DEVELOPMENT OF SN BASED MULTI COMPONENT SOLDER BALLS WITH CU CORE FOR BGA PACKAGE

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ABSTRUCT

Cu-cored Sn-Ag solder balls were fabricated by coating pure Sn and Ag on Cu balls. The melting behavior and the solderability of the BGA joint with the Ni/Au coated Cu pad were investigated and were compared with those of the commercial Sn-Ag and Sn-Ag-Cu balls. DSC analyses clarified the melting of Cu-cored solders to start at a rather low temperature, the eutectic temperature of Sn-Ag-Cu. It was ascribed to the diffusion of Cu and Ag into Sn plating during the heating process. After reflow soldering the microstructures of the solder and of the interfacial layer between the solder and the Cu pad were analyzed with SEM and EPMA. By EDX analysis, formation of a eutectic microstructure composing of β-Sn, Ag_3Sn, and Cu_6Sn_5 phases was confirmed in the solder, and the η'-(Au, Co, Cu, $Ni)_6Sn_5$ reaction layer was found to form at the interface between the solder and the Cu pad. By conducting shear tests, it was found that the BGA joint using Cu-cored solder ball could prevent the degradation of joint strength during aging at 423K because of the slower growth rate of η'-(Au, Co, Cu, $Ni)_6Sn_5$ reaction layer formed at the solder/pad interface. Furthermore, Cu-cored multi-component Sn-Ag-Bi balls were fabricated by sequentially coating the binary Sn-Ag and Sn-Bi solders on Cu balls. The reflow property of these solder balls was investigated. Melting of these solder balls was clarified to start at the almost same temperature as that of Sn-2Ag-0.75Cu-3Bi solder. A microstructure composing of (Sn), Ag_3Sn, Bi and Cu_6Sn_5 phases was found to form in the solder ball, and a reaction layer containing primarily η'-(Au, Co, Cu, $Ni)_6Sn_5$ was formed at the interface with Ni/Au coated Cu pad after reflow soldering. By conducting shear test, it was found that the BGA joints using this Cu-core solder balls hardly degraded their joint shear strength during aging at 423K due to the slower growth rate of the η'-(Au, Cu, $Ni)_6Sn_5$ reaction layer at the solder/pad interface.

KEYWORDS

BGA (ball grid array), Pb free solder, interfacial reaction, Sn-Ag system, Cu-cored ball

1. Introduction

The ball grid array (BGA) package has recently been extensively used in electronics package due to their capabilities of the higher density packaging. On the other hand, since the conventional Pb-containing solder alloys bring serious environmental problems, development of Pb-free alternative alloys is under critical demands. But the material optimal as substitution of the Sn-Pb solder has not been still found. Although the solders present near practical use are Sn-Ag system, these solders have the problem that the wettability is poorer and melting temperature is higher than that of the Sn-Pb solder. Consequently, the reflow process temperature becomes higher and interfacial reaction between the solder and the pad may be more remarkable. So the control of interfacial reaction becomes more important.

In the previous work, paying the attention to the excellent in the electrical and thermal property of Cu, the authors have fabricated Cu-core Sn-Pb solder ball by coating Sn-Pb solder on Cu ball. BGA joint between this Cu-core solder ball and Ni/Au coated pad hardly degraded their joint shear strength during heat treatment due to the slower growth rate of the reaction layer at the solder/pad interface[1]. Based on the reports about the excellent BGA reflow solderability of Cu-cored Sn-Pb solder balls, in this paper, reflow solderability of the Sn-based multi-component Pb-free solders was investigated. Cu-cored Sn-Ag solder balls were fabricated by coating pure Sn and Ag on Cu balls and were applied to the BGA package. Furthermore, Cu-cored Sn-Ag-Bi balls were fabricated by sequentially coating the binary Sn-Ag and Sn-Bi solders on Cu balls as Cu-cored multi-component Pb free solder balls. By comparing the solderability of this Cu cored balls with that of previously alloyed commercial solders with same composition, applicability of Cu core balls with multiple plating was examined.

