Microfocus X-ray Computed Tomography and It's Industrial Applications
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Microfocus X-ray computed tomography (CT) is now becoming widely used for the cutting edge industrial fields such as semiconductor testing. By this non-destructive inspection method, we can observe and evaluate tiny soldering ball joint of the state-of-the-art semiconductor package with spatial resolution as fine as one micron. With the volume rendering techniques, it also gives three-dimensional data such as 3D configuration of bonding-wire. Moreover, so called “Reverse Engineering” will be realized with combination of CT data and sophisticated computer software. Thus we consider that microfocus x-ray CT is a very effective tool not only for academic R&D fields but also for technology-driven high-tech industrial ones.

Until now, optical and cross-sectional observation was the mainstream of failure analysis technology in semiconductor packaging. That is to say, by optical measurement of the mounting solder shape, the quality of the solder joint is evaluated, and the cause of the trouble has been estimated by the visual observation of cross section. However, accurate inspection and failure analysis becomes more difficult by optical and cross-sectional observations with improving the packaging density. This is because that the optical inspection of the solder joint becomes already impossible by the appearance of high-density packaging semiconductor of BGA (Ball Grid Array) and CSP (Chip Scale Packaging). Moreover the deformation and stress by the cutting makes true failure analysis extremely difficult.

In the progress of such semiconductor packaging technology, the space-resolving power of Microfocus X-ray equipment rapidly improves non-destructive inspection and failure analysis technology of BGA and CSP. In the section of "Microfocus X-ray generation system", we describe the high resolution X-ray emission system that the high energy electron beam are strongly converged as fine as one micron or a few microns, and irradiated on the target. In the following section of "Microfocus X-ray CT scanner", the industrial X-ray CT scanner using the X-ray generation system is described. In last section of "Industrial Application", we explained the application for semiconductor industries is described.

Microfocus X-ray generation system

Conventionally, the bremstrahlung X-ray radiation is generated when the accelerated electron beam collides with the heavy metal target. In the present system, the contrivance was elaborated in filament diameter, the radius of curvature, the shape of the Wehnelt electrode and the high magnification magnetic lens, those are critical corpornents for the space resolving power.

In the present sysytem, the technology of Electron Probe Micro Analyzer (EPMA) was utilized and also by putting on the localized magnetic field right before the electron beam collides with the heavy metal target, high magnification magnetic lens with small aberrations was realized (Figure 1).

In addition, the method for minimizing the self-absorption of the X-ray by the heavy metal target was devised. Conventionally, the heavy metal foil of the several decades micron thickness, for example, tungsten, was used. However, in the energy region of the present X-ray system, the self-absorption of the X-ray has been generated in the foil and it causes brightness lowering of the X-ray.

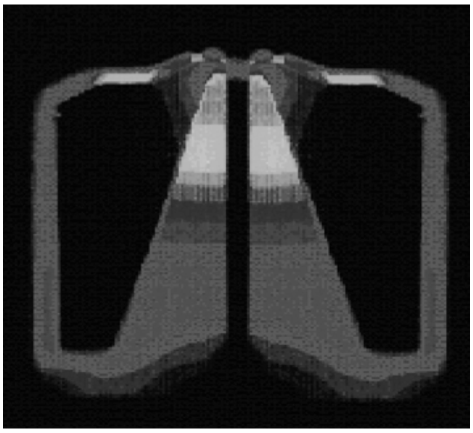

Figure 1 Finite Element Method for Magnetics Lens

Table 1 shows the self-absorption rate in the tungsten in the energy independence of the X-ray. In the soft X-ray region, it is shown that the self-absorption becomes very remarkable. Then, using the WF6 gas, the tungsten thin film was formed at CVD (Chemical Vapor Deposition), while the film thickness control (about 10 microns) is carried out on the backing metal such as aluminum, and the brightness lowering by the self-absorption should be minimized.

Table 1 Self-absorption rate in the tungsten Films.

