Intermetallic Compound Formation Behavior and Bump Shear strength at Sn-In Eutectic Solder/UBM Interface

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Abstract

Reactions between 48Sn-52In solder and under bump metallurgies(UBM) such as 100nm Ti/8 μm Cu and 300nm Al/400nm Ni(V)/400nm Cu have been investigated, and the shear strength of 48Sn-52In solder bumps on each UBM has been evaluated. While intermetallic compounds with two different morphologies were continuously thickened on Ti/Cu with repeating the reflow process, the intermetallics on Al/Ni(V)/Cu spalled into the solder with increasing the number of reflow times. The solder bumps on Ti/Cu exhibited higher shear strength than those on Al/Ni(V)/Cu.

1. Introduction

Recently, chip on glass(COG) technologies using anisotropic adhesive film(ACF) or solder bump reflow have been investigated to attach IC chip directly on glass substrate of liquid crystal display(LCD) panel [1-4]. Compared to one with ACF, the COG process using solder bump reflow has several advantages such as low contact resistance at solder joints and self-alignment during reflow [4]. As IC chip and LCD panel have to be heated to reflow temperature of the solder bumps for the COG bonding, it is necessary to use low-temperature solders such as Sn-In, Sn-Bi, Ag-In to prevent the damage of the liquid crystals and polarization plate of the LCD panel during the COG process [4].

In the COG process utilizing solder bump reflow, the reaction between solder and under bump metallurgy(UBM) is of great importance as the yield and reliability of the solder joints are of concern. UBM should have good wettability to solder so that a rapid solder reaction occurs simultaneously in all the solder joints on the chip. At the same time, the growth rate of intermetallic compounds at the interface between solder and UBM should be slow enough to ensure that the UBM will not be consumed completely so that it can survive a prolonged reaction before dewetting occurs [5].

In this study, interfacial reactions between 48Sn-52In solder and UBMs such as Ti/Cu and Al/Ni(V)/Cu have been investigated, and the shear strength of 48Sn-52In solder bumps on each UBM has been evaluated.

2. Experimantal

Under bump metallurgies of 100nm Ti/8μm Cu and 300nm Al/400nm Ni(V)/400nm Cu were deposited on Si wafers by DC magnetron sputtering of Ti and Al first and then Cu and Ni(V)/Cu on top of Ti and Al, respectively. Commercially available 48wt% Sn-52wt% In ingot was rolled to a sheet of 60㎛ thickness, manually punched out to make discs of 1.2㎜ diameter, and then immersed into mildly activated rosin (RMA) flux at 150±3℃ to form spherical beads. The samples for soldering reaction were prepared by dropping a solder bead on each UBM of 1㎝ × 1㎝ in heated rosin flux at 150±3℃ for a duration time of 1 minute. Such reflow process was repeated for 1, 5, 10, and 20 times, respectively. The reflowed samples were mounted in an epoxy resin, and ground and finally polished using diamond pastes down to 1㎛ particle size. To expose the interfacial compounds, samples were preferentially etched using the etchant composed of 10㎖ HF, 10㎖ H_2O_2, and 80㎖ H_2O. Backscattered electron image(BEI) mode of a scanning electron microscopy(SEM) was used to observe the intermetallic compounds formed at solder/UBM interface.

To make samples for ball shear test, 100㎚ Ti was sputtered as solder mask to define Ti/Cu and Al/Ni(V)/Cu UBM pads of 500㎛ in diameter using photolithography. Solder balls of 48Sn-52In were reflowed at 150℃ for 1 minute on the UBM pads in a RMA flux ambient, and such reflow was process was repeated for 1, 5, 10, and 20 times, respectively. Ball shear test was conducted using Dage-BT4000 shear tester at a constant shear speed of 100㎛/sec with a fixed shear tip position at 150㎛ above the solder mask surface. For each reflow condition, more than 30 solder bumps were sheared off to obtain the ball shear strength.

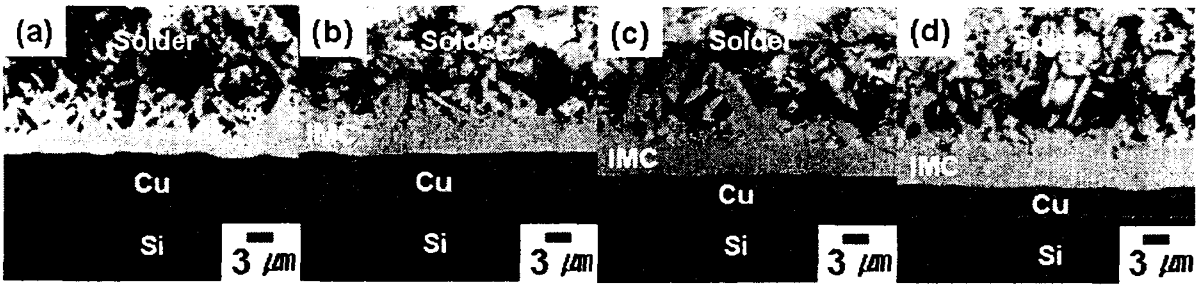

Fig. 1. SEM micrographs of the 48Sn-52In solder on Ti/Cu after (a) 1 reflow, (b) 5 reflows, (c) 10 reflows, and (d) 20 reflows.