2. Experimental Procedure

The BGA substrates used in this study are Cu pad (30μm) on which surface 7μm thick Ni and 1.5μm thick Au were electroplated. The Au surface layer provides an oxidation or corrosion resistance during storage prior to assembly. Moreover, the high dissolution rate and solubility of Au in molten solders lead to ultra fast wetting of the solders to the substrate pad. The intermediate Ni layer acts as a diffusion barrier that inhibits the formation of a thick Cu-Sn intermetallic layer during aging. The Ni coating contains Co as a contaminant.

Cu-cored Sn-Ag solder balls were prepared by barrel plating of pure Sn and Ag coating on Cu ball with a diameter of 670μm. The thickness of each layer was calculated so that the composition of plating after melting might be set to Sn-3.5wt.%Ag. Cu-core Sn-3.5Ag solder balls were also fabricated for comparison. Cu-core multi-component Sn-Ag-Bi solder balls were fabricated by sequentially coating the binary Sn-3.5Ag solder and Sn-7Bi solder on Cu balls. The thickness of each layer was calculated so that the composition of plating after melting is designed to Sn-2Ag-3Bi. We named SB/SA ball the sample coated in order of Sn-Bi and Sn-Ag on the ball, and SA/SB ball the sample coated in order of Sn-Ag and Sn-Bi. Thickness of each coating for these Cu-core solder ball is shown in Table 1. Previously alloyed commercial solder balls used for comparison were the Sn-3.5Ag and Sn-3.5Ag-0.76Cu solders with a diameter of 740μm and Sn-2Ag-0.75Cu-3Bi ball with a diameter of 760μm.In order to research the melting behavior of Cu-cored solder balls and determine reflow conditions, Differential Scanning Calorimeter (DSC) was used.

Figure 1 shows the schematic illustrations of solder balls and pads for BGA joints used in this study. The solder balls were dipped into water-soluble flux and then planted on the pads manually. The solder balls were reflowed by using a hot air oven. The peak reflow temperature was 518K. Figure 2 shows reflow profile. After the reflow, the BGA joints were subjected to heat treatment at 423K for 500h. To study the microstructural evolution of the BGA joints, the cross-sections of the samples were observed by Scanning Electron Microscope (SEM) and Electron Probe Micro-Analyzer (EPMA) with energy dispersive X-ray (EDX) analyses. The strength of obtained BGA joints was measured through the shear fracture test. The shear tool was set 0.1 mm distant from the substrate and the traverse speed was fixed to 0.2mm/sec.

Table 1 Thickness of plating on Cu-core balls

	Thickness of plating(μm)			
	Sn	Ag	Sn-7Bi	Sn-3.5Ag
Sn/Ag plated Cu-cored ball	34.2	0.8		
Cu-cored Sn-3.5Ag solder ball				35
Sn-Bi/Sn-Ag plated Cu-cored ball (SB/SA)			15.8	19.2
Sn-Ag/Sn-Bi plated Cu-cored ball (SA/SB)			14.1	20.9

