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Detecting Wafer Level Cu Pillar Defects Using Advanced 3D X-ray Microscopy (XRM) with Submicron Resolution

Seeing beyond

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Abstract

In this work we present a new defect localization capability on Wafer Level Chip Scale Packages (WLCSP) with small-scale Cu pillars using advanced 3D X-ray microscopy (XRM). In comparison to conventional microcomputed tomography (Micro-CT or microCT) flat-panel technology, the synchrotron-based optically enhanced 3D X-ray microscopy can detect very small defects with submicron resolutions. Two case studies on actual failures (one from the assembly process and one from reliability testing) will be discussed to demonstrate this powerful defect localization technique. Using the tool has helped speed up the failure analysis (FA) process by locating the defects non-destructively in a matter of hours instead of days or weeks as needed with destructive physical failure analysis.

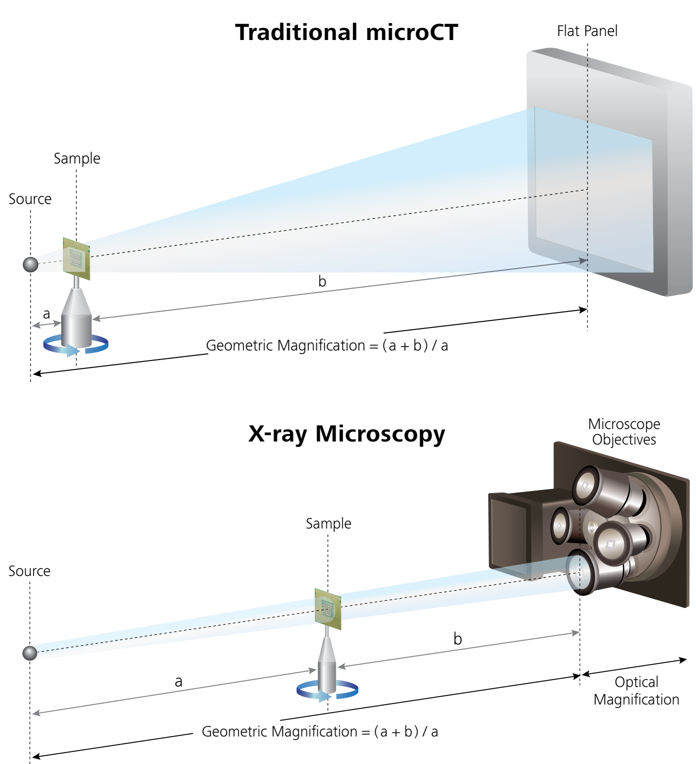

Figure 1 Comparison of XRM optical architecture with traditional microCT.

Introduction

2D X-ray imaging and inspection remain the most commonly used X-ray technique. Incident X-ray irradiates samples and a 2D detector is utilized to collect shadow or projection images, where absorption contrast is generated by the difference in X-ray absorption between different materials or thickness. This technique, however, is not adequate for revealing true 3D structures because it projects 3D objects to a 2D plane. As a result, when it is used for semiconductor packages, important information such as internal faulty regions of a device may remain hidden due to complicated multi-layer structures. The disadvantage may be overcome by using 3D X-ray computed tomography (CT) technique.

In a CT system, a series of 2D projection views is captured at different angles while the specimen rotates. These 2D images are used to reconstruct 3D X-ray tomographic volume by applying mathematic models and algorithms. The spatial resolution of the imaging technique can be improved by the integration of an optical microscopy system. The improved technology, named as 3D X-ray microscopy (XRM), was used in this work for high resolution 3D imaging, providing an insightful vision for non-destructive FA technology.

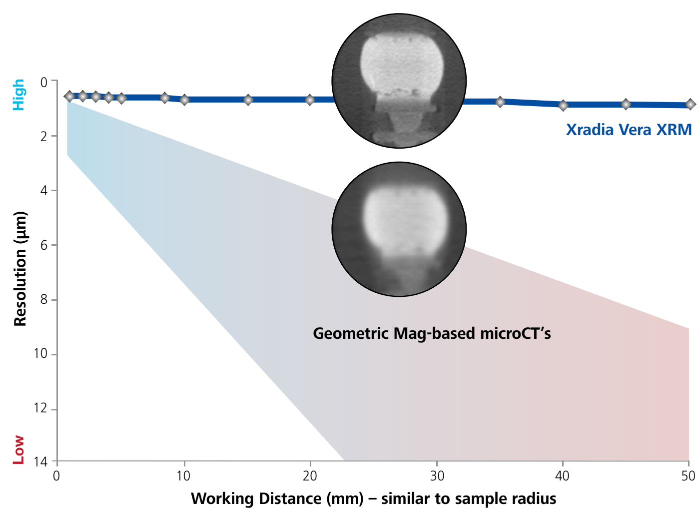

Figure 2 Resolution performance comparison between traditional microCT and XRM. The sample was about 55x55 mm in size.

