Examination of electronic components with the nano3DX X-ray CT microscope

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1. Introduction

X-ray computed tomography (CT) is a nondestructive imaging technique that can be used to examine the internal features of an object in three dimensions (3D). The first commercial X-ray CT scanner was introduced 45 years ago[1] and the technique has been widely used in the medical and industrial fields since.

Recently X-ray CT for examining microstructures of size less than 10 μm (X-ray micro-CT) has seen rapid growth in the research and development of materials. This method is mainly used in the automotive industry to analyze defects such as voids or cracks in castings and resin molded products, and in the electronics industry to evaluate bonding defects in electronic printed circuit boards (PCBs)[2].

As the X-ray micro-CT technique has become more popular, the demand for new sample analysis applications is emerging. One of these applications is examination of micrometer-scale structures of electronic components or PCBs. Typical X-ray micro-CT systems can be used to examine such objects, but their spatial resolution is not very high (5 μm). Therefore, it has been difficult for these instruments to render the internal microstructure of those objects in detail needed for this application.

Another application is examination of engineering materials made up of only carbon-containing compounds, that is, polymers and carbon fiber reinforced polymers (CFRP), which are essential to develop lightweight parts, composite materials, etc. (Fig. 1).

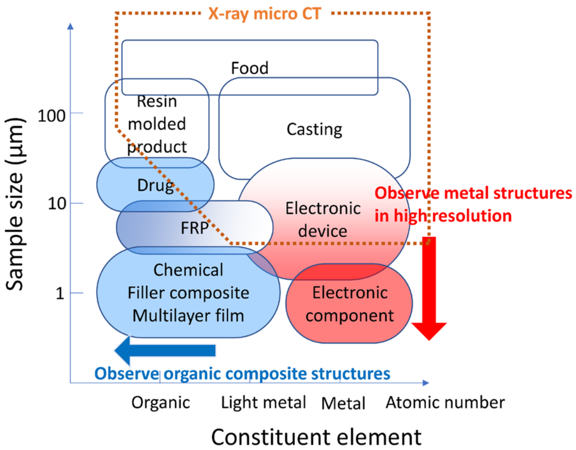

Fig. 1. X-ray micro CT and sample objects.

In order to meet such demand, we have developed the nano3DX X-ray CT microscope, combined with a chromium (Cr), copper (Cu), or molybdenum (Mo) target, each of which emits highly monochromatic, long wavelength X-rays yielding a large interaction cross section (high sensitivity) for the materials described above (Fig. 2).

Using these X-rays, the nano3DX can examine structures nondestructively at the 1 micrometer scale, in objects such as CFRPs, pharmacological agents and chemical products, with a sensitivity one order of magnitude greater than that of conventional X-ray micro-CT systems. As the result, identifying the relationship between internal structure and material properties, which can't be done by the cross section method (e.g., conventional optical microscope, electron microscope), is now possible[3],[4].

2. Addition of a tungsten target and increased tube voltage

The nano3DX provides a high sensitivity for examining carbon-containing materials and light metals by virtue of the Cr, Cu and Mo targets. However, Mo X-rays can penetrate only 20 to 30 μm into first row transition metal-containing materials. To address this limitation, we have employed a tungsten (W) target for generating white radiation (Bremsstrahlung) X-rays and increased the tube voltage from 50 kV to 60 kV. With this modification, the penetration depth is increased by one order of magnitude, and the system now has the potential to inspect electronic components that require high spatial resolution yet have a small interaction cross section.

3. Measurement examples of electronic parts

3.1. Multilayer chip inductor

CT images of a multilayer chip inductor were acquired by the nano3DX using Mo and W targets.

Figure 3(a) indicates that the Mo X-rays did not penetrate the sample sufficiently and thus the internal structure of the chip inductor was not clearly observed. While Fig. 3(b) indicates that the W X-rays penetrated the sample sufficiently. The image clearly shows the gap between the coils as well as the many voids. This result shows that the nano3DX with the W target enables inspecting defects or variations of these types of products by analyzing such micrometer-scale defects and the thickness of coils.