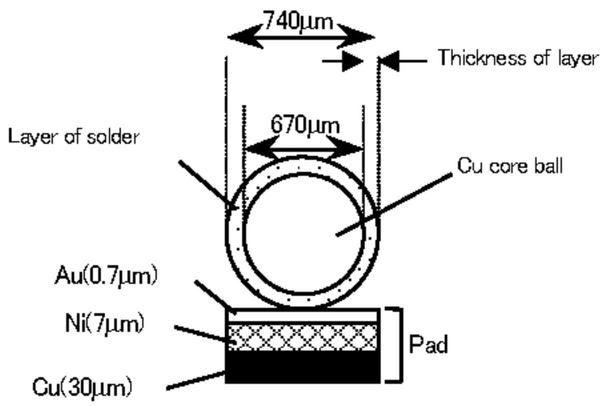


Fig. 1 Schematic illustration of BGA sample using Cu-core solder ball

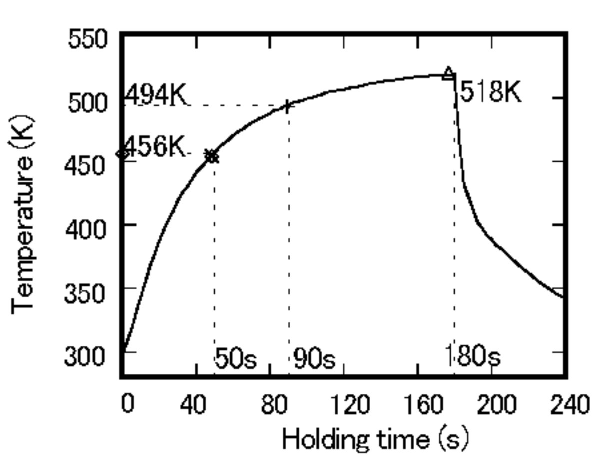
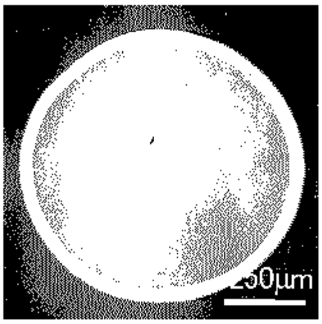
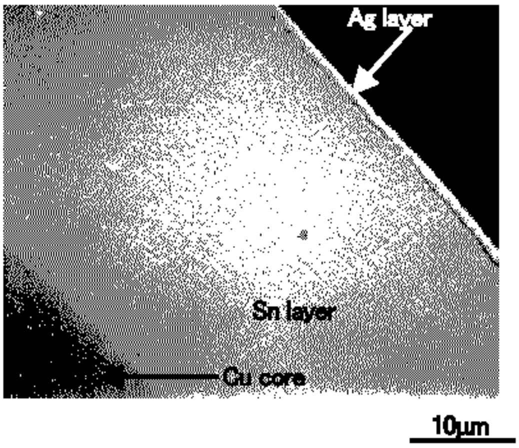


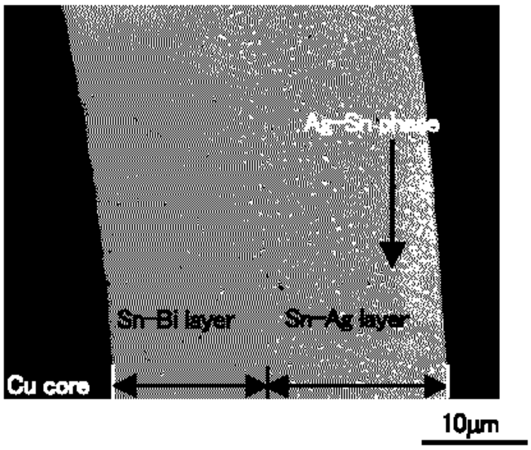
Fig. 2 Thermal profile applied for reflow



(a-1) General view of cross section of Sn/Ag Cu core ball



(a-2) Higher magnification of (a-1)



(b) Cross section of SB/SA ball

Fig. 3 Photographs of the microstructure for as plated (a) Sn/Ag Cu core and (b) SB/SA solder balls

3. Results and Discussion

3.1 Microstructure of as received Cu-cored solder ball

SEM images of the cross-section of as received Sn/Ag plated Cu core solder ball and Sn-Bi/Sn-Ag plated Cu core ball (SB/SA ball) were shown in Fig. 3. These balls took on the almost globular shapes, but as for Cu-cored Sn-3.5Ag ball and SA/SB ball, unevenness was seen on the surface.

The formation of the any reaction layers was not observed at the Sn plating / Ag plating and Sn plating /Cu core interface for the Sn/Ag Cu core ball. Moreover, from the results of the quantitative analysis, it found that it had the possibility that Cu was slightly diffused into Sn plating at a plating process.

