CHARACTERIZATION AND ANALYSIS OF SHEAR TEST WITH TESTING CONDITIONS ON BGA PACKAGE

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Abstract

This study investigates the variations of shear force, displacement, and fracture surface with the shear speed and the number of reflows. The experimental data of shear tests indicate that the shear force increases as increasing the number of reflows and the shear speed due to the formation of a kind of intermetallic compound, Ni_3Sn_4, on Au/Ni/Cu pad, and the work-hardening. However, general trends show that the shear force decreases due to increasing the thickness of the intermetallic compound over 4x reflow. It is observed that the intermetallic compound which is formed between solder and pad increases according to increasing the number of reflows, and the growth rate of the intermetallic compound at central region on the interface is faster than one at edge part. The general tendencies of shear force and displacement with different shear speeds are almost identical as an increase of the number of reflows.

Keywords

Shear test, Displacement, BGA(Ball Grid Array), Fracture surface, Solder ball

Introduction

Ball grid array(BGA) technologies are the main themes with flip chip(FC) for IC packaging industries in the 90s. The BGA package has many advantages over conventional modules; larger I/O, smaller form factors, and better thermal/electrical perfomance, etc. For surface mounted components(SMCs), the solder joints are not only the passage of electrical signals, power, and ground, but also the mechanical support to hold the module in position on the printed circuit board(PCB). Therefore, the solder joint reliability is a major concern for BGA packages.

Ball shear testing is the most common method used for assessing solder ball attachment quality on area array packages. Being a simple and convenient test, the test has a problem being difficult to compare a package with another due to lack of the standardization. In July 2000, JEDEC established a new standard(JESD22-B117) upgrading the ASTM standard(ASTM F 1269-89) to verify the integrity of the bond between the gold ball and semiconductor pad for BGA ball shear tests; i.e. (a) The typical value of shear force for solder ball may be evaluated more than 1kgf for BGA package with 0.76mm solder ball, (b) The specification is that the gap between the edge of the shear ram and the surface of ball mounting should be larger than 0.05mm and smaller than (or equal to) 25% of the ball height. (c) Failure type can be divided into six Mode with BGA conditions. However, the shear speed (or loading rate, displacement rate) doesn’t have been mentioned as a specific parameter in this standard, although it had been already studied that the shear force increases according to shear speed due to work-hardening.

The present study is aimed at establishing the mechanics foundation for the ball shear tests to evaluate attachment between the Sn-37Pb and Sn-3.5Ag solder balls and the Au/Ni/Cu BGA pad; the variations of shear force, displacement, and fracture surface with shear speed. It is investigated into the variations of shear mechanics according to the number of reflows, and the optimum thickness of the intermetallic compound for the maximum shear force. It is observed that the intermetallic compound which is formed between solder and pad increases according to increasing the number of reflows, and that the growth rate of the intermetallic compound at central region on the interface is faster than one at edge.

Experimental Procedures

The solder balls used in this work were Sn-37Pb and Sn-3.5Ag solder spheres in diameter of 760㎛. The BGA substrates for solder ball attachment were BT laminates with 544 pads for commercial applications. The surface finish was electrolytic Au/Ni/Cu pad with Au and Ni layers of 0.5㎛ and 7㎛ thickness, respectively. This pitch was 1.27mm and the pad diameter of Au/Ni/Cu was 640㎛. The solder balls were dipped into flux, and then planted on the pads manually. And, the balls were reflowed by using a IR reflow machine (RF-430-M2, Japan Pulse Laboratories Inc.). As shown in figure 1, the peak reflow temperatures of Sn-37Pb (figure 1-(a)) and Sn-3.5Ag (figure 1-(b)) solder were 235℃ and 255℃ with the reflow time of 50sec, respectively. The pre-heating time was about 2min, and its temperature was sustained in the range between 150 and 180℃. The specimens after multiple reflows (1x to 5x) were evaluated by shear tester(PTR-1000, RHESCA) with the shear speed (10㎛/sec ~ 1000㎛/sec). The specimens were sheared after 5 hours, because it was oberved that the shear force of the specimens directly after reflow indicated abnormally high values over 20%, and that the values over 12 hours after reflow decreased due to the effect of room-temperature aging. The height of ram was fixed at 50㎛. For each testing condition, 20 solder balls were sheared. During each run, the displacement and the corresponding shear force were recorded. In order to examine, the fracture surfaces and cross-sections of all specimens were observed by a secondary electron image (SEI) and backscattered electron image (BEI) of the SEM(Secondary Electron Microscopy). Backscattered electron image was used to obtain the micrographs of better contrast among the formed phases. The composition of formed phases was determined using the energy-dispersive X-ray (EDX), and X-ray diffractometer(XRD) analysis.