Thickness of Tungsten	X-ray Energy 30keV	X-ray Energy 50keV	X-ray Energy 100keV
1o microns	38%	11%	8%
20 microns	63%	21%	16%
30 microns	76%	30%	23%

By these, it was possible to develop X-ray emission system of the high brightness at the space resolving power 1 micron and 4 microns refferd in "Hirakimoto et al. ". The former X-ray emission system has the capability of 160kV output voltagae with 200μA output current, used for microfocus X-ray realtime TV system. And the later one has the capability of 225kV and 1000μA, used for the microfocus X-ray computed tomography scanner described in the following section.

Microfocus X-ray CT scanner

Generally, computed tomography scanners are widely used for the medical application, in which X-ray generator and detectors rotate the patient circumference of the bed. However, the present scanner is dedicated for the industrial usage, in which the X-ray generator and detectors (Image Intensifier) are stationary and the sample is rotated on the rotation stage. In obtaining the cross-sectional image, the CT scanner system accumulates X-ray fluoroscopic image from all angles in the computer which reconstructs the inner-structural image (Figure 2). The rotation stage moves perpendicularly, thus it is possible to obtain the cross-sectional image in the optional position of the measuring object sample. This is the principle of two dimensional computed tomography.

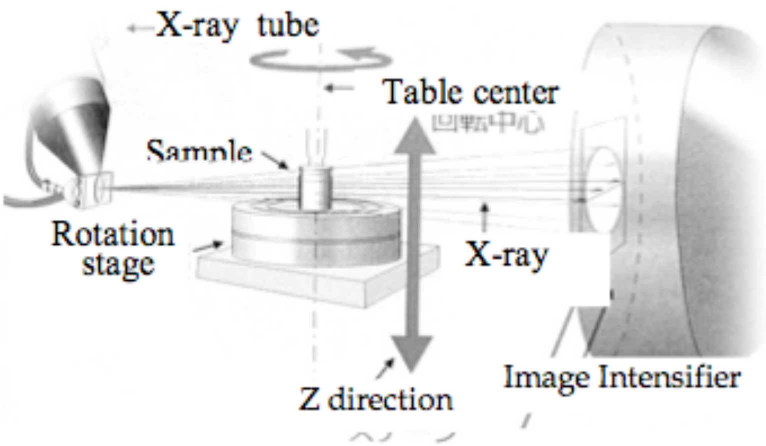

Figure 2 Computer Tomography Scanner for Industrial usage

Till now, the reconstruction calculation has taken very much time. However, by the exclusive high speed computation hardware such as Digital Signal Processor, it is possible to calculate in quickest 3.5 seconds for 512x512 two dimensional image matrix with 1800 angle views.

In addition, three dimensional volumetric CT (Cone Beam CT system "C Solver") which enables to obtain three dimensional cross-section data at once was developed. Thus it is possible to obtain the three-dimensional image in an hour in which considerable time (a day) was necessary in the conventional two-dimensional computed tomography. So the accurate judgment becomes possible by inputting and comparing the three dimensional CT data and CAD (computer aided engineering) data of tested samples into high speed computer. When these techniques develops, it would be possible to reversely obtain the CAD data from CT data of the samples. This is "Reverse Engineering by CT". Therefore, microfous CT is possible to be an ultra-precise non-destructive three dimensional measuring device of the inspection.

