Joint strength between Sn-Ag based lead-free solder and Cu pad by ball shear test†

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Abstract

The interfacial reaction between the solder/Cu plate and the joint strength of the solder joint with a Cu pad were investigated for both as-reflow and thermal exposed conditions in this study. Sn-3.5mass%Ag-xCo solders (x=0, 0.1, 0.5, 1.0 mass%) were specially prepared. A reaction test between solder and a Cu plate was performed to reveal the effect of the addition of Co to solder on the morphology of intermetallic compounds at the interface. A bump shear test of the solder joint on a Cu pad was carried out to evaluate the effect of the addition of Co to solder on the joint strength of the solder with a Cu pad. As a result of the reaction test, it was clear that the formation of an intermetallic compound (IMC) layer at the interface for Sn-3.5Ag-Co solders was quite different from that for binary Sn-3.5Ag solder. During the aging process at 423K, the growth rate of the IMC layer for Sn-3.5Ag-Co solders was slow compared to that for binary Sn-3.5Ag solder. As a result of the bump shear test, it was clear that there was little difference in the shear strength between a Sn-3.5Ag solder joint and Sn-3.5Ag-Co solder joints, though the IMC morphology at the interface was quite different.

KEY WORDS: (Lead-free solder), (Element addition), (Joint strength), (Ball shear test), (Interface)

1. Introduction

Over the last decade, many researchers have studied a wide range of alloys to replace the Sn-Pb eutectic solder. Some different solder alloy systems, such as Sn-Ag, Sn-Cu, Sn-Zn, and Sn-Bi, have been proposed as the potential lead-free solder. In the present situation, the Sn-Ag family solders such Sn-3.5Ag and Sn-3.0Ag-0.5Cu are generally recognized as the most promising lead-free solders for both wave and reflow soldering. Accordingly, extensive research and development activities are mainly focused on the Sn-Ag-Cu system to understand the fundamental issues and to evaluate the reliability associated with solder joints formed from this solder system[1-6].

For lead-free solder joints, the interfacial reactions are known to be more severe than Sn-Pb eutectic solder, because of their high Sn content and high process temperature. Many investigations with lead-free solders have been recently conducted to understand the mechanisms of their interfacial reaction and the reliability of the solder joint. During the reflow process, it is inevitable that the intermetallic compounds (IMCs) form and grow at the solder/substrate interface. The formation of the IMC layer at the interface between the solder and a substrate is important for the reliability of the solder joint, because a too-thick IMC layer at the interface is sensitive to stress and sometimes provides sites of initiation and paths of propagation for cracks. Therefore it is very important to estimate the interfacial reaction between the solder and a substrate and the joint strength of that solder joint[7,8].

Recently to improve the properties of solder and interfacial reactions, microelements, such as In, Ni, and Ge have been added to the solder, and the effects of these elements have been explored[9-12]. For example, Choi, *et al.*[9] studied the effect of the addition of In on binary eutectic Sn-Ag solder. They reported that the microstructure of the solder and the morphology of secondary phases in the solder matrix changed accordingly. Chaung *et al.*[12] investigated the intermetallic compound formed during the reflow and aging of Sn-3.0Ag-0.5Cu solder and Sn-3.0Ag-0.5Cu-0.06Ni-0.01Ge solder BGA packages with Au/Ni surface finishes. They reported that the growth thickness of the interfacial intermetallic layers and the consumption of the Ni surface-finished layer on the Cu pads in Sn-3.0Ag-0.5Cu-0.06Ni-0.01Ge solder joints were both slightly less than those in Sn-3.0Ag-0.5Cu.

In this study, the microstructure at the interface between the solder and a Cu plate and the joint strength

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of the solder ball bonded on a Cu pad were investigated to reveal the effect of the addition of Co to the solder.

