TUTORIAL ABSTRACT

Non-Destructive 3D X-Ray Microscopy to Complement Physical Cross-Section in the Failure Analysis and Package Development Workflows

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This tutorial will describe the novel technique of using leading-edge 3D X-Ray Microscopy (XRM) technology to complement physical cross-section in Failure Analysis (FA) and 3DIC package development workflows. Contrary to popular believe that "3D X-Ray" is too slow, we explain how XRM, a new 3D X-Ray variant technique differs from conventional 3D X-Ray Micro Computed Tomography (MicroCT), and can be optimized to provide non-destructive, near-SEM imaging of a sample within 10-300min throughput time (TPT) depending on its physical properties—material composition, critical feature dimensions, and sample size. The specifics of the inspection technique itself and how X-rays interact with the sample to achieve high-quality images will be discussed. Example images comparing and correlating optical and Scanning Electron Microscope (SEM) images taken from a physical cross-section and a *virtual cross-section* images taken from XRM scans will be shown (Figures 1 and 2).

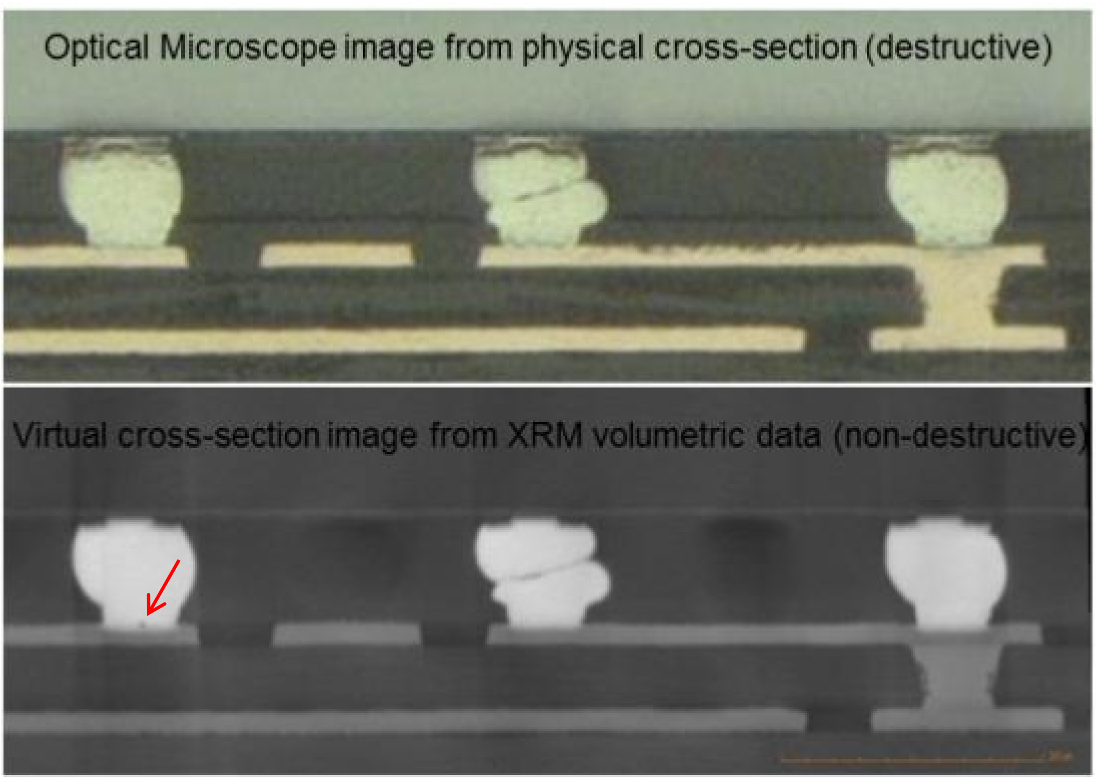

Figure 1: Comparison between images collected with an optical microscope taken after destructive cross-sectioning (top) and a virtual cross-section image taken from the non-destructive XRM scan (bottom).

The red arrow points to a ~2µm void between the Cu pad and the solder bump that was missed by physical cross-section. High-resolution volumetric data is powerful because it allows the user to review a very large number of v*irtual cross-sections* through any direction through the volumetric dataset, shortening the time that it takes to isolate a defect and determine the cause of package failure, all in one scan. Collection time for the single image collected with an optical microscope after cross-section was ~1hr (as shown). Collection time for a 1x1x1mm^3 internal volume of CT data for the same sample was ~2hrs (as shown).