As for SB/SA ball, Sn-Bi plating layer exhibited a single phase structure as shown in Fig. 3, and the diffusion of Ag from Sn-Ag plating was not detected. On the contrary, in Sn-Ag plating, formation of Ag_3Sn phase and diffusion of Bi in the matrix Sn were confirmed by EDX analysis. This is because the diffusion coefficient of Bi is rather large (1.93×10^{-12} cm^2/sec in 293K[2)]) that Bi can diffuse into Sn-Ag plating from Sn-Bi plating even by holding at room temperature for 20 days.

3.2 Melting behavior of Cu-cored solder ball

Figure 4 shows DSC curves of Cu-cored solder balls heated at a heating rate 60K/min, and Fig. 5 shows the changes in onset and offset melting temperature as a function of heating rate.

As for the Sn/Ag plated Cu core ball, it was found onset and offset melting temperature were about the same as those for Sn-3.5Ag-0.76Cu. In order to investigate the melting behavior of this ball, the sample which was heated to 488K and was cooled rapidly was fabricated. The formation of Ag_3Sn phase in the Sn plating / Ag plating interface and that of Cu_6Sn_5 layer in the Cu-core/Sn plating interface were observed. It means that Ag and Cu diffused into Sn and the melting started at the eutectic temperature of Sn-Ag-Cu.

As for SB/SA ball, it was found that onset melting temperature was about the almost same as Sn-2Ag-0.75Cu-3Bi alloy. This is because Bi and Cu diffused into Sn-Ag plating and the composition of the Sn-Ag plating partially became the similar composition of Sn-Ag-Cu-Bi. On the other hand, offset melting temperature of SB/SA ball was lower 9K than Sn-2Ag-0.75Cu-3Bi, i.e. 508K. This is probably because the thermal conductivity of SB/SA ball is probably larger than Sn-Ag-Cu-Bi alloy.

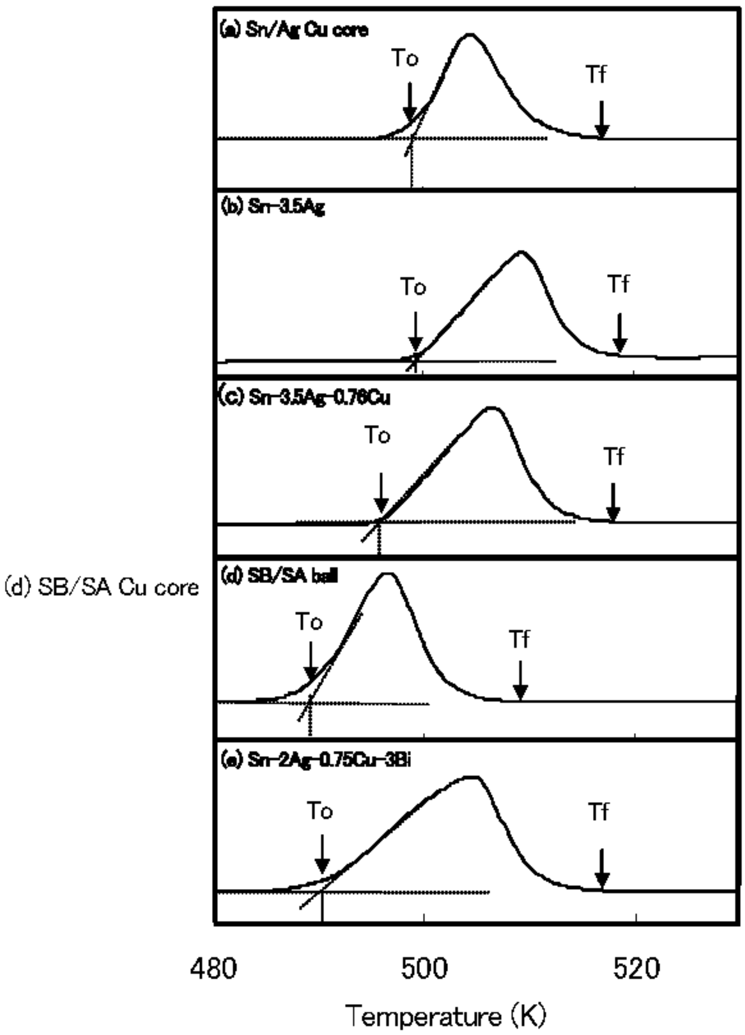


Fig. 4 DSC curves of (a) Sn/Ag Cu core, (b) Sn-Ag, (c) Sn-Ag-Cu, (d) SB/SA Cu core and (e) Sn-Ag-Cu-Bi solder balls at a rate of 1K/sec