2. Experimental

The reaction test between Sn-Ag-Co solder and Cu base metal was performed to examine the effect of Co addition into solder on the formation of intermetallic compound (IMC). A shear test for both reflowed and thermally exposed joints was performed to evaluate the joint strength. As the lead-free solder alloys, four different solders, that is Sn-3.5mass%Ag-*x*Co solders (*x*=0, 0.1, 0.5 and 1.0mass%) was used in this study.

For the reaction test, phosphorous-deoxidized copper (30mm×30mm×0.3mmt) was prepared as the Cu base metal. Solder (0.3g) was put on the base metal and activated flux (0.03ml) was dropped on the specimen after the base metal was immersed in 3%HCl solution for 120s and rinsed with ethanol solution. Then the specimen was put into the radiation furnace in a nitrogen atmosphere. As the reflow process, it was preheated at 373K for 120s and was subsequently heated at 523K for 60s. Some specimens were heat-treated in an oil bath at 423K for 168, 504h. After cooling, the specimen was cut and its cross-section was polished. A scanning electron microscope (SEM) was used to observe the interface between the solder and Cu base metal, and the thickness of the intermetallic compound was measured by optical microscopy.

Figure 1 shows a schematic image of the shear test for the solder joint between Sn-3.5Ag-*x*Co solders and Cu pads. Solder (3.8mg) with activated flux was put on a Cu pad after the substrate was immersed in 3%HCl solution and rinsed with ethanol solution. Then the specimen was heated under the same condition as the reaction test and some specimens were heat-treated in oil bath. During heating, solder was transformed to the spherical form as shown in Fig.1. The size of the solder bump was approximately 1.1 mm in average and the diameter of a Cu pad was 0.8mm. The shear test of the solder joint was performed by using a bump shear tester (Rhesca Co., STR-1000). The shear tool was set at 0.1mm distance from the substrate and the test speed was fixed at 0.06 mm/s for all samples.

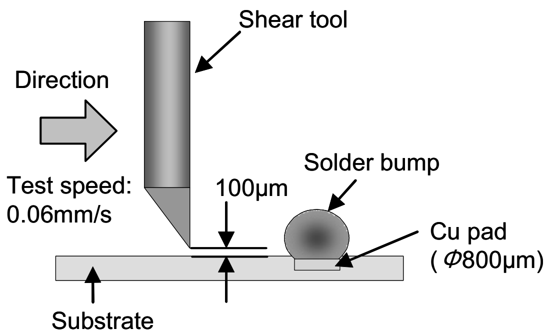

Fig. 1 Shear test method for solder joint.

3. Results and Discussion

3.1 Reaction with Cu base metal

For soldering processes, it is very important to estimate the reaction with a Cu base metal. So the reaction between Sn-Ag-Co solder and a Cu base metal was investigated to clarify the effect of the addition of Co to solder on the wettability and the formation of the IMC layer at the interface.

The wettability was evaluated by a spread area on a Cu base metal. Figure 2 shows the appearances of test samples just after the reflow process for measuring spread area. Regardless of the addition of Co, the appearances of test samples are almost similar in all solders. Figure 3 shows the results of spread area on a Cu base metal and the effect of the addition of Co to Sn-3.5Ag solder on that spread area. The spread areas of Co added solder seem to be slightly smaller than for the Sn-3.5Ag solder. There was little effect of Co addition on the wettability of Sn-3.5Ag solder.

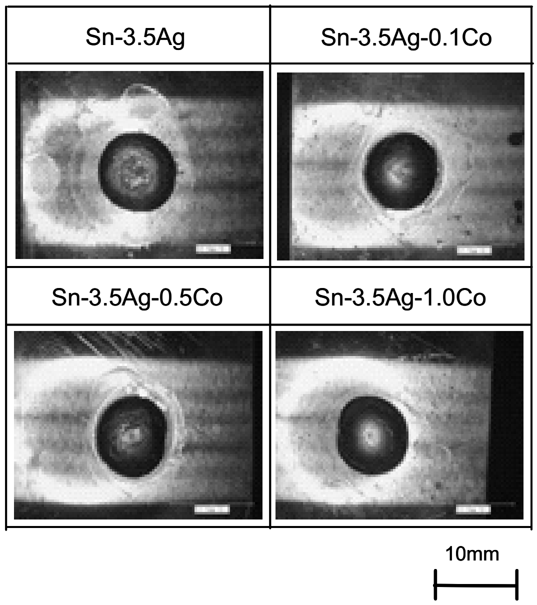

Fig. 2 Appearance of test specimens after reflow process.

