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Nondestructive Warpage Measurements of LSI Chips in a Stacked SiP by Using High-Energy X-ray Diffraction

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1. Introduction

Advanced packaging technologies, including chip thinning, chip stacking, etc., can increase the influence of mechanical stress on LSI chips. On the other hand, mechanical stress in LSI chips is known to affect their electrical characteristics [1, 2]. Furthermore, large warpage can lead to chip crack and failure of wiring. Therefore, the chip warpage characterization in packages is important. However, nondestructive warpage measurements of packaged LSI chips have not been reported yet because of the lack of nondestructive measurement methods.

We applied high-energy X-ray diffraction using a laboratory scale diffractometer to examine the warpage of a packaged LSI chip without destruction [3]. In this paper, we describe its details and demonstrate that it is possible to measure the warpage of LSI chips stacked in a system in package. Our examination shows that the stress due to printed circuit board substrate and that by molding resin affects the chip warpage.

2. Warpage measurements by high-energy X-ray diffraction

A higher energy X-ray suffers less absorption in a medium [4]. Thus it is effective for nondestructive warpage measurements. Figure 1(b) is the Si (0 0 4) rocking curve from the ball grid array (BGA) package drawn in Fig. 1(a). Cu $K\alpha$ radiation of 8.04 keV energy was used. A diffracted X-ray is not observed because of the absorption by molding resin. Figure 1(c) shows the Si(0 0 12) rocking curve obtained using Mo $K\alpha$ radiation of 17.5 keV energy. A diffracted X-ray is observed at ω=51.5 deg.

Without warpage, if diffraction occurs at position A on the chip (Fig. 2(a)), diffraction occurs also at position B (Fig. 2(b)) because the angle between chip surface normal, $\boldsymbol{n}$, and the propagation direction of an incident X-ray, α, equals a particular value α_B at both positions. For a warped chip, even if diffraction occurs at position A (Fig. 3(a)), a diffracted X-ray does not generate at position B (Fig. 3(b)) since the value of α does not equal α_B by warpage. To observe diffracted X-ray here, ω must be adjusted to cancel the change in α (Fig.3(c)). Therefore, chip warpage can be obtained from the change in ω at which diffraction occurs. The changes in rocking curves due to warpage are shown in Fig. 4. The peak position change corresponds to the change in the direction of chip surface normal.

3. LSI chip warpage in a BGA and a System in Package

Figure 5 shows the chip warpage in the BGA package depicted in Fig. 1(a). Before the packaging process, the chip warps into a convex below less than 2μm. After the packaging process, the warpage increases to 11μm. Furthermore, the warpage changes direction after molding resin is removed. This is because tensile stress due to the printed circuit board (PCB) substrate emerges by removing molding resin that has compressive stress. The warpage after packaging process is considered to be determined by the balance of the thermal stresses at chip mounting and at resin molding.

Figure 6(b) is the Si(0 0 8) rocking curve from the stacked System in Package (SiP) drawn in Fig. 6(a). Mo $K\alpha$ radiation was used. It was possible to detect the diffracted X-rays from three chips. Since the X-ray diffracted by the lower layer chip should be absorbed more, in order of intensity, the three peaks are considered to belong to the first, second, and third chips from the top, respectively. Figure 7 indicates the warpage of the three chips. They were found to warp into the shape of waves before high temperature storage. This warpage is different from the chip warpage in a single chip BGA package. This difference seems to have been caused by the difference of the balance of the stresses due to PCB substrate and molding resin. After the high temperature storage at 150 ºC for 900 hrs., the warpage of the three chips changed into the warp convex below. This change may have resulted from the thermal deterioration of molding resin and/or PCB substrate. It is also suggested that the long-time use of packaged LSI at high temperature can lead to the characteristic variation originating from the warpage change.