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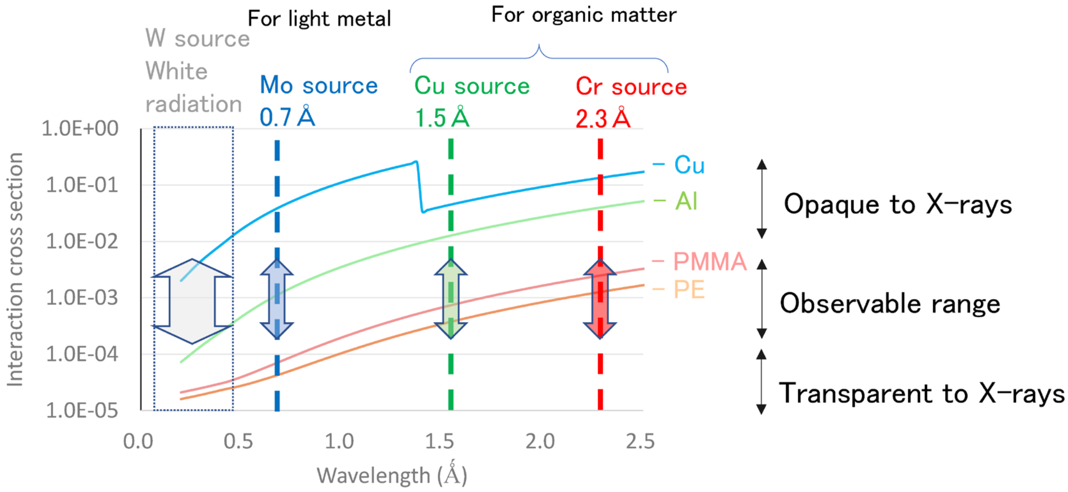
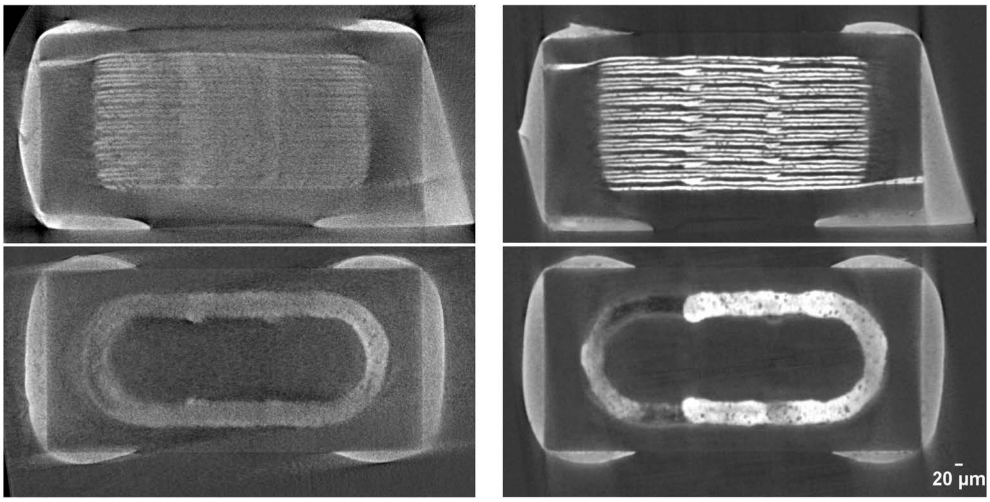
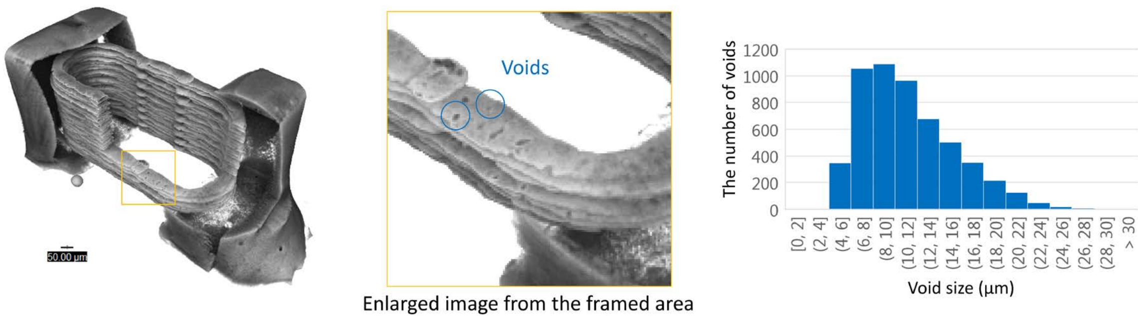