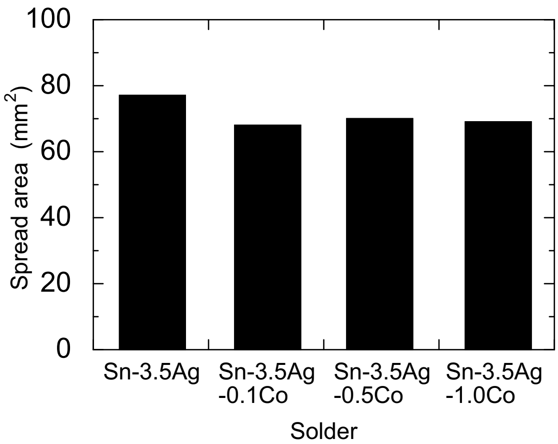

Fig. 3 Effect of Co addition to Sn-3.5Ag solder on spread area on Cu substrate.

In general, a too-thick IMC layer at the interface is sensitive to stress and sometimes provides sites of initiation and paths of propagation for fractures, and the growth of the IMC layer could degrade the joint strength between solder and substrate. Therefore, it is important to clarify the relationship between the morphology of IMC layer and the joint strength. Figure 4 shows the SEM images of the interface between solder and Cu base metal just after the reflow process at 523 K for 60 s. The interface for Sn-3.5Ag solder and Sn-3.5Ag-0.1Co solder are shown in the figure. As can be seen in this figure, the formation of IMC at the interface for Sn-3.5Ag-0.1Co solder was quite different from that for Sn-3.5Ag solder. For Sn-3.5Ag solder, the IMC layer had a scallop like morphology. On the other hand, for Sn-3.5Ag-0.1Co solder, the IMC layer had a coral-like morphology[10] and some solders were trapped in the IMC layer. Regardless of the amount of Co addition in the solder, this behavior was observed for Sn-3.5Ag-Co solder. The SEM images of the interface between the solder and Cu base metal after aging process at 423 K for 504 h are shown in Fig. 5. In the case of Sn-3.5Ag solder, the morphology of IMC layer became smooth and thicker. In the case of Sn-3.5Ag-0.1Co solder, solders inside the IMC layer disappeared.

Figure 6 shows the effect of the addition of Co to solder on the IMC thickness just after the reflow process and after the aging process at 423 K for 168 h and 504 h. The reflow temperature was 523K and the reflow time was 60s. After the reflow process, the IMC thickness for Co added solder was considerably thicker, regardless of Co content, compared with that for the Sn-3.5Ag solder. Adding Co to solder enhanced the IMC formation at the reflow process. After the aging process, in the case of Co added solder, the growth rate of the IMC layer was extremely low compared with the case of Sn-3.5Ag solder. In the case of Sn-3.5Ag solder, the IMC layer grew distinctly with increasing aging time. After aging for 504 h, the IMC thickness was almost similar. Within this test, the addition of minor Co to solder was effective in reducing the growth rate of the IMC thickness during the aging process.

