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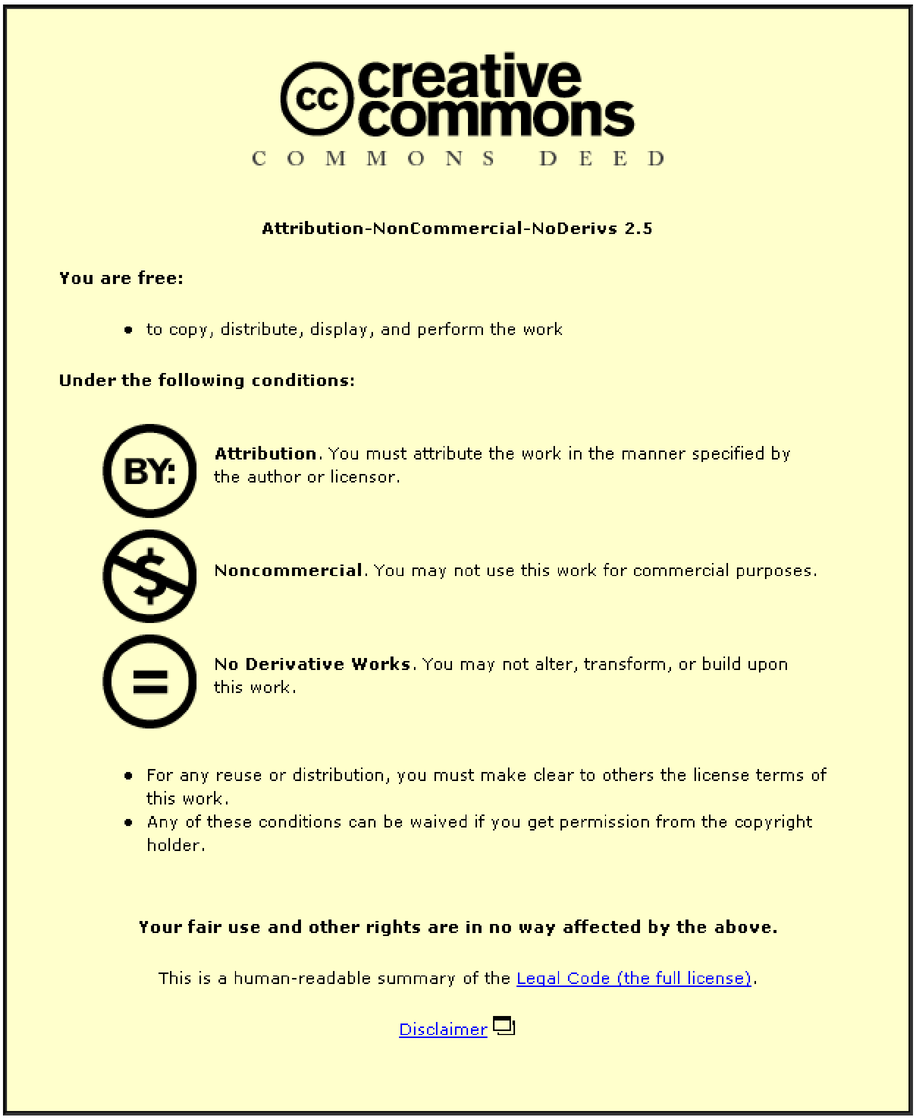

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Study of Self-Alignment of μBGA Packages

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***Abstract*—In this paper, a detailed study of the self-alignment of μBGA packages is presented. Complete self-alignment can be achieved even for a misalignment of the package of larger than 50% off the test board pad centres. A small residual displacement of the package from perfect alignment after reflow is observed. The reason for this displacement is the action of gas flow viscous drag on the package during reflow. The use of eutectic SnPb solder paste slightly reduces self-aligning ability, due to the increase in the solder volume, which reduces the restoring force. Exposure of the solder paste to a 25 °C and 85% RH humidity environment also has a detrimental effect on the self-alignment of the μBGA package, due to solvent evaporation and moisture absorption in the paste causing solderability degradation. The self-alignment of the package is also affected when there is slow spreading of molten solder on the pad surface. This is attributed to the reduction of restoring force due to the decrease in effective wetting surface area of the board pad.**

