Failure of SAC solder under thermal cycling

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Introduction

β-Sn in eutectic Sn-Ag-Cu (SAC) solder exhibits anisotropy in its elastic and thermal expansion properties that may induce a significant amount of stress at Sn-grain boundaries during thermal cycling [1]. Damage can initiate at boundaries with maximum induced normal/shear stress. Therefore, details investigation of failure in solder joints under thermal cycling has a paramount importance for the reliability concern of microelectronics devices.

Experimental techniques

Shown in Fig. 1 (a) is a solder joint (height = 0.3 mm, length = 5 mm) prepared using commercial solder pastes (Multicore Ltd., UK). Copper blocks of dimensions 25mm $\times$ 10mm $\times$ 1mm were used as substrates.

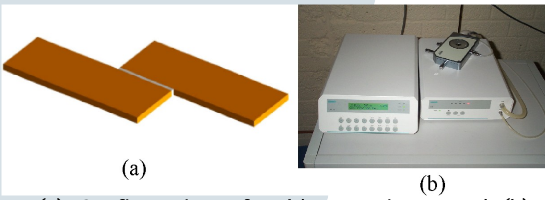

Figure 1 *(a) Configuration of solder specimen and (b) Linkam heating-cooling stage.*

The specimens were thermally cycled within three temperature ranges (ΔT) of 253 K to 353 K, 293 K to 353 K, and 253 K to 401 K using Linkam stage (Fig. 1 (b)). Backscatter-electron-microscopy, polarizing light microscopy and orientation imaging microscopy (OIM) were performed for characterization purpose.

Results and discussion

Fig. 2 shows optical micrographs from an identical area of a solder interconnection before and after thermal cycling within 253 K to 353 K (Δ T = 100 K). Cracks formation along grain boundary can be observed after thermal cycling (TC) (see Fig. 2 (b)).

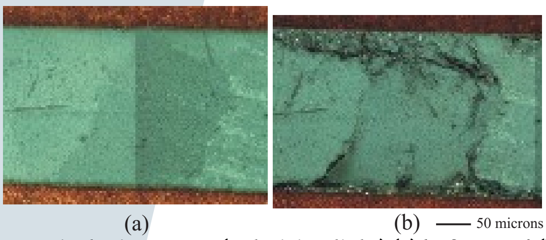

Figure 2 *Optical microscopy (polarizing light) (a) before and (b) after thermal cycling within ΔT of 253 K to 353 K for 1000 cycles.*

BSE micrograph obtained from the same area after TC is presented in Fig. 3 (a). One can see localized damage along grain boundaries and near to the interface between solder and substrates. Another observation from a joint thermally cycled between 293 K to 353 K for 1000 cycles also shows sliding (SL)/separation (SP) of grain boundaries (see magnified image of marked area "2" in Fig. 3 (b)). Two arrows in the micrograph of magnified image of marked area "3" indicate propagation of microcracks that linked together. It also depicts some prominent shear bands.

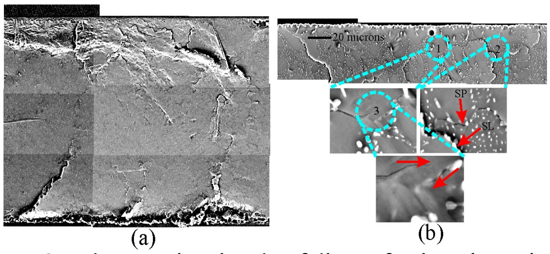

Figure 3 *BSE micrographs showing failure of colony boundaries after TC within ΔT of (a) 253 K to 353 K and (b) 293 K to 353 K for 1000 cycles.*

Figs. 4(a)–(b) show inverse pole figure (IPF) maps before and after thermal cycling within 253 K to 353 K. Colors in these maps indicate orientations of crystals. Highly misoriented grain boundaries have been identified through OIM analysis. Cracks initiate and propagate along these boundaries (see for instance Fig. 4 (b)). IPFs of Sn, Ag_3Sn, and Cu_6Sn_5 are presented in Figs. 4(c)–(d) which depict crystallographic orientation relationship among those phases.

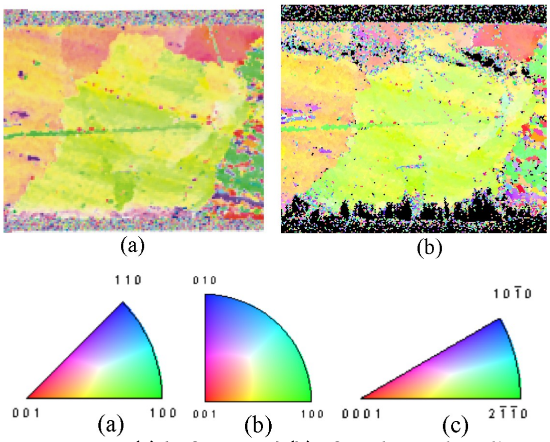

Figure 4 *IPF maps: (a) before, and (b) after thermal cycling. IPFs for (c) Sn, (d) Ag_3Sn, and (e) Cu_6Sn_5.*

The degree of crystallographic misorientations at Sn grain boundaries determines induced local 3-D stress state during thermal excursions. Sliding and separation of boundary can be attributed to the induced maximum shear stress parallel to the boundary and maximum principal stress perpendicular to boundary respectively.

Conclusions

Grain-boundary sliding/separation and shear band formation are the predominant damage phenomena in solder under thermal cycling. Amount of induced damage increases with increase in ΔT.

References:

[1] Subramanian, K. N. and Lee, J. G. : *Journal of materials science 15, 235, 2004.*

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