Microstructure Evolution and Stress-Strain Analysis of Wafer Level Chip Scale Package (WL CSP) Solder Joints with Different Thermal Cycles

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Introduction

The primary failure mode in Sn-Ag-Cu solder interconnects during thermal cycling is coefficient of thermal expansion (CTE) mismatch-induced cracking in the bulk solder near the chip-side interface. Because the reliability of solder joints can be affected by various factors (package design, anisotropy, thermal cycling etc.), quantitative studies on microstructural evolution and its mechanism need to be carried out on particular joints through their histories.

In this study, a complete outer row of solder joints in a fully assembled WL CSP unit were studied with incremental thermal cycling.

Materials & Experiments

The sample configuration is shown in Fig. 1, A generalized Schmid factor m for each slip system was calculated using the equations in Fig. 1 (* means unit vector), using pure shear in a direction from the center of the package (neutral point) as an estimate of the stress acting in the joint.

Optical microscopy, scanning electron microscopy (SEM) and electron backscatter diffraction (EBSD) were performed to assess the microstructural changes due to thermal cycling.

Slip trace analysis was performed to identify the active slip systems during thermal cycling. Fig. 2 demonstrates one example of this analysis.

![Figure 2 Example of slip trace analysis based on SEM images and Schmid factors](image)

Figure 2

General Microstructural Evolution

The optical micrographs in Fig. 3a and b show initially uniform surfaces, but after 112TC, darker regions indicating surface roughening appear at the top of joints 1, 2, 3, 5, 6, and 9 in sample A, but only the two corner joints (1, 10) in sample B. This implies that more plastic deformation occurred in sample A than sample B. Deformation continued to develop in the same manner with further cycling. Enlargements of surface topography were observed in all joints in sample A, while no dramatic change occurred in sample B except in balls 1 and 10.

Two joints are investigated in detail to determine how the microstructure evolution took place and how this is correlated with observed slip activity and grain boundary characteristics.

Case Study 1: Continuous Recrystallization

Dislocation slip activity was examined in ball 3 of Sample A in Fig. 4, which has a dominant dark-green orientation. This solder joint has a different orientation from the other joints in the same row, so shear strain as well as normal strain would be imposed. Slip system 7 and 12 were activated after 112 TCs and more slip systems were activated after 219 TCs.

During thermal cycling, the number fraction of boundary rotation axes changed dramatically, as shown in Fig. 4(f). An increase of grain boundaries with [110] rotation axes has been correlated with activation of facile slip system #2 [110][001] [11].

![Figure 4 (a) Optical image and (b) c-axis EBSD maps of ball 3 in sample A in different thermal cycling conditions; (c), (d) & (e) are magnified optical, c-axis maps and grain reference orientation deviation maps of the boxed area in (a); (f) is number fraction of lengths of grain boundaries with different rotation axis.](image)

Figure 4

Case Study 2: Damage Propagation & Twin boundary

Fig. 5 shows the microstructure evolution with slip activities in ball 10 of Sample B. At the top right corner of this joint (red box in Fig. 5a), there is a pre-existing twin boundary. It can be observed in Fig. 3c that more slip activity was present within the twin after 112 TCs, and this activity was further enhanced with more TCs. However, slip traces in the parent grain were not obvious until 219 TCs.

Fig. 5e shows changes in the twin boundary with increased thermal cycling. Further analysis in Fig. 5f showed that in the first 112 TCs, the propagation of a grain boundary ledge was facilitated by the activity of slip system #9; after 219 TCs, propagation of the ledge changed direction and the new trajectory matches the traces of slip systems #7 & 8. Further propagation of this ledge was stopped and the boundary followed the twin boundary. Similar observations can also be found at the top right corner of this joint.

![Figure 5 (a) Optical image and (b) c-axis EBSD maps of ball 3 in sample A in different thermal cycling conditions; (c) and (d) are magnified optical and c-axis maps of the boxed area in (a); (e) is a schematic of the twin boundary evolution; (f) magnified SEM images and EBSD maps of the twin boundary evolution.](image)

Figure 5

Conclusion

1. Two rows of solder joints from sectioned WL CSPs showed very different slip activity during thermal cycles, which can be explained by the grain orientation and CTE mismatch.
2. Development of grain boundary ledges and continuous recrystallization are correlated with slip activity.
3. Random high-angle grain boundaries are more vulnerable to crack or grain boundary ledge formation, twin boundaries showed more resistance to cracking or ledge formation.

References


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