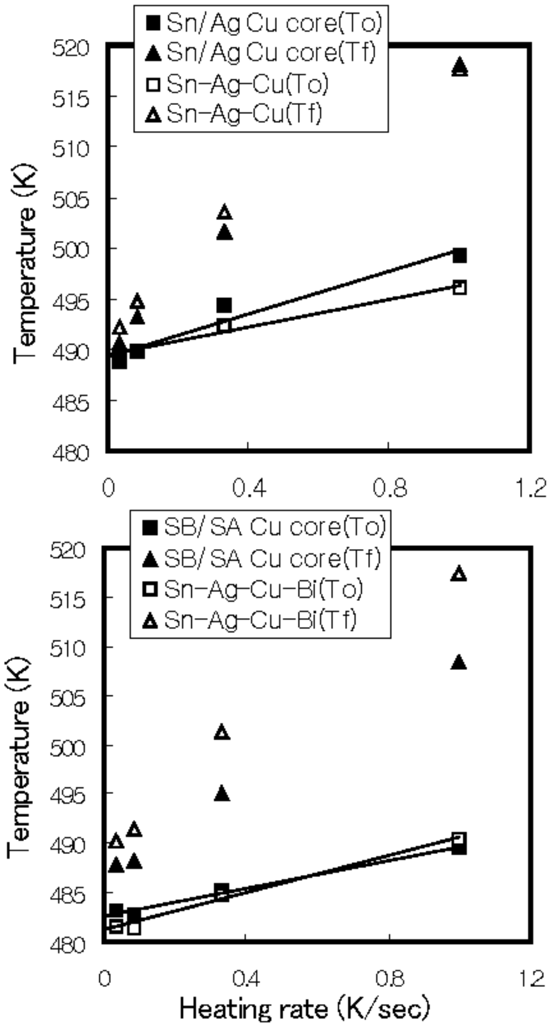
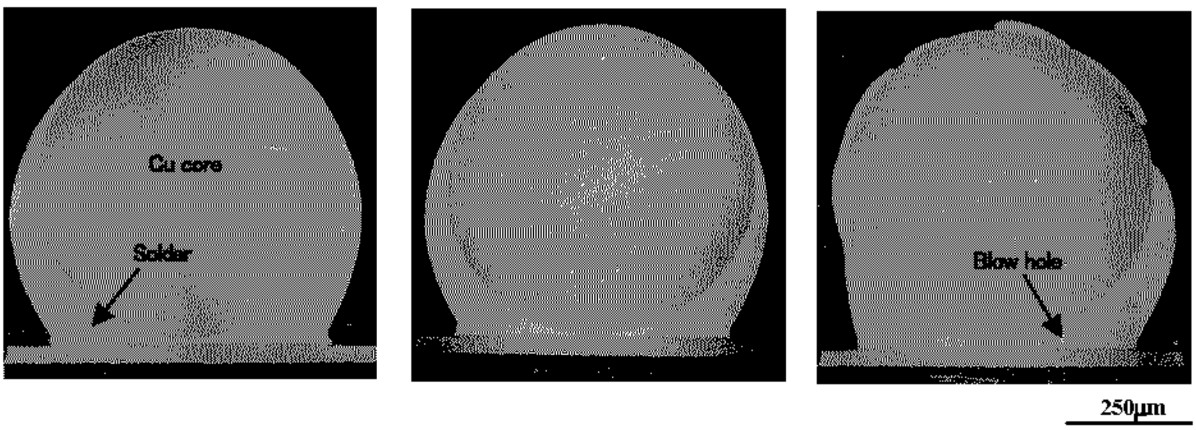