3. Results and Discussion

Fig. 1 shows cross-sectional SEM images of the 48Sn-52In solder reflowed on 100㎚ Ti/8㎛ Cu UBM for 1, 5, 10, and 20 times, respectively. It has been reported that only phase of $Cu_2(In,Sn)$ composition forms during soldering reaction of 48Sn-52In and 49Sn-51In on Cu at temperatures below 200℃ [6,7]. As shown in Fig. 1, the intermetallic compounds were consisted of two different morphologies, scallop-type structure on the solder side of the interface and planar layer on the Cu side of the interface. At the initial stage of reflow, scallop-type intermetallics were formed at the molten 48Sn-52In/Cu interface and then grew laterally to make grooves disappear, which resulted in the formation of planar intermetallic layer [6]. As the reflow proceeded, the scallop-type intermetallics grew into the molten 48Sn-52In with diffusion of Cu atoms through the intermetallics, while planar layer-type intermetallics grew into the Cu UBM with diffusion of Sn and In atoms through the intermetallics [6]. This growth mechanism of the intermetallics may explain the microstructure of two different morphologies shown in Fig. 1.

Variation of the Cu UBM thickness is shown in Fig. 2 as a function of the number of reflow process. Cu consumption rate during reaction with 48Sn-52In at 150℃ was estimated as 160nm per 1 min reflow, that is, 160nm/min. Consumption rate of Cu to the molten 63Sn-37Pb at 240℃ has been reported to be 230nm/min [8]. Although the reflow temperature of 48Sn-52In, 150℃, was much lower than 240℃ for 63Sn-37Pb, the consumption rate of Cu to molten 48Sn-52In was comparable, even though lower, with that to the liquid 63Sn-37Pb. This might be attributed to the fact that In as well as Sn in the molten 48Sn-52In is involved in the soldering reaction on Cu to form intermetallics. On the contrary, Pb in the molten 63Sn-37Pb does not react with Cu and does not contribute to the Cu consumption during reflow.

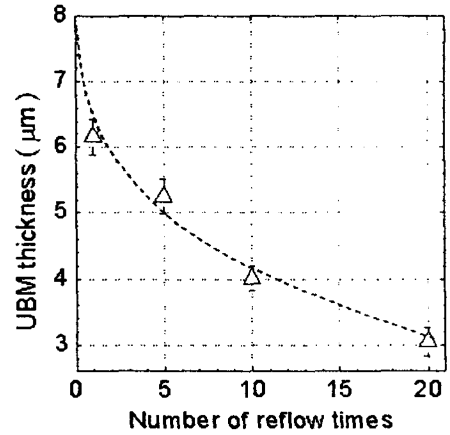

Fig. 2. UBM thickness as a function of the number of reflow times.

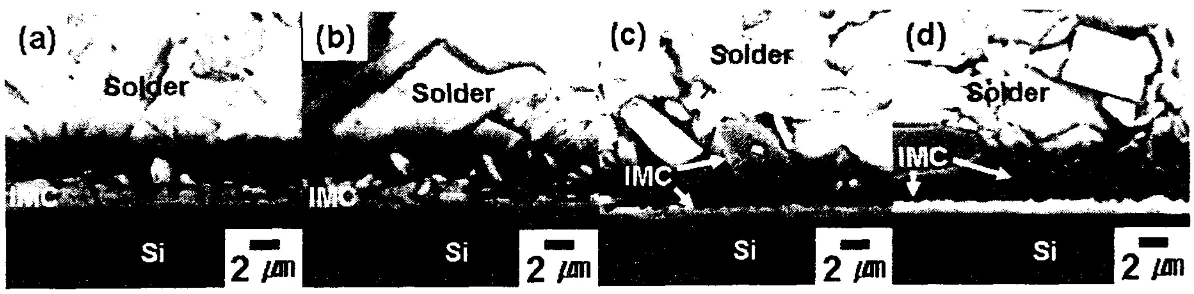

Fig. 3. SEM micrographs of the 48Sn-52In solder on Al/Ni(V)/Cu after (a) 1 reflow, (b) 5 reflows, (c) 10 reflows, and (d) 20 reflows.