3.2 Joint strength with Cu pad

For evaluating the effect of the addition of Co to solder on the joint strength just after the reflow process and after the aging process, bump shear tests were performed. Figure 7 shows the shear strength of the Sn-3.5Ag solder and Sn-3.5Ag-Co solder joints with a Cu pad just after reflow process. The shear strength for all

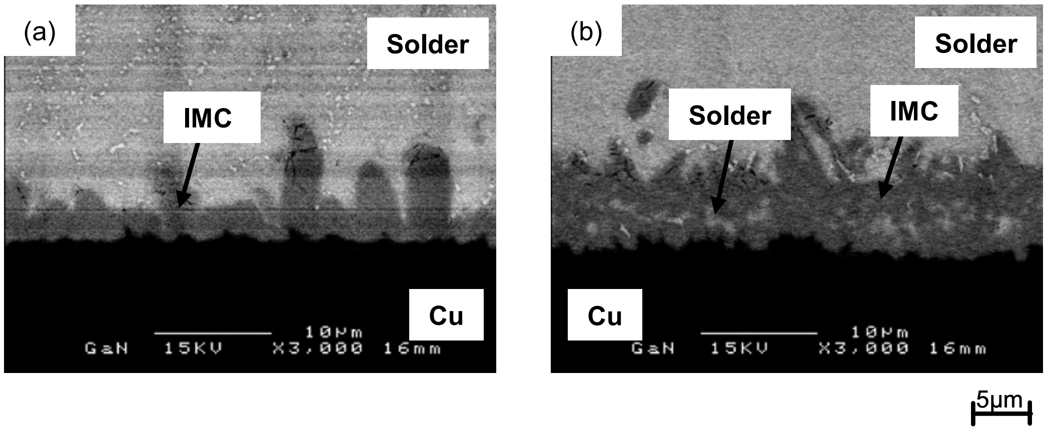

Fig. 4 SEM images of intermetallic compound formed at interface between solder and Cu plate just after reflow at 523K for 60s. (a) Sn-3.5Ag solder, (b) Sn-3.5Ag-0.1Co solder.

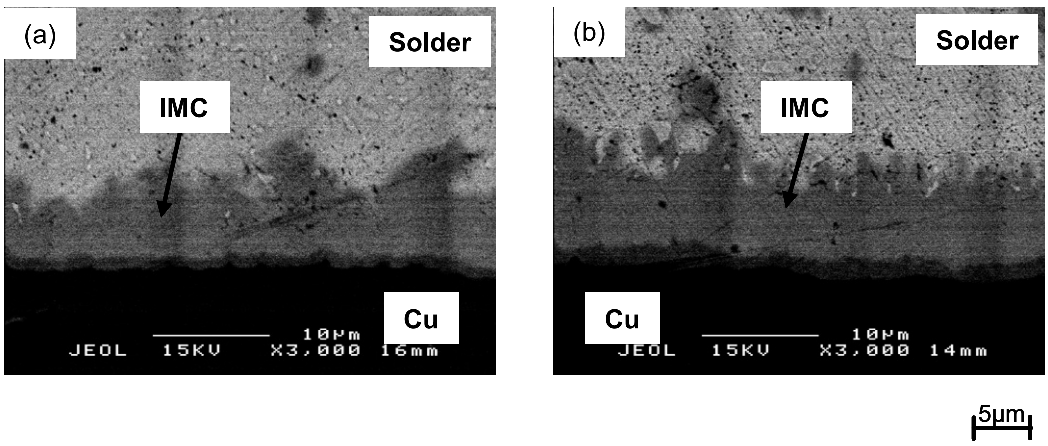

Fig. 5 SEM images of intermetallic compound formed at interface between solder and Cu plate after aging at 423K for 504h. (a) Sn-3.5Ag solder, (b) Sn-3.5Ag-0.1Co solder.

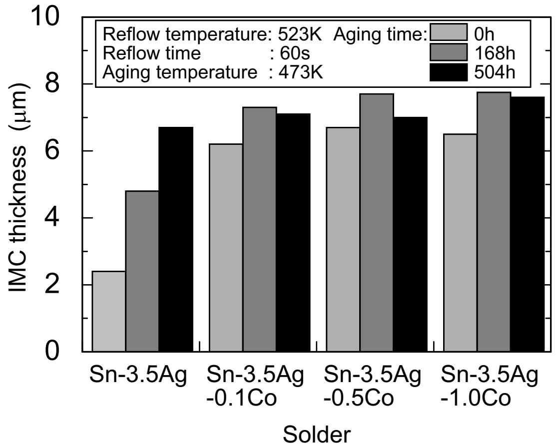

Fig. 6 Effect of Co addition to Sn-3.5Ag solder on IMC thickness during aging process.