Fig. 2. Interaction cross section.
If the interaction cross section is too large, the X-rays do not penetrate the sample, or if too small, the sample becomes transparent, both of which prevent observing individual structures precisely. Thus, an X-ray wavelength having an interaction cross section appropriate to the measurement sample should be selected.



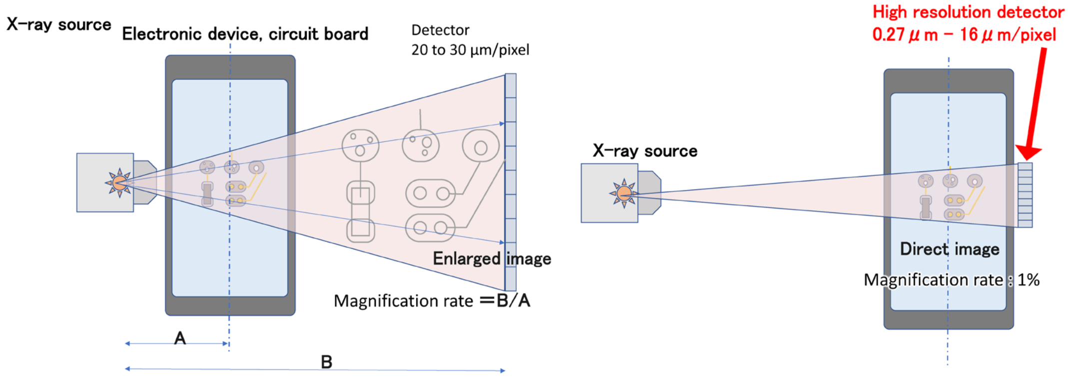
(a) Mo target, tube voltage 50 kV (b) W target, tube voltage 60 kV

Fig. 3. Measurement example—Multilayer chip inductor.



(a) 3D rendering image (b) Void size distribution of a coil

Fig. 4. An analysis example of a multilayer chip inductor.



X-ray micro CT: Mechanical magnification nano3DX: Pseudo-parallel beam＋High resolution detector

Fig. 5. Measuring an electronic device with different optical systems.
In the conventional X-ray micro-CT method, the shorter the distance between a sample and an X-ray source is, the more the magnification increases. Thus, if a large sample such as PCB is measured, the distance between them has to be longer, resulting in a decreased magnification. In contrast, the nano3DX uses a high-resolution detector, making the resolution independent of the sample size. As a result, the internal structure of even a large sample such as an electronic device can be observed non-destructively.