4. Conclusions

By using high-energy X-ray diffraction in a laboratory scale diffractometer, the warpage of the packaged LSI chip(s) was clarified without destruction. The stress caused by PCB substrate and molding resin affects the chip warpage. High temperature storage changes the warpage direction of LSI chips in a stacked SiP. High-energy X-ray diffraction is effective to measure the LSI chip warpage in a SiP nondestructively.

Acknowledgements

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References

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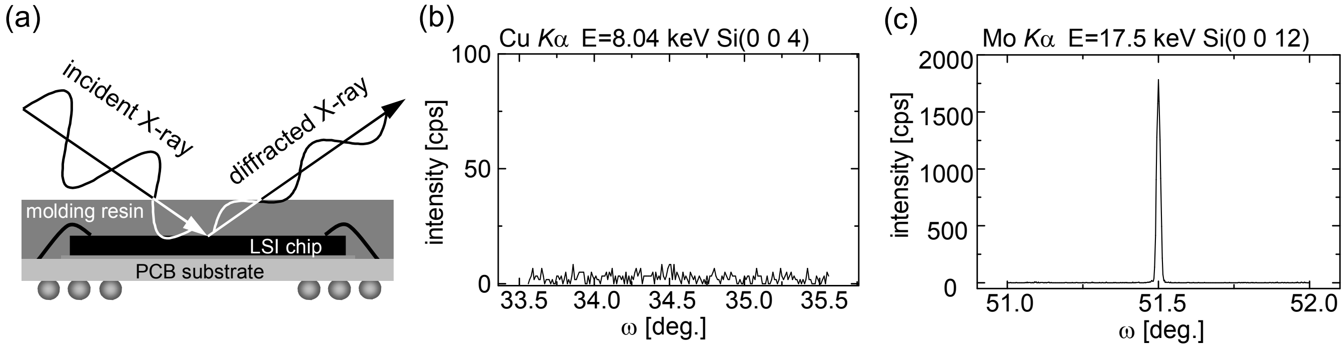

Fig. 1 (a) Schematic image of BGA package. (b) Si(0 0 4) rocking curve by Cu $K\alpha$ radiation . (c) Si(0 0 12) rocking curve by Mo $K\alpha$ radiation.

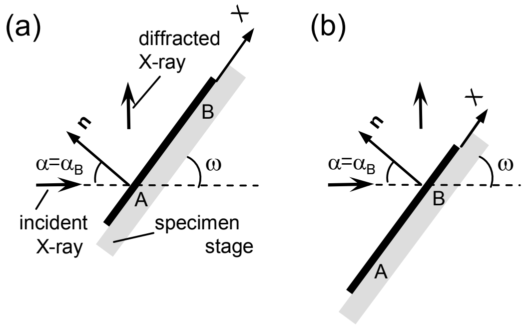

Fig. 2 Diffraction from a chip without warpage. At positions A (a) and B (b), diffraction occurs.

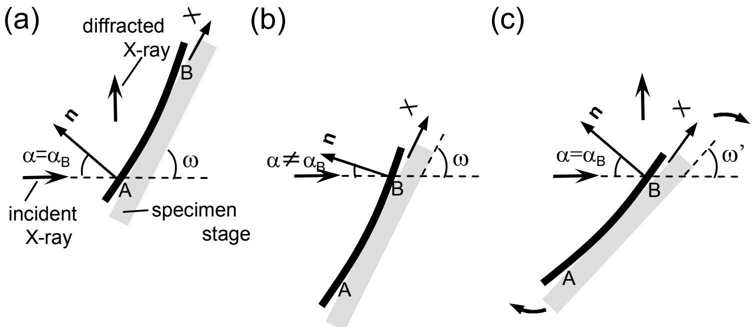

Fig. 3 Diffraction from a warped chip. (a) At position A diffraction occurs. (b) At position B, diffraction does not occur because of warpage. (c) By adjusting ω to cancel the warpage, diffraction occurs at position B.