Fig. 3 illustrates cross-sectional SEM images of the 48Sn-52In solder reflowed on 300nm Al/400nm Ni(V)/400nm Cu UBM for 1, 5, 10 and 20 times, respectively. The intermetallics were adherent to the UBM layer after 1 and 5 reflows. However, spalling of the coarse, rectangular-shaped intermetallics occurred at 10 and 20 reflows. It has been reported that only one compound, either $Ni_{28}In_{72}$ or Ni_3Sn_4 phase formed with reaction of Sn-In alloys at 160℃ [9]. Due to the extensive ternary solubility of the binary compounds in Sn-In-Ni alloys system, it was difficult to identify the phase of the intermetallics in Fig. 3 using EDS analysis. As shown in Fig. 2, the consumption rate of Cu to the molten 48Sn-52In at 150℃ was about 160nm per 1 min reflow. Thus, the 400nm-thick Cu in Al/Ni(V)/Cu UBM was dissolved completely and Ni(V) layer was exposed to the molten 48Sn-52In during reflow for 5 times. As the consumption rate of Ni to the molten 63Sn-37Pb at 240℃, 0.89×10^{-3} µm/s [10], is about 4 times slower than 3.84×10^{-3} µm/s of Cu [8], the consumption rate of Ni to the liquid 48Sn-52In at 150℃ would be lower than that of Cu. However, complete spalling of the coarsened intermetallics, shown in Figs. 3(c) and (d), may suggest that the 400nm-thick Ni(V) layer was consumed all by the reflow for 10 times and more. As Sn does not wet Al, dewetting of the 48Sn-52In solder would occur complete consumption of Cu and Ni(V) layers in Al/Ni(V)/Cu UBM.

Fig. 4 shows the ball shear strength of the 48Sn-52In solder bumps on Ti/Cu and Al/Ni(V)/Cu UBMs. The ball shear strength on Ti/Cu UBM was much higher than the value on Al/Ni(V)/Cu UBM, which could be related to the interface reaction on each UBM. As the intermetallics were firmly adherent to the Ti/Cu UBM, the shear crack was observed to propagate within the 48Sn-52In solder, enhancing the ball shear strength. In the case of the solder bumps on Al/Ni(V)/Cu, less sufficient intermetallic compound formation and easy consumption of thin Cu and Ni(V) layers caused the low shear strength values. Substantial decrease in the shear strength of the samples reflowed on Al/Ni(V)/Cu for 10 and 20 times might be caused by complete spalling of the intermetallics, as depicted in Fig. 3.

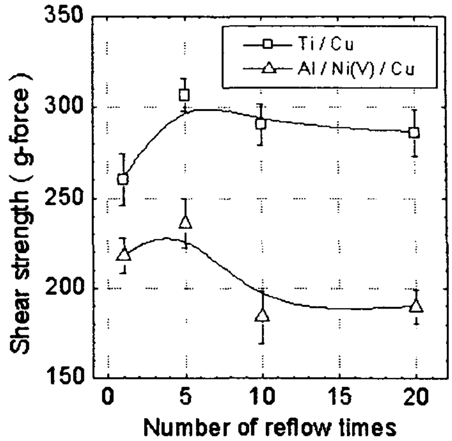

Fig. 4. Shear strength of the 48Sn-52In bumps on Ti/Cu and Al/Ni(V)/Cu

4.Summary

Reactions between 48Sn-52In solder and 100nm Ti/8㎛ Cu and 300nm Al/400nm Ni(V)/400nm Cu have been investigated, and the shear strength of the 48Sn-52In solder bumps on each UBM has been evaluated. The intermetallic compounds formed by reaction of 48Sn-52In with Cu at 150℃ were consisted of two different morphologies, scallop-type structure on the solder side of the interface and planar layer on the Cu side of the interface. Consumption rate of Cu to 48Sn-52In at 150℃ was estimated as 160nm/min, which was lower, but comparable to 230nm /min for Cu consumption to 63Sn-37Pb at 240℃. In the case of the 48Sn-52In solder bumps on Al/Vi(V)/Cu, severe spalling of the coarse, rectangular-shaped intermetallics was observed for the samples reflowed for 10 and 20 reflows. The shear strength of the 48Sn-52In solder bumps on Ti/Cu UBM was much higher than the value on Al/Ni(V)/Cu UBM, which could be attributed to different interfacial reaction on each UBM.

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