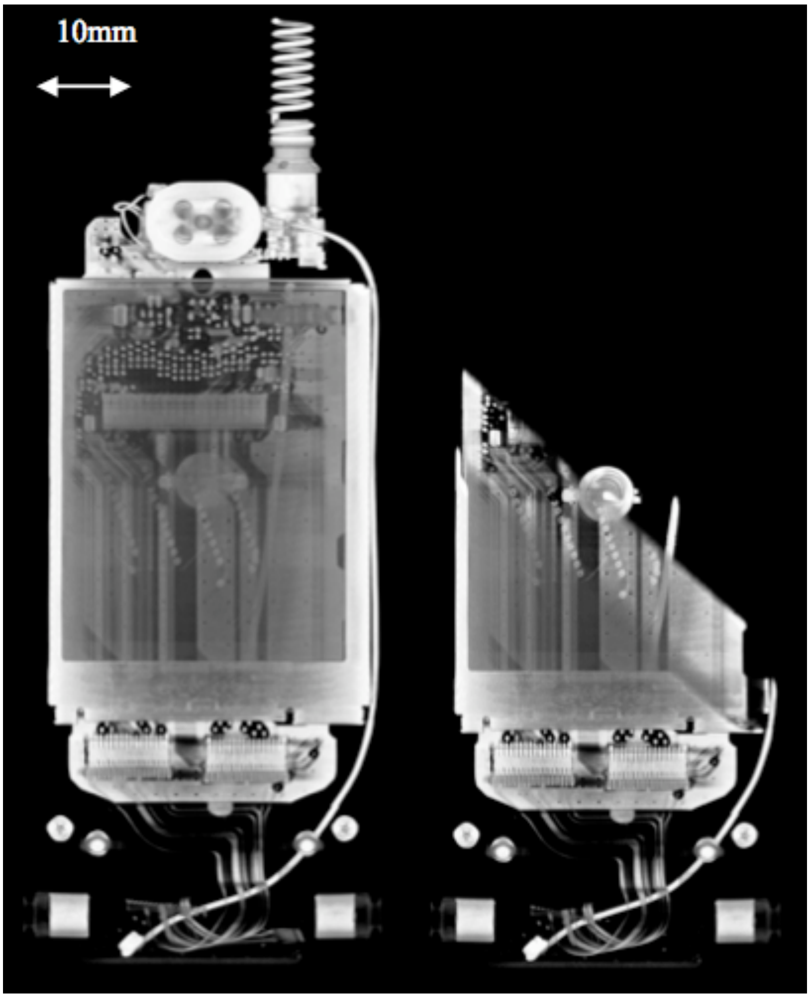

Figure 3 Mobile Phone image by 3D CT data

Industrial Application

By taking the example in electronics and semiconductor fields where precise and complicated inspection are necessary, the applications of the microfocus computed tomography scanner are explained in “Takado et al. ”, “Hirakimoto.” and “”Takado et al.”.

To begin with, a mobile phone is shown in Fig.3. These images are obtained by cone beam CT. The left-side image is three dimensional volume-rendering of CT data with maximum intensity projection (MIP) mode. The right-side one is an oblique cut image with also MIP mode

In Fig. 4, a high-speed CPU (Central Processing Unit) and a multi-layered Printed Wire Board (PWB) are shown. It is known that the wire bonding (bright points in Fig. 4) has been formed in the CPU with 2 layered wiring. And it is proven that the BGAs (white balls in Fig. 4) are utilized for the junction between the CPU and the PWB. It can be also observed that the PWB becomes the multistory structure of the 7～8 layers and the through holes.

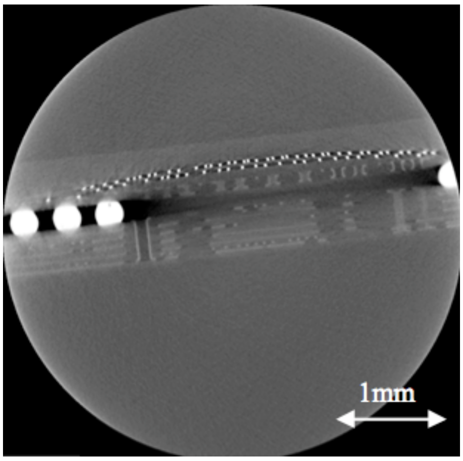

Figure 4 High Speed CPU and PWB

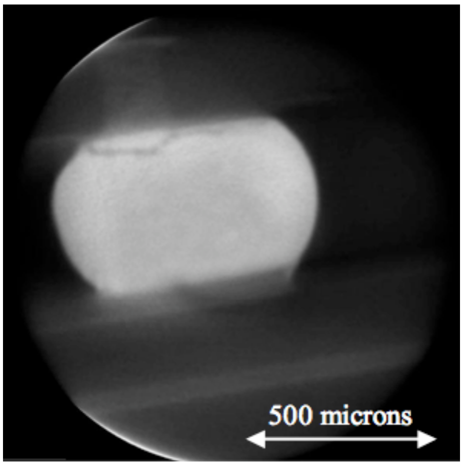

Figure 5 Micro-cracks in BGA

When the dicing of the sample is carried out, it is possible to obtain the extension image (Fig. 5). It can be confirmed that the micro-cracks are being generated at the upper part of BGA in diameter of 500 microns. It is the thermal stress by temperature cycle that the micro-cracks were generated. Such cracks cause the effect which is important for the reliability of the electronic equipment.

