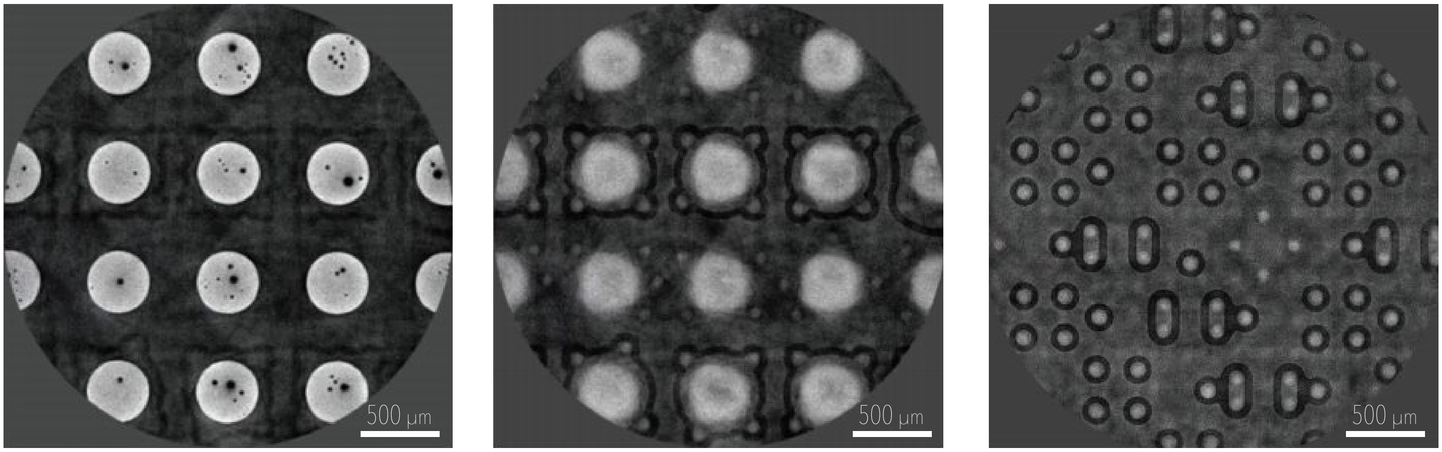

Figure 4: Delayering virtual cross-sections of the intact GPU at 1.0 µm resolution. Acquired on Sigray Apex XCT at 140 kVp and 50 minutes.

The scans were then compared to tomographies acquired by a leading 3D X-ray Microscope (XRM). The large FOV scans at 8.6 µm voxel of a BGA layer region of interest (Figs. 5 to 6) demonstrate that the Apex produces superior, artifact-free image quality in a fraction of the time.

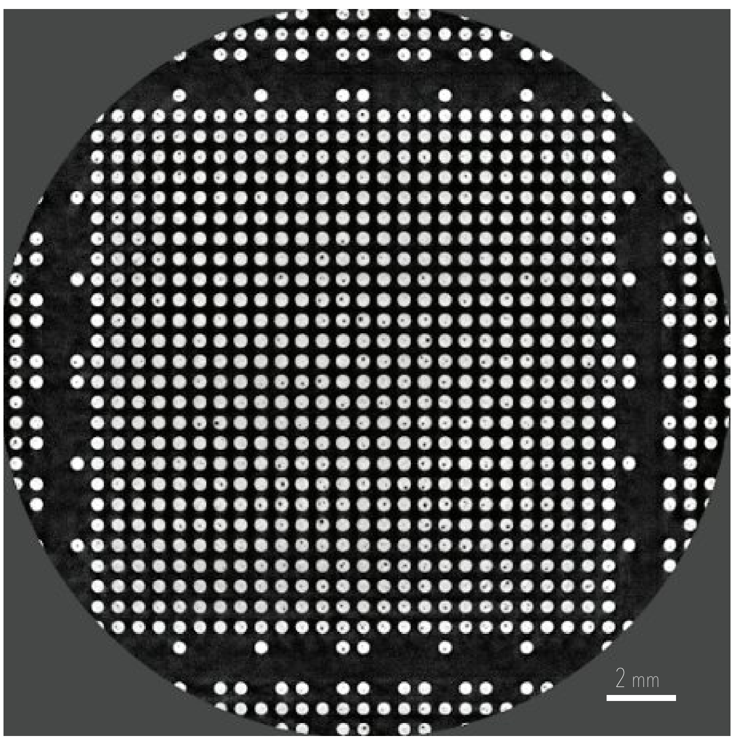

Figure 5: Apex XCT LFOV (8.6 µm) scan of BGA layer. Defects can be easily seen and the image is crisp and free of beam hardening artifacts. Acquired on Apex XCT at 160 kVp and 34 minutes.