Fig. 5 Relationship between To, Tf for various solders and heating rate for (a) Sn/Ag Cu core and Sn-Ag-Cu, (b) SB/SA Cu core and Sn-Ag-Cu-Bi solder balls



(a) Sn/Ag Cu core ball (b) SB/SA ball (c) SA/SB ball

Fig. 6 General images of cross section of BGA joints using (a) Sn/Ag Cu core ball, (b) SB/SA ball and (c) SA/SB ball after reflow soldering

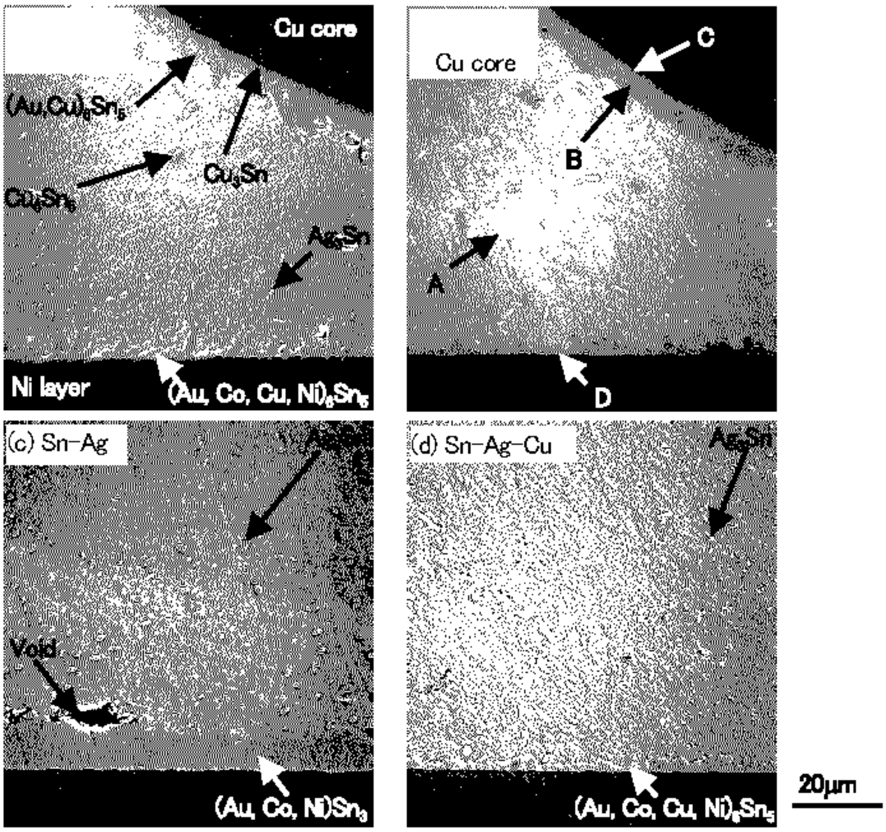


Fig. 7 Microstructures near the interfaces after the heat-treatment at 423K for 500h for the BGA joints between Au/Ni electroplated pads and (a) Sn/Ag Cu core, (b) SB/SA Cu core, (c) Sn-Ag and (d) Sn-Ag-Cu balls

Table 2 Results of the quantitative EDX analyses for each phase, A～D defined in Fig. 6

	Composition (mol%)							Phase
	Ag	Au	Bi	Co	Cu	Ni	Sn	
A	0.06	0.71	1.74	0.00	3.05	0.01	94.43	(Sn)
B	0.03	3.13	0.02	0.01	50.98	0.00	45.84	$(Au, Cu)_6Sn_5$
C	0.01	0.56	0.01	0.03	75.15	0.00	24.24	Cu_3Sn
D	0.61	2.38	0.04	1.39	47.02	2.47	46.09	$(Au, Co, Cu, Ni)_6Sn_5$

3.3 Joint property using Cu-cored solder ball

SEM images of BGA joints between electro plated Ni/Au coated pad and Sn/Ag Cu core ball, SB/SA ball and SA/SB ball were shown in Fig. 6. Sn/Ag Cu core ball and SB/SA ball showed good morphologies of BGA joints, but for SB/SA ball many voids were observed in the plating. For the Cu-cored Sn-3.5Ag solder ball, a similar phenomenon was observed.