Again, the description of the cone beam CT applications is carried out by the mobile telephone. The cone beam CT image of precise connector mounted on the mobile phone is shown in Fig. 6. It is possible to watch the Flexible Printed Wire Board (FPCB) connector with the shape of the crocodile mouth and with the shape of knife edge in the right side. Also in the left side, there is an axial cable connector connected with antenna. Thus many trouble cause of mobile phones are failures of contacting, the method of CT inspection will contribute the improvements in the reliability of connector contacting.

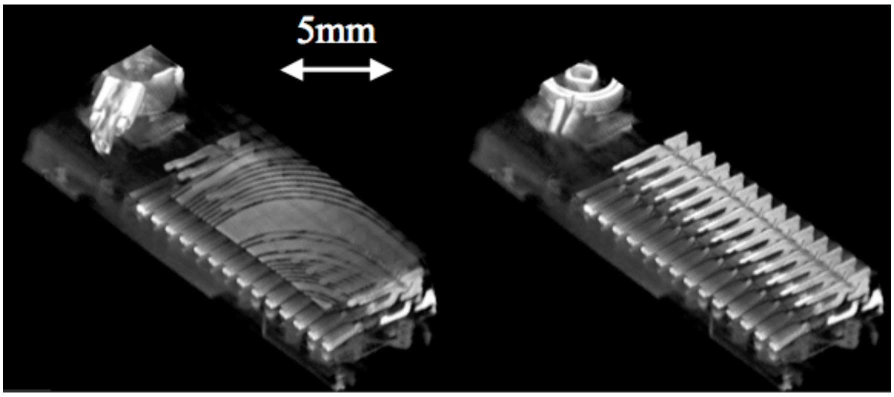

Fig. 6 FPCB Connector and CoaxialConnector

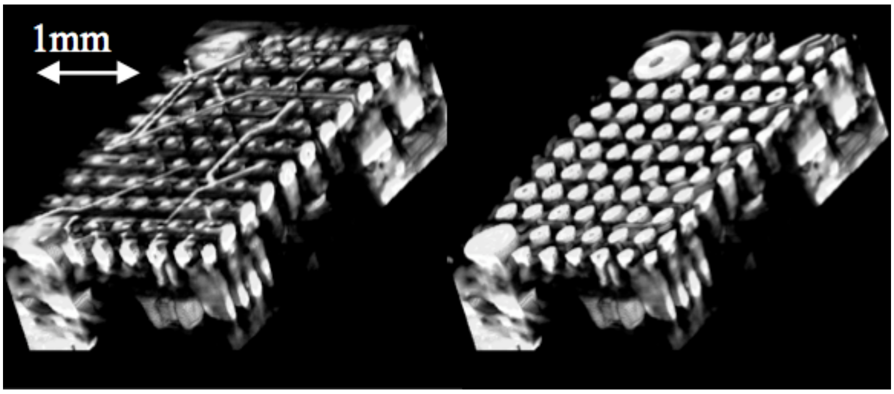

Fig. 7 CSP mounted on the Mobile Phone

Next is shown the example of the CSP mounted on the mobile phone in the Fig. 7.Copper redistribution pattern formed in the back surface of the CSP is shown in the left figure. The solder column which connects CSP and the PCB is shown in the right figure.

Next is shown the example of the micro-inductor mounted on the mobile phone. Micro-inductors are very tiny electronics parts in which the race-track shaped electrodes form the spiral strucuter. Top of Fig. 8 is the whole appearance of micro-inductor with 1.6mm in length and 0.8mm in height. The ends of the coil has respectively been connected with the electrodes of outer ends. Middleof Fig. 8 is cross-sectional cut, showing frontside joint points of the race-truck electrodes. Bottom of Fig. 8 is also cross- sectional cut, showing backside joint points of the race-truck
electrodes.