Figure 1 shows the comparison of the setup of a 3D XRM with the traditional microCT. In the XRM configuration, a high-resolution X-ray scintillator is coupled with optical lens system to further magnify the image and improve spatial resolution and contrast. This architecture with two-stage magnification mechanism is unique to provide the necessary resolution required to image subtle internal defects of large electronic devices (Figure 2). Because XRM's unique resolution-at-a-distance capability, XRM can be used to detect many different types of failure modes, shown in Figure 3.

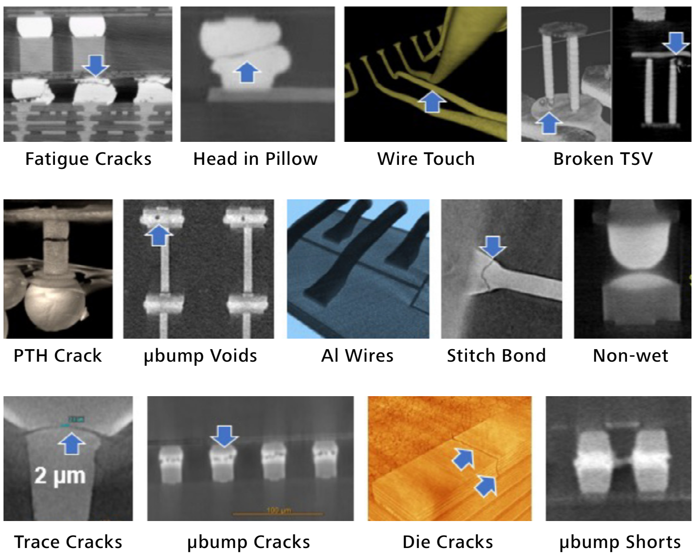

Figure 3 *A variety of defect types that can be detected with 3D X-ray microscopy with the sample sizes ranging from a few mm to tens of mm.*

3D X-ray tools have been widely used for non-destructive failure analysis to inspect wire-bonding related defects, solder joints and die attach voids, and other anomalies on printed circuit boards (PCBs) and IC packages [1]. 3D CT scanning compiles digital X-ray images into a 3D volume, resolving internal structures that can be virtually sliced, measured and viewed at any angle digitally, all without physically damaging actual parts [2-5]. A conventional flat-panel Micro-CT X-ray system can achieve resolutions of the order of 2-10 µm depending on the size and materials of a device being analyzed and can reveal defects such as fused bond wires or wires touching the lead post [6] (Figure 4).

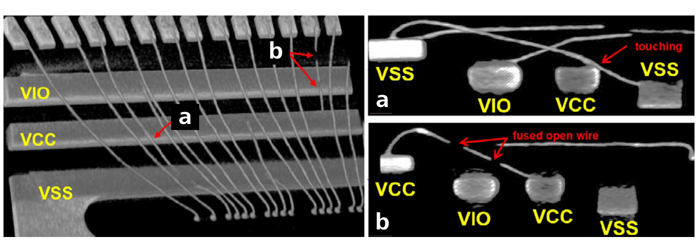

Figure 4 *Conventional Micro-CT images showed a bond wire touching the lead post (a) and a fused open bond wire (b).*

However, it normally cannot detect small, subtle defects such as separated solder joint interfaces, slightly lifted wire bonds, or bump cracks. It also cannot reveal the details on small-scale Cu pillars (25-30 µm in diameter), such as those used by an automotive fingerprint sensor (Figure 5a).

Advanced 3D XRM systems utilize the innovations first developed for synchrotron-based instruments. It uniquely employs scintillator-coupled optics as an integral part of the X-ray detector. Unlike conventional Micro-CT techniques, where spatial resolution solely relies on geometric magnification, the optical objective-based XRM utilizes a unique two-stage magnification mechanism to achieve high resolution over large working distances. Better resolution can be achieved even for large semiconductor package samples. The latest 3D XRM system enables users to visualize and quantify internal structures with resolution down to 0.45 µm, significantly beyond the conventional Micro-CT flat-panel technology.

This advanced XRM tool is ideal for revealing defects in the fingerprint sensor's small-scale Cu pillars – defects which other conventional Micro-CT X-ray systems cannot detect. Without any sample preparation, the data of a targeted area was acquired at 0.72 µm/voxel resolution with 70 kV X-ray source energy and a 4X objective in XRM. It took about 1.3 hours for the 3D scan and reconstruction, and the detailed small-scale Cu pillars' joint conditions including solder joint non-wetting and cracking were revealed (Figures 5b, 5c and 5d).

