Post Mechanical Shock Test Failure Analysis on Mixed SnAgCu-BiSn BGA Solder Joints

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***Abstract*—Drop Shock Reliability of mixed alloy SnAgCu-BiSn Flip Chip BGA solder joints assembled on a Shock Test Board with two different surface finishes (Cu Organic Solderability Protectant and Electroless Nickel Immersion Gold) using three different categories of BiSn solder pastes was investigated. A metallographic analysis of the failed solder joints was undertaken to ascertain location of the cracks, their propagation paths, and to characterize microstructural features close to the cracks. Results indicated all failures occurred close to the solder-to-board land interface. The diminished reliability of solder joints on the nickel-gold based surface finish was determined to be due to the crack propagation pathway being between the intermetallic compounds and the Ni(P) layer. For the copper surface finish, the crack pathway was within the solder just above the intermetallic compound layer, and this resulted in a higher shock resistant solder joint. Bi wt% analysis in the crack region revealed that the enhancement of the solder ductility by minor quantities of elemental additions more than compensated for the higher localized Bi wt% concentration near the board lands, improving the solder joint shock reliability.**

Keywords— Low Temperature Solder, BGA solder joints, Bi-Sn metallurgy, Mechanical Drop Shock Reliability

I. INTRODUCTION

iNEMI has an ongoing Low Temperature Solders Process and Reliability (LTSPR) Project with the goal of developing low temperature BiSn solder pastes for use in assembling board products within the consumer computer industry. As part of the Mechanical Shock Reliability Assessment phase of this project, mixed SAC-BiSn alloy solder joints of a high density FCBGA component were subjected to multiple shock drops under relevant testing conditions. These components were assembled on a specially designed shock test board (STB) with either Copper Organic Solderability Protectant (Cu OSP) or Electroless Nickel Immersion Gold (ENIG) surface finish on its lands, using 12 different BiSn metallurgy solder pastes from leading suppliers in the industry. Three of the solder pastes were `baseline` BiSn eutectic solder pastes with varying amounts of Ag. Four were of the Joint Reinforced paste (JRP) type, which created polymeric reinforcement around the solder joints near the PCB land. The remaining five solder pastes were termed `ductile BiSn` because these solders were developed specifically by the suppliers to enhance their ductility by various metallurgical strategies [1]. Results from these shock tests have been published in the recent past [2,3]. A summary of the salient Shock Test results follows.

By comparing one of the two most reliable ductile BiSn solder pastes, code named Sultan 2, with one of the BiSn baseline (BiSnAg) solder pastes, code named Balik Pulau (0.4% Ag), this paper discusses the solder joint mechanical shock reliability differences between Cu OSP and ENIG surface finishes. The metric used in this study to compare the mechanical shock reliability of the FCBGAs formed with various solder pastes was the characteristic life (eta) of the Weibull plot drawn from the shock test's in-situ failure data. As illustrated in Fig. 1(a), Solder Joints formed on Cu OSP surface finish lands were significantly better in shock drop reliability than those formed on ENIG surface finish lands. The solder paste with the better reliability was different for the two surface finishes. This is in evidence from Fig. 1 (b) and 1 (c). Solder Joints formed on ENIG surface finish lands using the BiSn baseline paste Balik Pulau exhibited higher shock drop resistance than those formed by the ductile BiSn solder paste Sultan 2, even though the solder metallurgy in the Sultan 2 paste was designed to impart higher ductility to the solder joints. For solder joints on Cu OSP lands, the Sultan 2 ductile BiSn pastes were, as expected, more reliable than the Balik Pulau BiSn baseline solder joints.

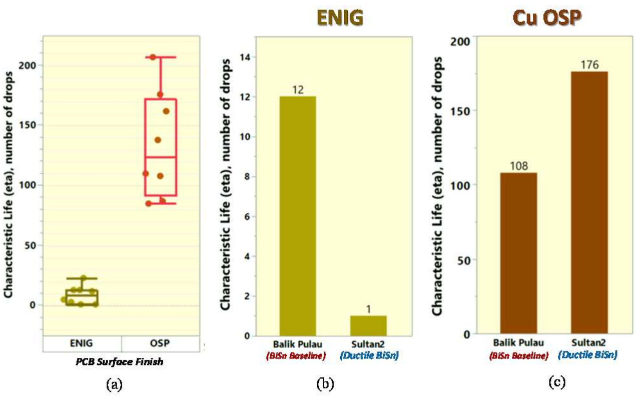

Fig 1. Characteristic Life comparison for FCBGA Solder Joints on Cu OSP and ENIG Surface finishes, between a BiSn baseline solder paste and a ductile BiSn solder paste.

To investigate possible causes of these shock results, failure analysis (FA) was performed on failed solder joints from STBs assembled with Balik Pulau and Sultan 2 solder pastes on both Cu OSP and ENIG surface finishes.