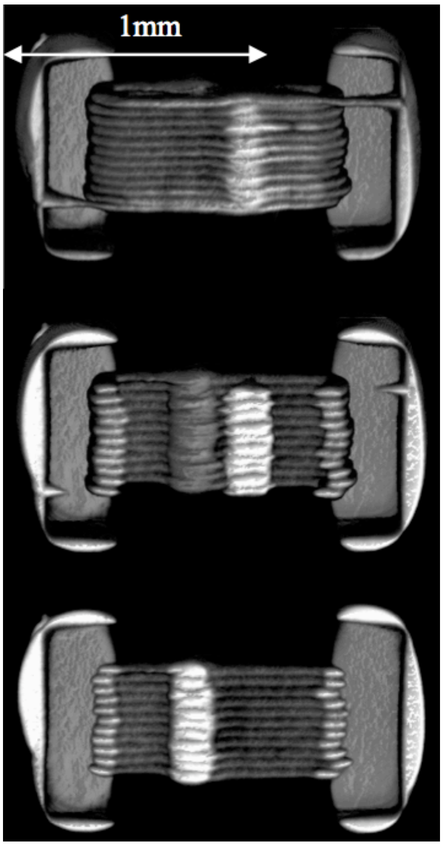

Figure 8 Micro-inductor

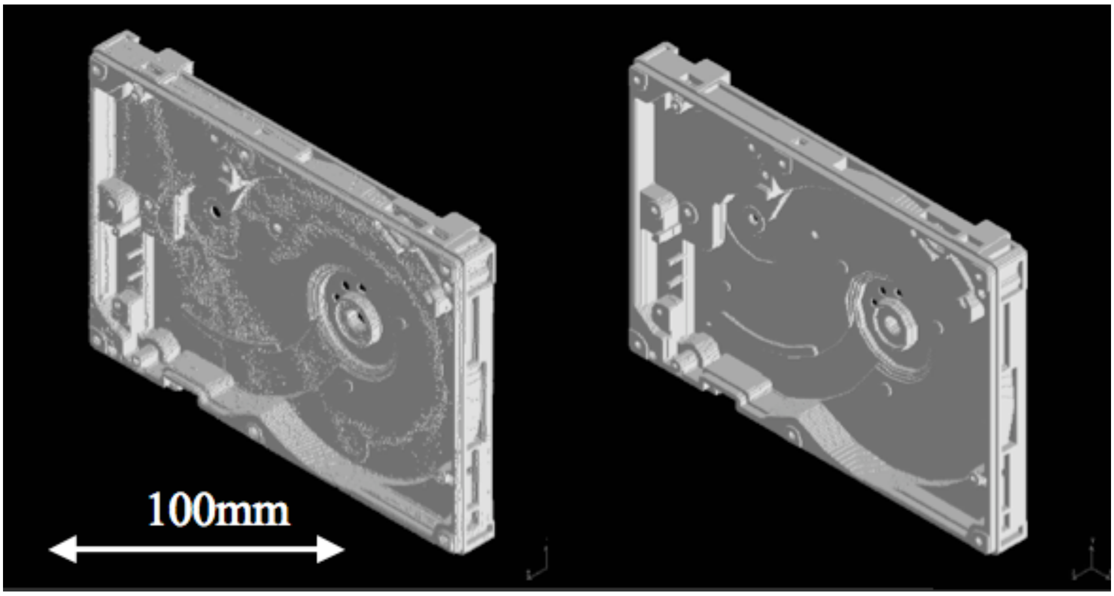

Figure 9 Comparison of the CT data (left) and CAD data (right) of Hard-disk Plastic Cover

Last is shown in Fig. 9, as example of “Reverse Engineering”, comparison between CAD data and CT data of hard-disk plastic cover. Left of the Fig. 9 is CT data and right is CAD data. With the detailed calculation of software "VOXELCON" developed by Fujitsu Limited and Quint Corporation, it was confirmed that CT data agreed CAD data substantially. In the near future, it will be possible that the CAD data will be derived and obtained from the CT data of the tested samples. That is to say, the true meaning of "Reverse Engineering".

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