In this paper, we will describe how to use the latest 3D XRM tool to analyze failing devices from the assembly process and after reliability testing and obtain very impressive results in a much shorter analysis cycle time.

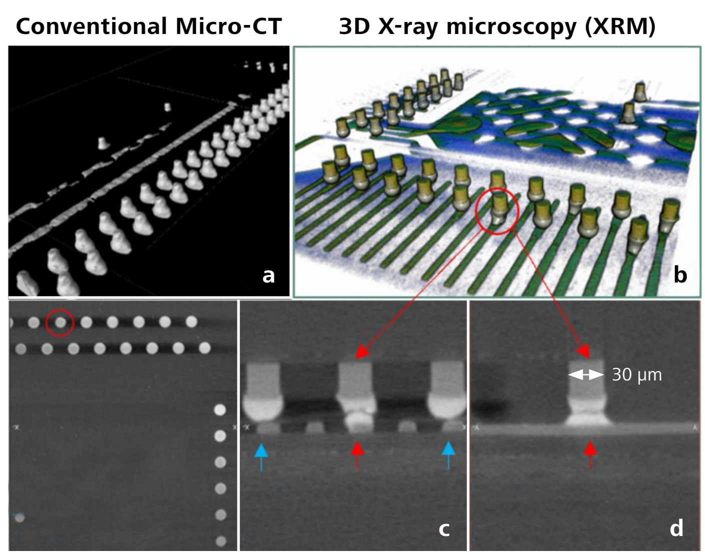

Figure 5 *Compared to a) conventional Micro-CT X-ray, b) 3D XRM reveals more details of the small-scale Cu pillars including solder joint non-wetting (blue arrows) and cracking (red arrows) (c and d).*

Results and Discussion

The failing device analyzed is a fingerprint sensor with a Flip-Chip die mounted on a PCB substrate through small-scale Cu pillars. It is used for automotive applications and is therefore subjected to stringent reliability tests. Some failures were observed after 1000 cycles of temperature cycling test, while others were found right after the assembly process. Two units with failures at transmit (TX) or receive (RX) pins were selected for the 3D XRM analysis.

Case Study 1

One fingerprint sensor device failed at three RX pins and three TX pins right after assembly process. 2D X-ray inspection was initially performed on the unit, and an abnormally shaped Cu pillar was found at one of the failing RX pins, but nothing abnormal could be seen at other failing RX and TX pins.

The intact unit was then analyzed using 3D XRM at the failing RX and TX pins. The scan was performed at 0.73 µm/voxel resolution at 70 kV for 1.3 hours. The detailed 3D X-ray images showed the deformed Cu pillar with a shorter Cu stem, open solder joint, and even a slightly bent Cu trace at the affected failing RX pin where an anomalous Cu pillar was detected under the 2D X-ray inspection (Figure 6). The 3D X-ray analysis also showed non-wetting solder joints at the other failing RX and TX pins that conventional Micro-CT could not see (Figure 7).

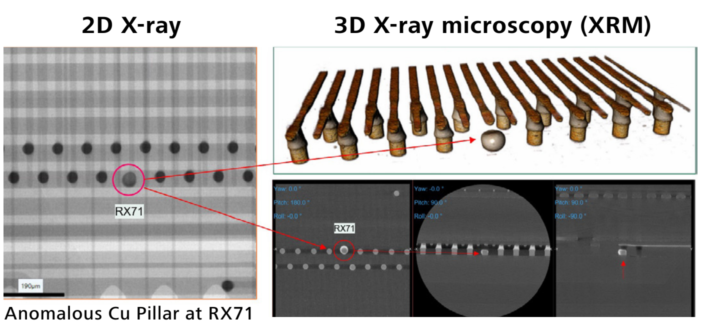

Figure 6 *3D X-ray microscope image can resolve the detailed structure and defects at the deformed Cu pillar of the failing RX pin.*

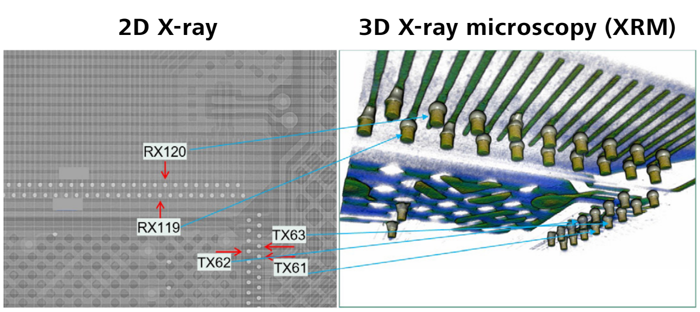

Figure 7 *The detailed 3D X-ray images revealed non-wetting solder caps at all reported failing RX and TX pins, indicated by original round solder caps (the rest of non-wetting pins shown were not electrically tested).*

The scan was performed with 1 µm/voxel resolution and completed within 1 hour. These findings enabled us to visualize the defects in detail, and the information was quickly fed back to the assembly team to implement corrective actions.

