Application of X-ray Microtomography to Evaluate Thermal Fatigue Crack Propagation and Lifetime in Flip Chip Interconnects

In high-density packaging technology, one issue of particular importance is the enhancement of reliability in micrometer-sized joints connecting LSI (large scale integrated circuit) chips to PCBs (printed circuit boards) electrically and mechanically. A microstructure approach is required to evaluate the reliability of these so-called microjoints, which are significantly affected by fatigue damage (microstructure evolution or fatigue cracks, etc.). To evaluate the microstructure damage due to fatigue, the development of a nondestructive inspection technology is highly desirable for industries producing electronic devices and components. However, none of the microstructure images of the joints obtained by industrially used nondestructive inspection methods such as ultrasonic flaw detection, X-ray radiography or X-ray tomography have sufficient spatial resolution. In this work, an X-ray microtomography system called SP-μCT with a spatial resolution of about 1 μm [1] was applied to the evaluation of thermal fatigue crack propagation and lifetime of solder microbumps in flip chip interconnects.

The specimens have a flip chip structure in which an LSI chip is mounted on an FR-4 substrate by joining Sn-37wt%Pb eutectic solder bumps 100 μm in diameter. A thermal cycle test was carried out under accelerated conditions with upper temperature 125°C, lower temperature –40°C and holding time 30 min. The specimens were picked up after various numbers of test cycles and the solder bumps were observed by using SP-μCT at **BL20XU**. Under typical measurement conditions 1800 projections were taken in 0.1° steps during 180° rotation, and the exposure time for each projection was 0.2 sec. The refraction-contrast imaging technique was applied to visualize fatigue cracks in the solder bumps. That is, the distance between the X-ray beam monitor and the specimen was optimized so as to maximize the contrast of the crack edges imaged by Fresnel diffraction.

Figure 1 shows a three-dimensional image of a specimen loaded for 300 cycles under the accelerated conditions. For convenient observation of the inner structure, the Si chip and some components are not shown in the image. The microstructure of the bumps and the fiber orientation of the FR-4 substrate are clearly identified.

The CT images in Fig. 2 show the process of microstructure change and crack propagation on the same cross section of the same solder bump due to the thermal cyclic loading [2]. After 100 cycles, no thermal fatigue cracks were observed and the microstructure maintained its initial characteristic state with fine, dispersed Pb-rich phases. After 300 cycles, fatigue cracks appeared at the corners of the interface between the solder bump and the Cu pad. This number of cycle corresponds to the mean lifetime of fatigue crack initiation determined by SEM (scanning electron microscope) destructive observation.

As the number of thermal cycle increases, the cracks gradually propagate to the inner region of the solder bump. The lengths of the same fatigue cracks were measured consecutively from CT images obtained at the centers of the same bump. Figure 3 shows the crack propagation process for some solder bumps in terms of the relationship between the fatigue crack length and the number of cycles N. The fatigue crack propagation is characterized by the average propagation rate being approximately constant even though transient acceleration or stopping is observed in each solder bump. The average propagation rate was calculated to be 0.058 μm/cycle, and the total fatigue crack lifetime to failure N_f was estimated as N_f = 1800 cycles. This estimate is relatively precise because the mean fatigue lifetime to failure determined by SEM observations was less than 2000 cycles.

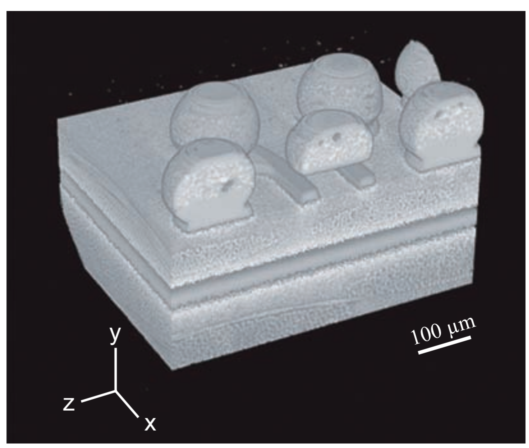

Fig. 1. Volume-rendered image of a flip chip specimen.

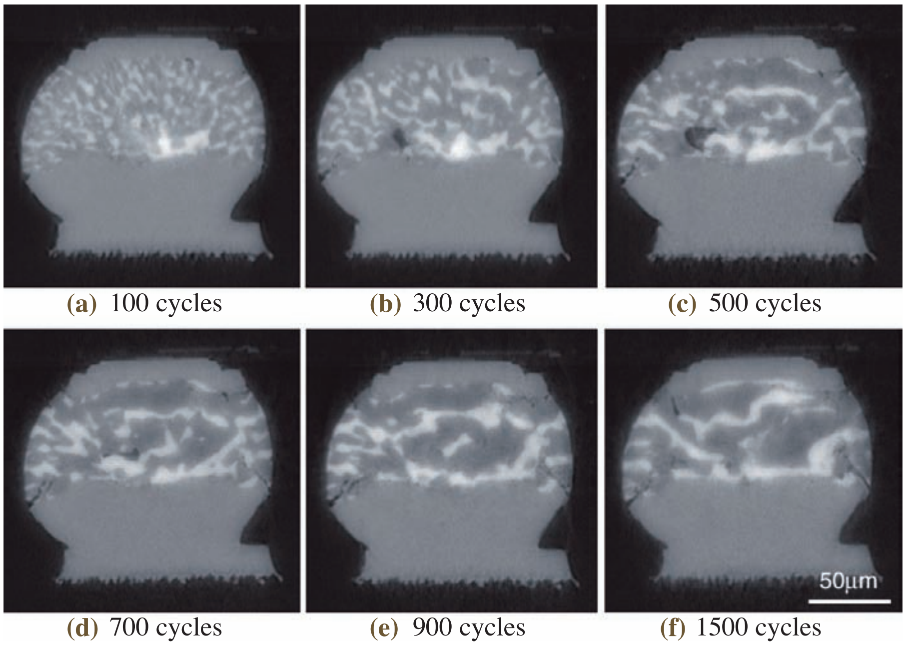

Fig. 2. CT images of the same solder bump showing fatigue crack propagation induced by thermal cyclic loading.

These results were not obtained by industrially used nondestructive inspection systems, and show that nondestructive testing by a synchrotron radiation X-ray micro-CT system is useful for evaluating the thermal fatigue lifetime in microjoints.

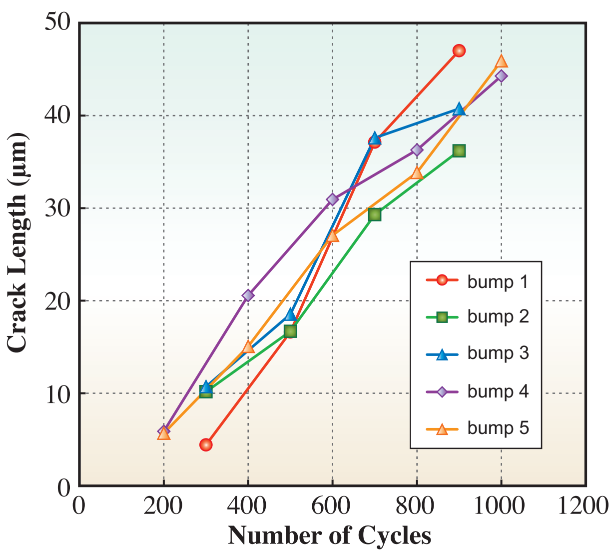

Fig. 3. Crack propagation process in solder bumps during thermal cyclic loading.

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References

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