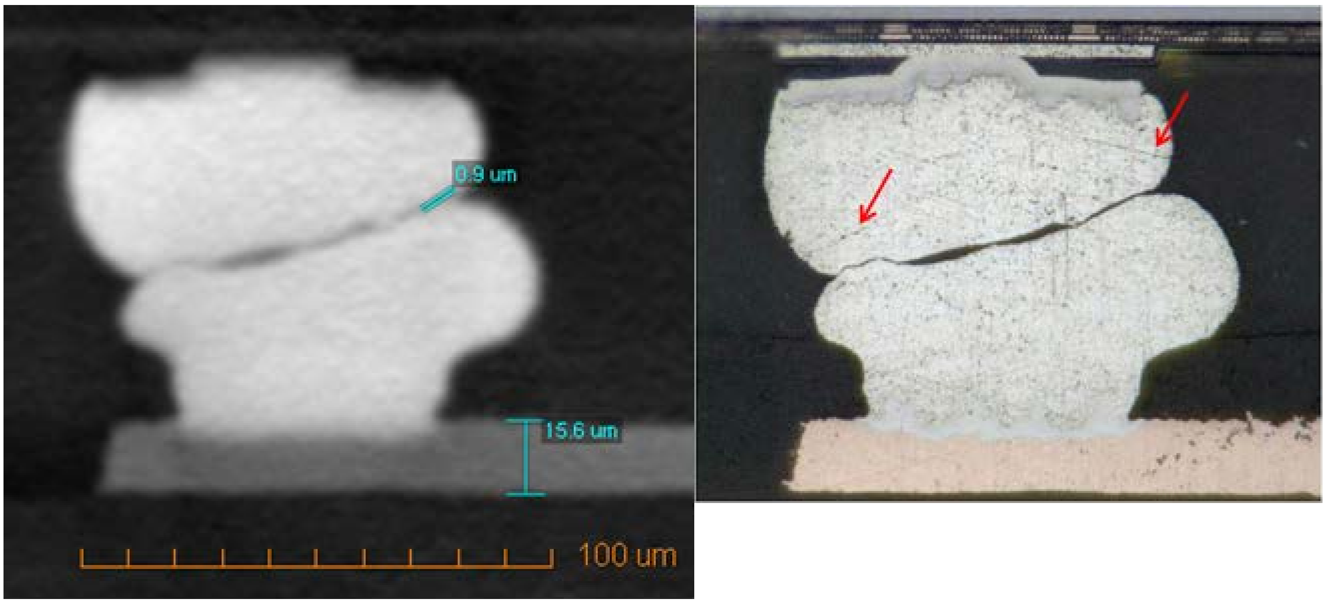

Figure 2: The left image is a *virtual cross-section* while the right image shows an optical micrograph image of the defect taken after physical cross-section. Note the high contrast and spatial resolution attained with XRM, where a 0.9µm non-wet separation can be clearly measured. The red arrows show polishing defects caused from physical cross-section. These artificially introduced defects can often times make it difficult to determine the location and size of the actual defects. Since XRM is non-destructive, the sample is intact and impervious to the introduction of polishing defects.

While 2D X-Ray and conventional 3D X-Ray MicroCT are useful to image large voids, rough misalignments, and non-contact opens from top-views of first- and second-level interconnects, these techniques—due to their unique dependence on geometric magnification—quickly become inadequate as more layers, with smaller µbumps, are stacked in modern 3DIC packages. Physical cross-sectioning is still the most widely used technique for 3DIC package development because the high quality (high resolution and high contrast) side-view images give enough detail to measure critical structures and defects. Despite these advantages and its widespread use, physical cross-sectioning is not an ideal solution to address the increasing demand of 3DIC packages because it is destructive and time consuming. Furthermore, optical images from cross-sections can be grossly misinterpreted if polishing defects are introduced, and defects can be completely missed if the incorrect polishing orientation is chosen. On the other hand, the introduction of XRM provides a means to obtain very similar results to electron and optical microscopy, without the downside of the destructive techniques. Greater adoption of XRM technology has occurred recently due to improvements in both resolution and TPT. In order to understand the capabilities and limitations of this novel technique as it applies to 3DIC packaging, it is important to understand the differences between MicroCT and XRM techniques and the way x-rays interact with the sample in XRM to achieve high quality images.

XRM has shown great success in replacing physical cross-sections in FA labs and shows great potential to bridge the gaps in 3DIC high volume production metrology. Unlike 2D X-Ray and MicroCT techniques that rely only on geometric magnification and fixed detector pixel size for high resolution, XRM employs geometric *and* optical image magnification to achieve higher spatial resolution at large working distances, as well as enhanced scintillators and charge-coupled detectors that can tune the X-Ray spectrums to achieve higher contrast and better signal. In this way XRM is being used to collect high-quality non-destructive images that are comparable in quality to the ones obtained from SEM and optical micrographs, enabling an unparalleled imaging capability to the failure analysis (FA) and process development workflows (see Figure 3).

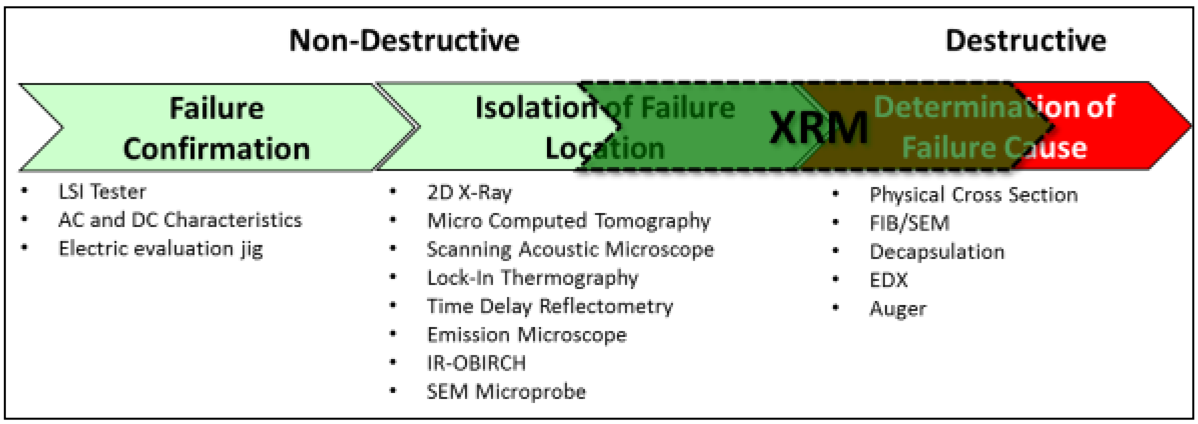

Figure 3: Proposed use of X-Ray Microscopy (XRM) to replace mechanical cross-sections to streamline the Failure Analysis Workflow and shorten the time-to-market of 3DIC process development.