Results and Discussion

The experimental results indicate the effect of the changing shear speed on the shear force for Sn-37Pb and Sn-3.5Ag solder balls on Au/Ni/Cu pad of BGA substrates after multiple reflows (1x to 5x).

Figure 2 shows the relationship between ball shear force and shear speed for Sn-37Pb and Sn-3.5Ag solders. The shear force was proportional to the shear speed and reached to a maximum at the highest shear speed, generally. The resistance to plastic deformation increased with an increase of the shear speed; i.e., the shear force-displacement curve could be shifted to higher force values for the same displacement by increasing the displacement during the test. The increase in the shear force with an increase in the shear speed was attributed to the effect of work-hardening. These data showed that shear speed had a significant influence on shear force. It was found that for Sn-37Pb and Sn-3.5Ag solder on Au/Ni/Cu pad, 31.0, 29.0% of shear force increased in the shear speed of the increase from 10㎛/sec to 1000㎛/sec, respectively. Shear speed should be specified whenever it is necessary to quantify correlating shear force data. With standard deviations, it might be deduecd that the ideal solder ball shear testing conditions were the cases with shear speed of about 200㎛/sec.

Figure 3 shows the relationship between the thickness of the intermetallic compound and the number of reflows for Sn-37Pb and Sn-3.5Ag solder on Au/Ni/Cu pad. The thickness of the intermetallic compound was proportional to the number of reflows, and the specimens for Sn-3.5Ag solder had faster growth-rate of intermetallic compound than the one for Sn-37Pb solder. In EDS and XRD analysis, it was observed that the intermetallic compound formed in interface identified the Ni_3Sn_4.phase. It was shown that the thickness of the intermetallic compound at central region in the interface is thicker than one at edge part. That problem was suggested that it caused by oxidation of surface, wetting delay, and heat divergence; First, the specimens were reflowed without flux during the multiple reflows (over 2x reflow). The oxide formed below surface might prevent the diffusion of Sn, and the increase of IMC. Second, owing to spreading time of melted solder, it might be observed to the difference of the thickness of IMC between center and edge of pad. But, its effect might be ignorable dissimilar to LCCC, because of small diameter of solder ball. Third, during cooling, the surface cooled faster than the edge due to heat-conductivity of solder, and latent heat of substrate below solder ball.

Figure 4 shows the variations of shear force for Sn-37Pb and Sn-3.5Ag on Au/Ni/Cu with the number of reflows. The maximum shear force was evaluated in 3x reflow, which the thickness of the intermetallic compound was measured to about 0.80㎛, i.e., the average value between center and edge parts.The shear force increased according to increasing the number of reflows, and the increase of intermetallic compound. It was evaluated that the tendencies of shear force with multiple reflows were almost identical in the shear speed of 100, 200, 300, and 1000㎛/sec.

Figure 5 shows variations of displacement for Sn-3.5Ag solder on Au/Ni/Cu substrate after multiple reflows (1x to 3x). Figure 5-(a) was a typical F-x curve after 1x and 5x reflow. The more number of reflow, the higher work-hardening rate, shear force, and displacement. The variations of displacement might be affected by the varations of solder ball diamter as well as the effects of intermetallic compound. It was suggested that the main cause of the variaions of the diameter was the variation of surface tension of liquid phase, and that the variaion of ball diameter caused the variation of displacement values on the shear test.

Figure 6 shows the variations of fracture surface for Sn-3.5Ag with shear speed, and the number of reflows. According to increasing the shear speed and the number of reflows, the fractography was rougher and coarser. The dispersion of applying stress by their fractography might cause the shear force to increase.

Acknowledgements

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References

[1] ASTM F 1269-89, 1991 Annual Book of ASTM Standards, ASTM, Philadelphia, (1991).

[2] JESD 22-B117, JEDEC Solid State Technology Association, July(2000).

[3] Coyle, R.J.; Solan, P.P.; Serafino, A.J.; Gahr, S.A.: 2000 Electronic Components & Technology Conference 50th, (2000), p. 160 –169.

[4] Robert Erich, Richard J. Coyle, George M. Wenger and Anthony Primavera: 1999 IEEE/CPMT Int'l Electronics Manufacturing Technology Symposium, (1999), p. 16-22.

[5] Xingjia Huang, S.W.Ricky Lee and Chien Chun Yan : 2002 Electronic Components and Technology Conference, (2002), p. 968-973.

[6] Richard J. Coyle and Patrick P. Solan: 2000 IEEE/CPMT Int'l Electronics Manufacturing Technology Symposium, (2000), p. 168-177.

[7] P. L. Tu, Yan C. Chan, Senior Member, IEEE, and J. K. L. Lai: IEEE Transactions on Components, Packaging, and Manufacturing Technology - Part B, 20(1997), Febrary, p. 87-93.