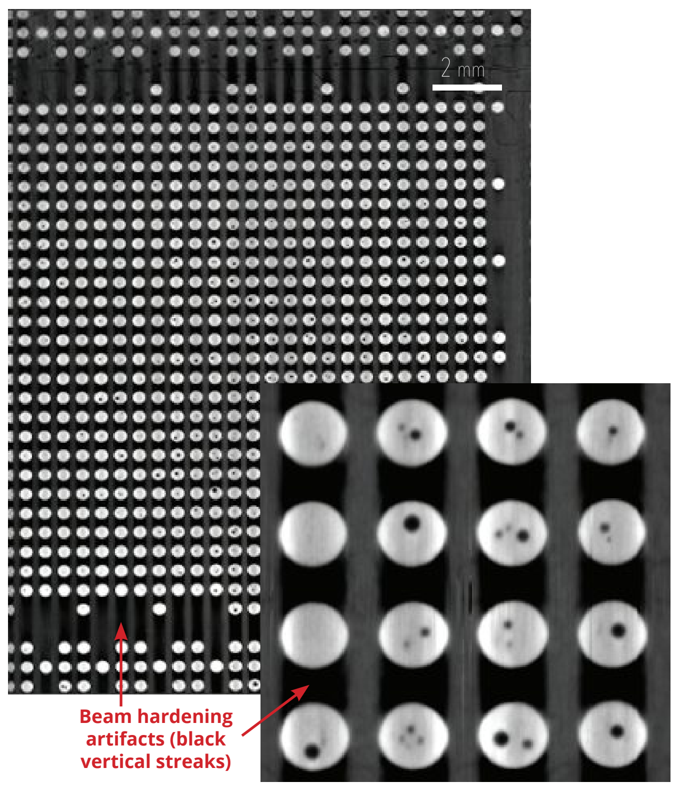

Figure 6: Comparison of the same ROI as Fig. 5 using a different system at the same (8.6 µm) voxel size. Vertical streaks (clearly seen on the inset) are due to beam hardening artifacts, which often obscure defects near metal parts. Taken on 3D XRM at 160 kVp and 2.5 hours.

Comparison for the high resolution scan at was even more dramatic. Apex XCT provides defect details within 50 minutes on even the microbump layer (Fig. 7). In comparison, no features or defects can be seen even after 16 hours of scanning using a leading XRM (Fig. 8). Note that because a 1.0 μm voxel was not achievable using a flat panel detector due to sample size and geometric constraints on the leading XRM, the comparative image was acquired using a high resolution detector (in which a scintillator is coupled to a 4X magnification objective lens).

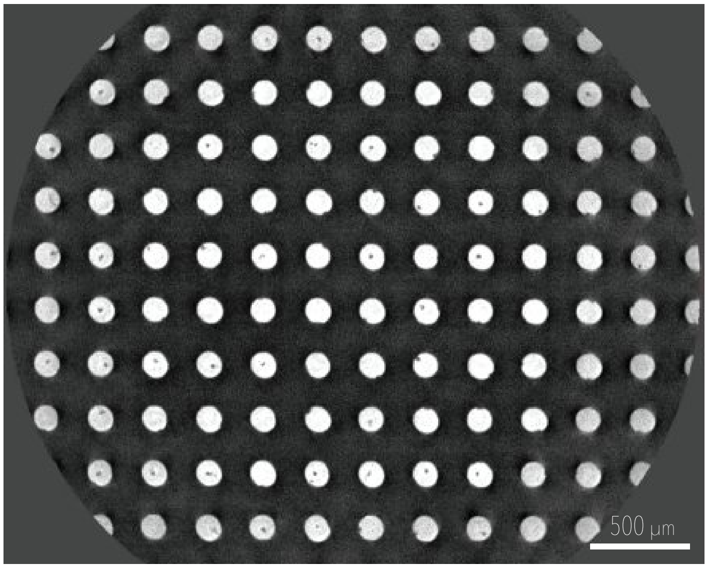

Figure 7: Cross-section of microbump layer at 1.0 μm voxel, with defects clearly visible. Focus indicates a degree of wafer warpage. Acquired on Apex XCT at 140 kVp and 50 minutes.

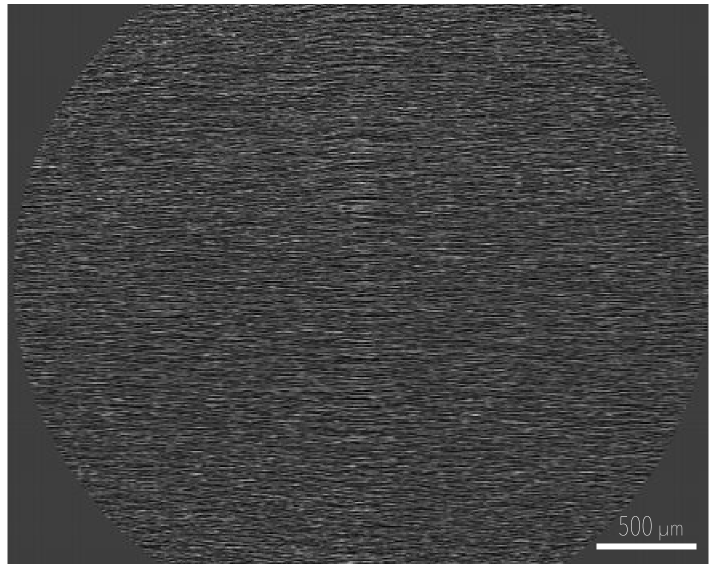

Figure 8: Comparison of the same ROI as Fig. 5 at 1.0 μm voxel using a different system. Nothing can be seen. Taken on 3D XRM at 160 kVp and 16 hours.

Summary

Apex XCT is a breakthrough 3D x-ray approach for inspecting large samples at sub-micron resolution. The patent-pending approach provides excellent image quality and fast imaging times of down to single digit minutes for intact samples. In this example of a GPU on an intact PCI card, Apex XCT was used to resolve microns-scale defects quickly. To demonstrate how challenging this sample is for 3D imaging, a leading 3D X-ray Microscope (XRM) was compared; at low resolution, the XRM displayed beam hardening artifacts and at high resolution, it could not resolve any features.

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