It is generally noted that H_2 and H_2O gases are apt to be absorbed in Sn-Ag plating when methanesulfonic acid bath is used to plate Sn-Ag solder on Cu ball. It can be thought that these gases generated during reflow soldering were not completely released, resulting in the formation of blow holes. In particular for SA/SB ball, the tendency is very remarkable since Sn-Ag plating is in the inside of the solder plating.

Figure 7 shows the microstructures near the interfaces of BGA joints using Ni/Au coated Cu pads after the heat treatment at 523K for 500h. Table 2 shows the results of the quantitative EDX analyses for each phase. .As for the Sn/Ag Cu core ball, the dispersion of needle shaped Ag_3Sn and oval shaped Cu_6Sn_5 phase in a matrix Sn was observed. Coarsening of these phases by heat treatment were confirmed. The formation of η'- $(Au, Co, Cu, Ni)_6Sn_5$ layer at the solder / pad interface and η'- $(Au, Co, Cu)_6Sn_5$ layer at the solder / Cu-core interface was observed. Although Cu_3Sn layer was newly observed on the solder / Cu core interface, the reaction layer at the solder / pad interface had hardly grown. For the sample using Sn-3.5Ag solder, the reaction layer which can be thought as metastable phase $(Au, Ni Co)Sn_3$ was formed at the solder / pad interface [3), and many voids were confirmed at the solder / reaction layer interface.

As for SB/SA ball, the microstructure composing of Sn, Ag_3Sn, Bi and Cu_6Sn_5 phases was found to form in the solder, and the reaction layers were the same as those of other Cu-cored solder balls. This microstructure was almost the same as that of the joint using Sn-2Ag-0.75Cu-3Bi. Any segregation of Bi that causes the degradation of ductility was not observed.

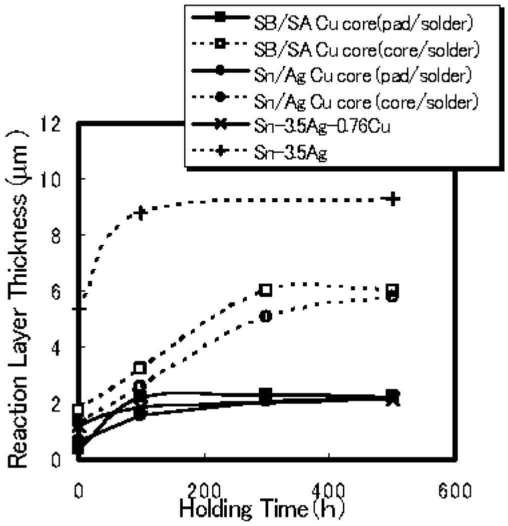


Fig. 8 Changes in the thickness of the reaction layers as a function of holding time at 423K

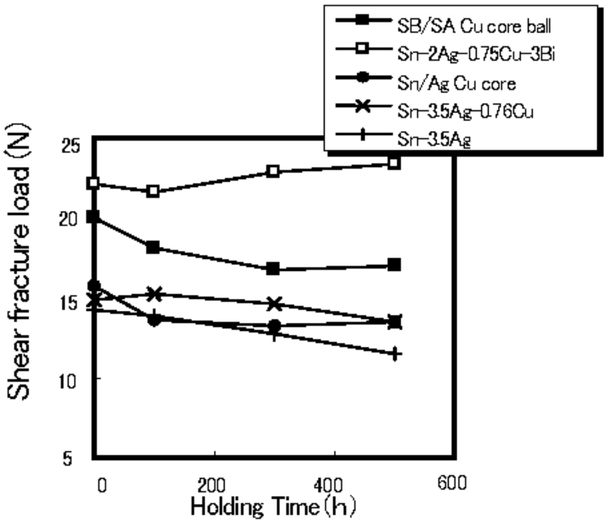


Fig. 9 Changes in shear fracture load of the BGA joints as a function of holding time at 423K

Cu_3Sn layer was confirmed on the Cu-core side of the solder /Cu core interface, and the thickness which added η'- (Au, Co, Cu)$_6$Sn$_5$ and Cu_3Sn was about 6μm after heat treatment at 423K for 500h. On the other hand, the reaction layer at the solder / pad interface was about 2.3μm after heat treatment for 500h. It was confirmed that this reaction layer played a role as a diffusion barrier between reactive Ni and Sn.