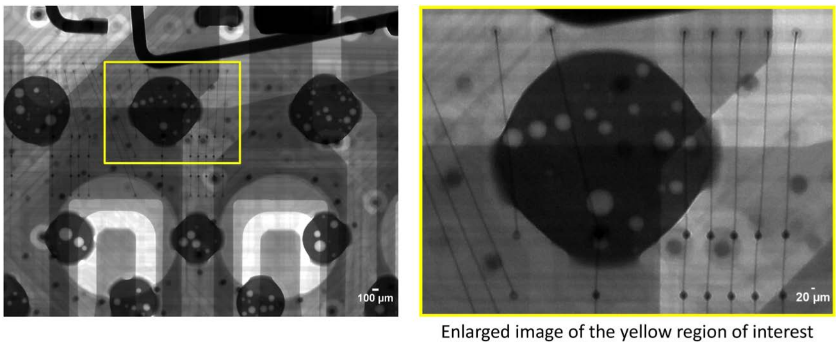
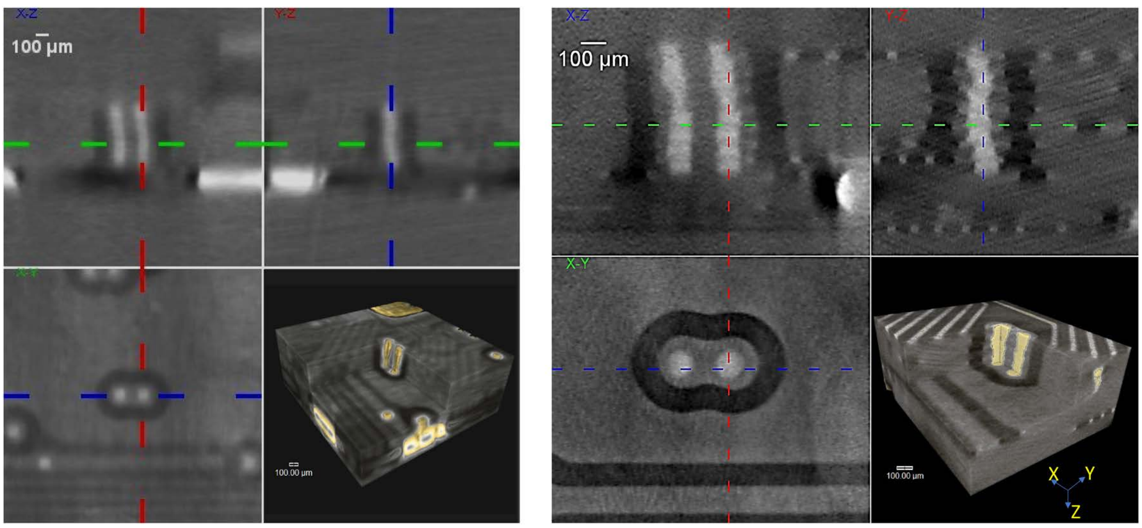


Fig. 6. An example of projection measurement with nano3DX (2 μm/pixel).



(a) Conventional X-ray micro CT (130 kV, 10 μm/voxel) (b) nano3DX (60 kV, 2 μm/voxel)

Fig. 7. CT images of a smartphone.

3.2. Electronic devices and PCB

Next, as a typical example of an electronic device, a smartphone[4] was scanned with the nano3DX. Although many X-ray micro-CT images of electronic devices and PCBs have been reported, the spatial resolution of those images is only 20 to 30μm due to a problem of the magnification geometry (Fig. 5). To observe the wire connections of a multilayer PCB by a conventional micro-CT system, the PCB must be cut into small pieces of 2 or 3 mm to place it closer to the X-ray source to increase the magnification ratio. This is a destructive measurement and a problem in examining electronic devices with X-ray micro-CT systems.

Figure 6 shows a projection measurement with nano3DX. The image of the bonds and voids in wires can be acquired with just a 2 or 3 second exposure. Moreover, Fig. 7(b) shows that the structure and microelectrode displacements of an eight-layer PCB are clearly rendered.

Compared to the conventional X-ray micro-CT images (Fig. 7(a)), the nano3DX can acquire images with a high spatial resolution even from a large sample.

Typically, when PCBs are inspected by X-ray micro-CT, a tube voltage of 100 kV or higher is used. However, this example measurement demonstrated that the W X-rays can sufficiently penetrate the plate-like sample at most angles of the CT scan, even at 60 kV, allowing the examination of internal structure.

4. Conclusion

With the addition of a W target and the increased tube voltage, the nano3DX X-ray CT microscope has achieved the visualization of internal structure and defects of electronic components and PCBs at the micron level. Therefore, the nano3DX is a promising tool as the first step in failure analysis which requires nondestructive inspection.

References

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