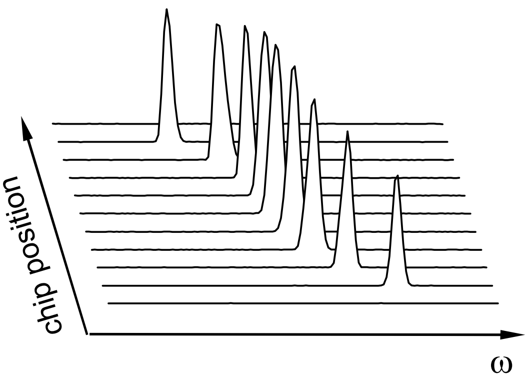

Fig. 4 Chip position dependence of rocking curve from the LSI chip in a BGA package.

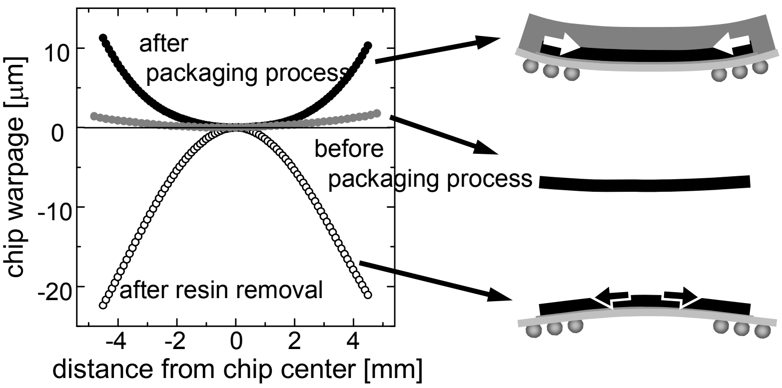

Fig. 5 Chip warpage in a BGA package at each state.

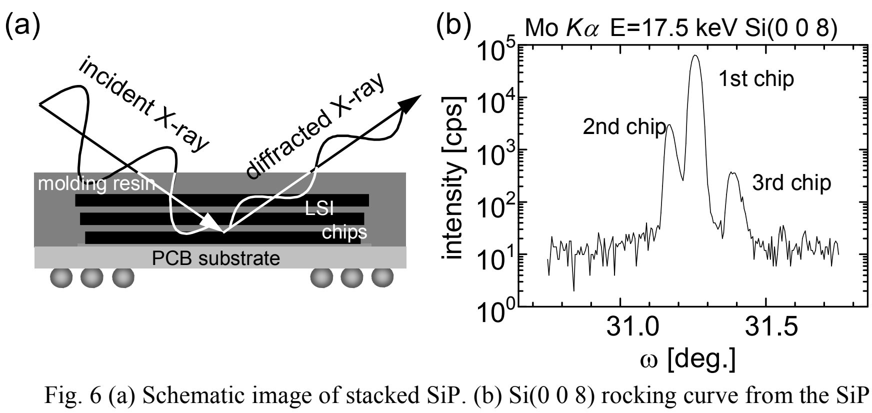

Fig. 6 (a) Schematic image of stacked SiP. (b) Si(0 0 8) rocking curve from the SiP using Mo $K\alpha$ radiation. Diffracted X-rays from three LSI chips are detected.

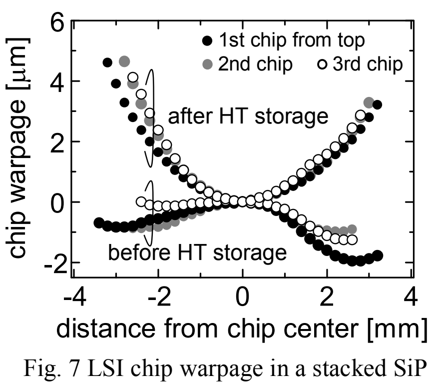

Fig. 7 LSI chip warpage in a stacked SiP before and after high temperature (HT) storage.