Changes in the thickness of the reaction layers as a function of holding time at 423K are shown in Fig. 8 for the samples using Cu-cored solder balls. The data using Sn-3.5Ag, Sn-3.5Ag-0.76Cu are also shown for comparison. The reaction layer of the sample using Sn-3.5Ag solder was (Au, Ni Co)Sn_3 and it grew to about 10μm after the heat-treatment for 500h. On the other hand, since the reaction layers at the interfaces of the joints using Cu-cored solder balls and Sn-3.5Ag -0.76Cu were about 2μm, it turns out that the interfacial reactions were suppressed during the heat-treatment. Figure 9 shows the changes in shear fracture load of the BGA joints as a function of holding time at 423K. The shear fracture load does not always correspond to the joint strength due to the different joint morphologies for each solder, but at least the changes of the load during heat treatment may indicate the joint reliabilities. For both Sn/Ag Cu core ball and SB/SA ball, the BGA joints showed the similar changes in the joint strength to the cases for other Cu-cored solder balls, and the degradation of joint shear strength was suppressed because of the slower growth rate of η'-(Au, Co, Cu, Ni)$_6$Sn$_5$ reaction layer formed at the solder/pad interface. In particular, the strength loss hardly took place during heat treatment from 100h to 500h. The fracture of the BGA joints using Cu-cored solder balls was initiated inside the solders, and the crack was propagated along the Cu-cored / solder interfaces. These crack paths did not change even by the heat-treatment. In this study, it turns out that the application of Cu-cored solder ball to BGA joint is one of the effective solutions about the joint reliability for near future.

4. Conclusion

In this study, the melting behavior and the solderability of the BGA joint with the Ni/Au coated Cu pad were investigated and were compared with those of the previously alloyed commercial Sn-Ag and Sn-Ag-Cu balls. The results obtained in this research were as follows.

(1) By DSC analysis, onset and offset melting temperature of Sn/Ag Cu core ball are almost the same as those of the commercial Sn-3.5Ag-0.76Cu solder. As for SB/SA ball, it confirmed that onset melting temperature was almost the same as the commercial Sn-2Ag-0.75Cu-3Bi and offset melting temperature was lower 9K than Sn-2Ag-0.75Cu-3Bi, i.e. 508K at the heating rate 60K/min.

(2) By EDX analysis, Sn/Ag Cu core ball exhibited a eutectic microstructure composing of β-Sn, Ag_3Sn, and Cu_6Sn_5 phases, and the η'-(Au, Co, Cu, Ni)$_6$Sn$_5$ reaction layer was found to form at the interface between the solder and the Cu pad. As for SB/SA ball, a microstructure composing of (Sn), Ag_3Sn and Cu_6Sn_5 phases was found to form in the solder ball, and a reaction layer was almost the same as that of other Cu-cored solder balls.

(3) BGA joints using this Cu-core solder balls hardly degraded their joint shear strength during aging at 423K due to the slower growth rate of the η'-(Au, Cu, Ni)$_6$Sn$_5$ reaction layer at the solder/pad interface.

References

[1] K. Uenishi, T. Saeki, Y. Kohara and K. F. Kobayashi: *Materials Transactions*, Vol. 42, No.5 (2001) pp.756-760
[2] D. Mitlin, C. H. Raeder and R. W. Messler, Jr.: *Metallurgical and Materials Transactions A*, Vol. 30A(1999)pp.115-122
[3] J. Haimovich: *Welding Journal*, Vol. 68 (1989) pp.102-111