[8] Li Li, Jin-Wook Jang, and Becky Allmen: 2001 International Symposium on Advanced Packaging Materials, (2001), pp. 347-353.

[9] Xingjia Huang, S. W. Ricky Lee, Chien Chun Yan, and Sam Hui: 2001 Electronic Components and Technology Conference, (2001).

[10] Hyun-Joo Han : The University of Seoul, (2000), Febrary, p. 33-36.

[11] Alex C. K. So and Y. C. Chan : IEEE, (1995), p. 1073-1080.

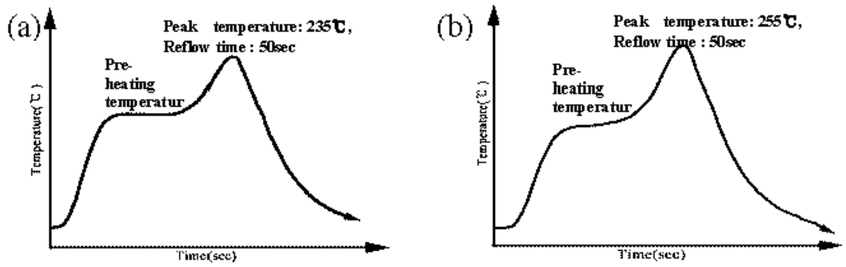

Fig 1. The temperature profile of reflow ; (a) Sn-37Pb , (b) Sn-3.5Ag.

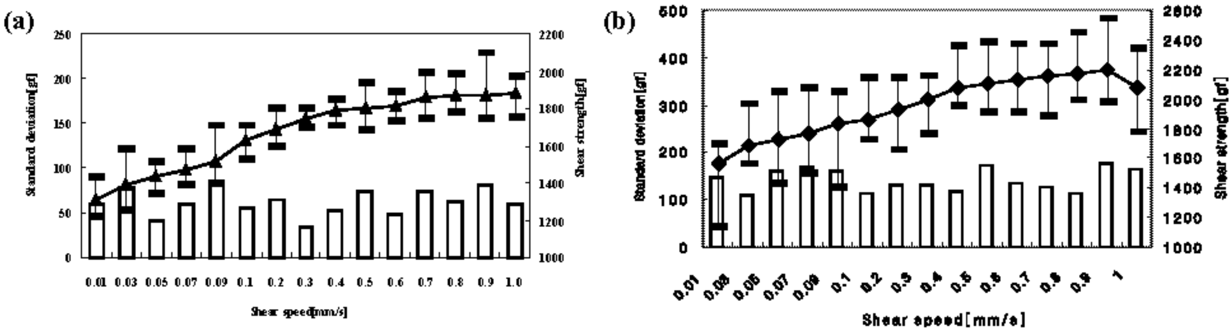

Fig 2. Variaions of shear force with shear speed on Au/Ni/Cu pad; (a) : Sn-37Pb solder, (b) : Sn-3.5Ag solder.

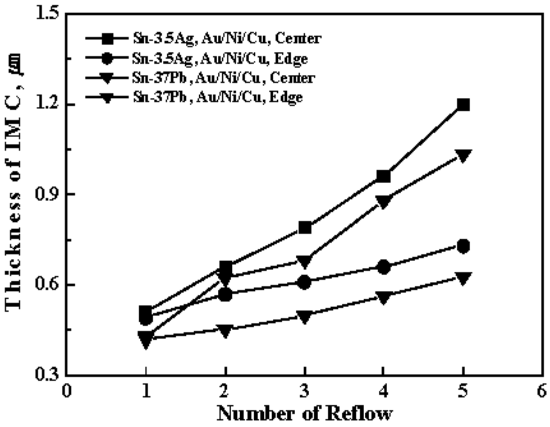

Fig. 3 Variation of thickness of intermetallic compounds with number of reflow, surface finish and solder material.

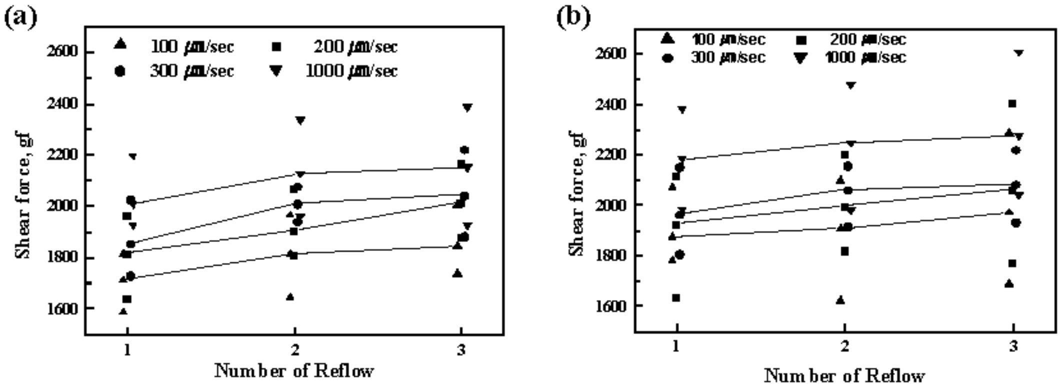

Fig. 4 Variations of shear force with the shear speed and the number of reflows on Au/Nu/Cu `substrate; (a) Sn-37Pb solder , (b) Sn-3.5Ag solder.