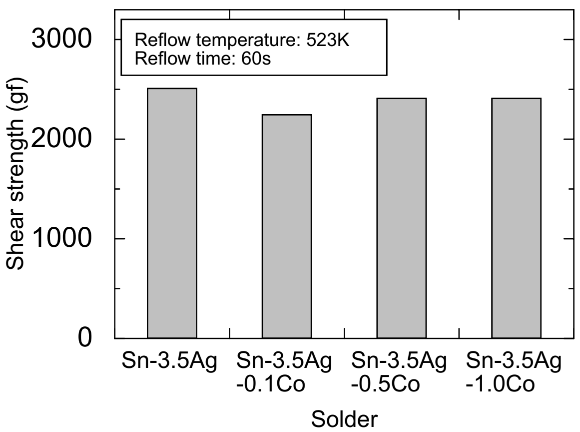

Fig. 7 Shear strength of Sn-3.5Ag solder and Sn-3.5Ag-Co solder with a Cu pad just after reflow process.

solders regardless of the Co addition was almost similar, though the IMC morphology at the interface was quite different as shown in Fig. 4. After the shear test, fracture surfaces of the solder joints were analyzed by EPMA. From this result, it was confirmed that for all solders the fracture progressed in the solder.

Figure 8 shows the effect of the aging time on the shear strength of the Sn-3.5Ag solder and Sn-3.5Ag-Co solder joints with a Cu pad after the aging process. Regardless of the solder composition, the shear strength decreased gradually with increasing of the aging time. After an aging process for 504 h, there was little difference in the shear strength between Sn-3.5Ag solder joint and Sn-3.5Ag-Co solder joints. Therefore, it was clear that the addition of Co to Sn-3.5Ag solder didn't affect the shear strength of the solder joints.

4. Conclusions

In this study, the microstructure at the interface between Sn-Ag-Co solder and a Cu plate and the joint strength of the solder ball bonded on a Cu pad were investigated to reveal the effect of the addition of Co to the solder on the formation of intermetallic compounds at the interface. The main results obtained in this study are summarized as follows.

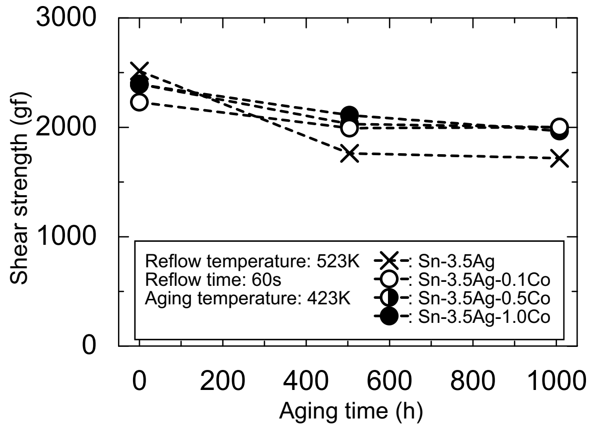

Fig. 8 Effect of aging time on shear strength of solder/Cu pad joint.

(1) For Sn-3.5Ag-0.Co solder, just after the reflow process, the IMC layer at the interface had a coral-like morphology and some solders were trapped in the IMC layer. After the aging process, solders inside the IMC layer disappeared.
(2) Within this test, the addition of minor amount of Co to solder was effective in reducing the growth rate of the IMC thickness in the aging process.
(3) After the reflow process, the shear strength for all solders, regardless of the Co addition, was almost similar, though the IMC morphology at the interface was quite different.
(4) It was clear that the addition of Co to Sn-3.5Ag solder didn't affect the shear strength of the solder joints.

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