II. FAILURE ANALYSIS

Failure Analysis of the post Shock BGA samples encompassed making cross-sections of the failed solder joints and inspecting them under optical microscopy and in a Scanning Electron Microscope (SEM). For each leg of the experiment, the location of, and propagation path of the cracks within the failed solder joints was determined. The thickness and morphology of the intermetallic compounds (IMCs) layer was measured with high-magnification SEM images. The element composition of the IMCs layer and the average Bi wt.% in the region where the crack propagated, were also analyzed by Energy Dispersive X-ray Spectroscopy (EDS).

III. RESULTS AND CONCLUSIONS

The results from failure analysis are recorded in Table I. Measurement of the various attributes of interest for each of the two Solder Paste legs, evaluated on both surface finishes used, are listed.

The failure crack was always located at or near the PCB land interface. This is to be expected since the highest concentration of the brittle Bi phase resides in that location in mixed alloy SAC-BiSn solder joints, as seen in the solder joint cross-section images in Fig. 2. The predominant discovery in this study was the difference between the crack propagation paths for the Sultan 2 ductile BiSn solder joints on the ENIG surface finish and that for the other 3 legs. As shown in Fig. 2, the path for the Sultan 2 ENIG solder joints was between the IMC layer and the Ni (P) layer in the land layer stack-up. For the other 3 legs, including the Balik Pulau ENIG leg, the path was in the solder joint just above the IMC layer.

Elemental IMC composition data in Table I indicates that the IMC formed with Cu OSP contains, as expected, Cu and Sn for both solder paste legs. For the Balik Pulau leg with ENIG, the IMC contains (again as expected), Cu, Sn and Ni. However the IMC formed on ENIG with Sultan 2 paste contains other elements too, such as Pd, Sb, Au. As mentioned earlier, the minor amounts of specific elements are added to Sultan 2 solder to impart ductility to the alloy. Whether the presence of these elements in the IMC causes a change in the crack propagation pathway needs to be investigated further.

The reflow soldering process could also have an effect in the location of the crack propagation path for the Sultan 2 on ENIG. Reflow soldering of the Sultan 2 solder paste was done at a peak temperature range of 190ºC to 194ºC, in contrast to that for the Balik Pulau solder paste which was 180ºC to 184ºC. Higher reflow soldering temperatures can lead to void formation within the Ni(P) layer under the IMC due to Ni being used up to form the IMC with Sn unable to diffuse in its place. These voids would weaken the Ni(P) layer.

TABLE I. FAILURE ANALYSIS RESULTS

	Code Name			
Attribute	***Balik Pulau***		***Sultan 2***	
PCB Surface Finish	Cu OSP	ENIG	Cu OSP	ENIG
Failure Crack Location	Near or at the Solder Joint-to-PCB land Interface			
Crack Propagation Interface	Solder + Solder/Cu_3Sn IMC	Solder / Sn-Cu-Ni IMC	Solder/ Cu-Sn IMC	Ni_3Sn_4 + solder/ Ni(P) land
Avg. IMC Thickness (µm)	0.9	1.1	1.1	2.0
IMC Morphology	Scallop Type	Needle Type	Scallop Type	Needle Type
IMC Elemental Composition	Cu_3Sn	Cu, Sn, Ni	Cu, Sn	Cu, Sn, Ni, Pd, Au, Sb
Avg. Bi wt.% in cracked region	16.6	15.9	21.7	23.4

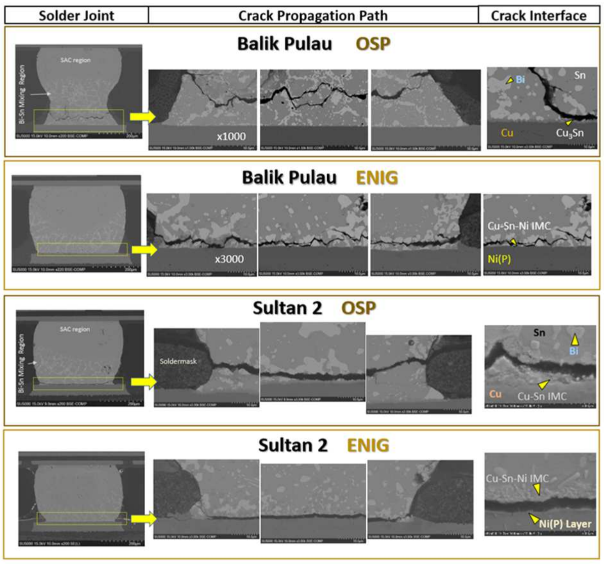

Fig 2. SEM Micrographs depicting the post Mechanical Shock test crack locations for solder joints on the Balik Pulau OSP and ENIG surface finish boards (top two rows) and on the Sultan 2 OSP and ENIG surface finish boards (bottom two rows).

An interesting finding from the FA showed that high Bi wt% in the cracked region of the Sultan 2 paste solder joint on the Cu OSP surface finish did not result in diminished reliability. It was in fact significantly better than that for the Balik Pulau formed solder joints on Cu OSP. Addition of the elements in minor amounts to increase solder ductility by microstructural refinement more than compensates for the high amount of brittle Bi phase in the cracked region.

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