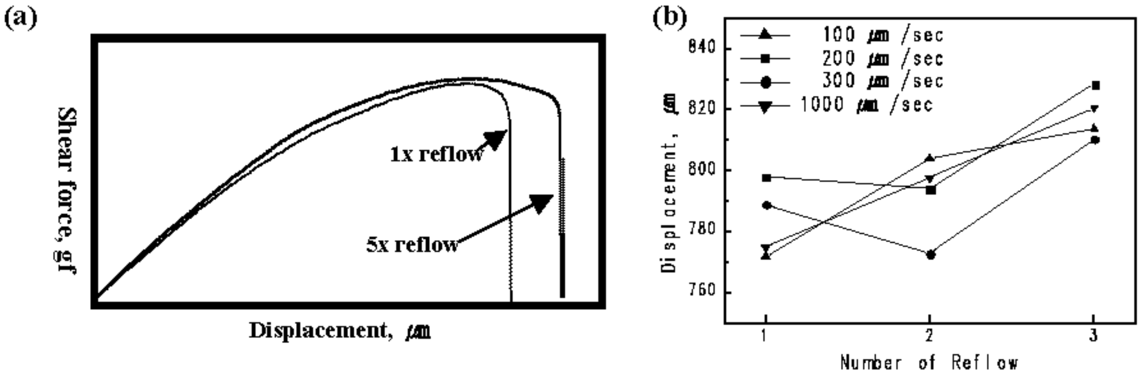

Fig. 5 Variations of displacement for Sn-3.5Ag solder on Au/Ni/Cu substrate after reflow (1x to 5x) ; (a) The diagram of the typical F (shear force) – x (displacement) curve, (b) Variations of displacement with the shear speed and the number of reflows.

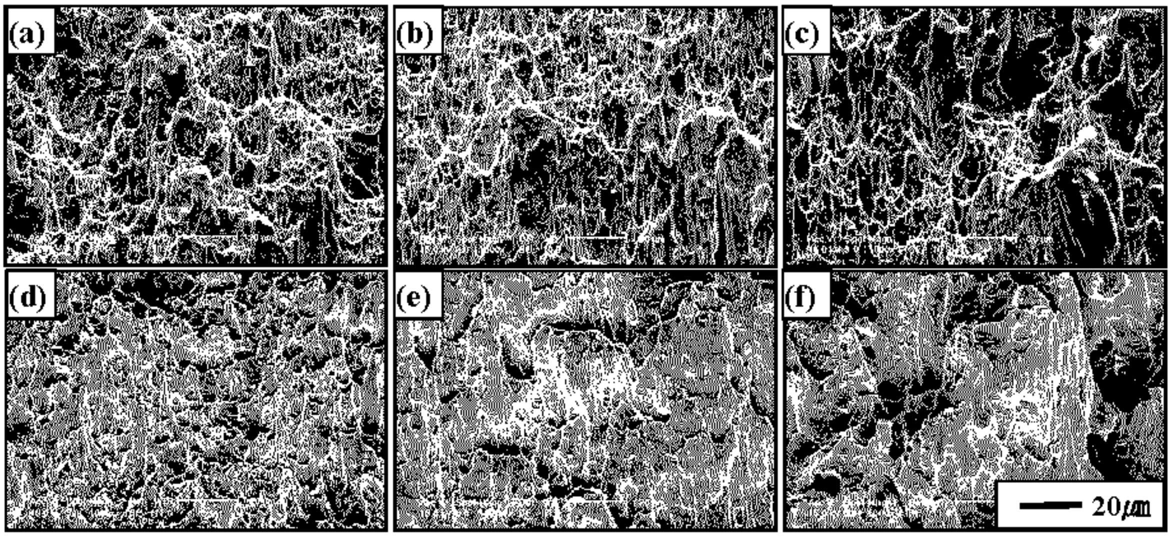

Fig. 6 Variations of fractography of Sn-3.5Ag on Au/Ni/Cu subsrtate with shear speed and number of reflow ; (a) ~ (c) : 1 reflow, (e) ~ (f) : 3reflow, (a), (d) : 10㎛/sec , (b), (e) : 200㎛/sec ,. (c), (f) : 1000㎛/sec.