Case Study 2

Another fingerprint sensor device showed a partial panel failure at one single RX pin after 1000 temperature cycles. Optical and Scanning Electron Microscope (SEM) inspection revealed an anomaly, possibly package surface damage, at the physical location where the partial panel failure was detected through the electrical testing (Figure 8).

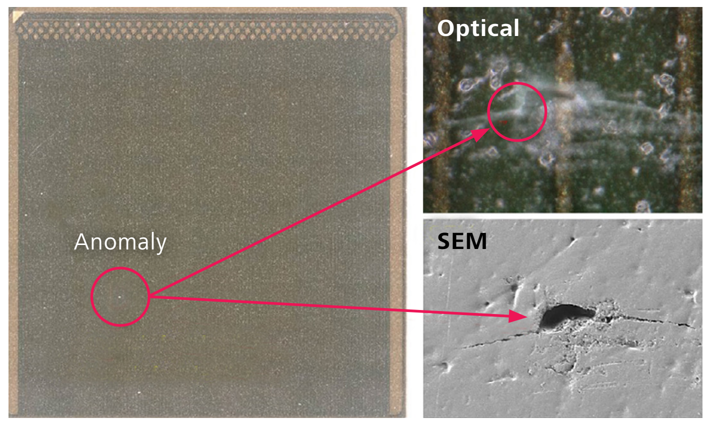

Figure 8 *Optical and SEM inspection showed an anomaly at the reported partial panel failing location.*

The unit was then analyzed using 3D XRM with focus on the anomalous location. The detailed 3D X-ray image showed a cut open Cu trace underneath the anomaly (Figure 9).

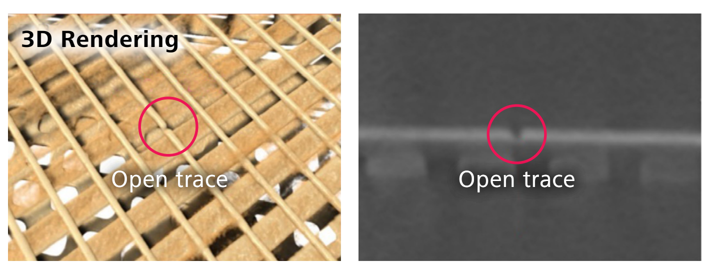

Figure 9 *3D X-ray image showed cut open Cu trace at the anomalous location where the partial panel failure was detected.*

To further understand the failure mechanism, FIB cross-section was performed at the affected location, and the result showed a sharp-edged SiO_2 piece pressed through the package surface, cutting the Cu trace (Figure 10). After checking the socket for ATE testing, it was confirmed that the affected location was right underneath the clamp of the test socket.

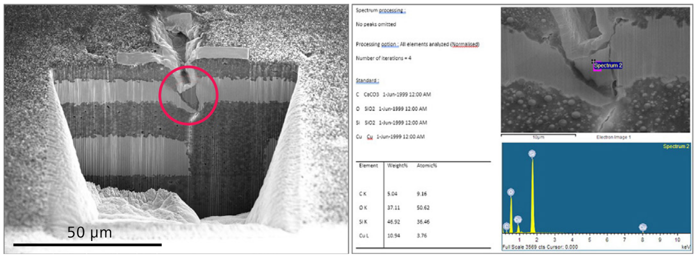

Figure 10 *FIB cross-section at the anomalous location showed a sharp-edged particle pressed into the package, cutting open the Cu trace underneath. EDX analysis showed the particle to be a piece of* SiO_2*.*

It is presumed that a loose particle landing on the package surface was pressed into the package surface during clamping of the test socket, cutting the Cu trace underneath. The damaged Cu trace became completely open after 1000 temperature cycles. The information was then provided to the product team for improving ATE test conditions and test socket cleanliness.

Conclusions

The analysis results obtained from this advanced 3D X-ray microscope tool significantly exceeded our expectations from a typical Micro-CT X-ray tool, and sped up the FA process by finding defects non-destructively in a matter of hours instead of days or weeks as would be the case with destructive physical failure analysis.

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