***Index Terms*—Gas flow effect, self-alignment, μBGA package, wetting.**

I. INTRODUCTION

FOR the portable electronics market, the size and weight of the product are among the most significant issues determining market share. This in turn drives the need for electronic components and electronic packages that are as thin, small, and lightweight as possible [1]. A consequence is burgeoning interest in chip scale packages (CSP) [2]. As is typical with an emerging market, there are many different CSP solutions offered by a variety of companies. The micro ball grid array (μBGA) package is one such package that has been successfully deployed for portable devices by big companies like Intel [3].

The μBGA package is unique in its construction. It uses a flexible circuit film as the substrate material. The chip is die attached to this material with a low stress, elastomeric adhesive. The circuit traces are formed into leads on certain sections of the tape and these leads are bonded directly to the bond pads on the chip. An elastomeric encapsulant-type of material surrounds the lead and chip bond pads, and finally solder bumps are attached to bump pad openings in the circuit tape. Since the size and pitch of the solder bumps are quite small (only 0.35 and 0.75 mm, respectively), high pick and place accuracy compared to older SMT standards is necessary. It is known that slightly misaligned parts (less than 50% off the pad centre) will automatically self-align during reflow for the ball grid array and similar packages [4], [5]. However, up to now, detailed study of the self-alignment of the μBGA packages is lacking. This paper studies the self-alignment ability of the μBGA package. Some important parameters that affect the self-alignment will also be discussed.

II. EXPERIMENTATION

The samples used in this study are the dummy versions of Tessera's μBGA package in which the bump size and pitch are respectively 0.35 and 0.75 mm, and the solder bump material is eutectic 63Sn/37Pb. The test board for assembly of the μBGA packages is composed of FR4. There are two categories of test board pads. Both are of copper plated with nickel but with different thickness of thin layer of gold flash on top. The diameter of the test board pads is 0.30 mm. Before mounting the μBGA packages onto the test board, no-clean flux is dispensed onto the test board pads. Two flux formulations, low viscosity (LV) and high viscosity (HV), are used in this study. Alternatively, no-clean 63/37 solder paste is printed onto the test board pads using a screen printer with a stencil of 0.1 mm thickness. The stencil life of this solder paste as claimed by the supplier is longer than 8 h. Following application of flux or paste, the μBGA samples are mounted on the test boards by a high-precision, high-speed flexible mounter (CASIO YCM-5500V). We make use of the high accuracy of the mounting machine to control the misalignment of the μBGA samples on the board pads. The misalignments chosen are 0, 0.05, 0.10, 0.15, and 0.20 mm. Before reflow, the mounted samples are inspected to ensure the correct misalignment by use of a SOFTEX real time x-ray inspection system. A five-zone reflow gas-forced-convection oven (BTU VIP-70N) is used to reflow the mounted samples in a compressed air environment. The time-resolved temperature during reflow between the component and the test board is measured using a wireless profiler (Super M.O.L.E, E31-900-45/10). A typical reflow profile is shown in Fig. 1. In this figure, the time above the melting temperature $T* =$ 183 °C of the eutectic solder is $t_{\mathrm{above}\,T^*} = 52$ s. After the assembly process, the samples are inspected by the x-ray inspection system again. Additionally, electrical tests, cross sectioning, and optical microscopic analysis are performed.

III. RESULTS AND DISCUSSION

A. Effects of Different Levels of Misalignment, Sample Flow Direction, and Viscosity on Self-Alignment of μBGA Packages

X-ray pictures of μBGA samples with various initial misalignments before and after reflow are shown in Fig. 2, in which (a) the sample flow direction is from left to right, and (b) the sample flow direction is reversed. The no-clean flux used is the

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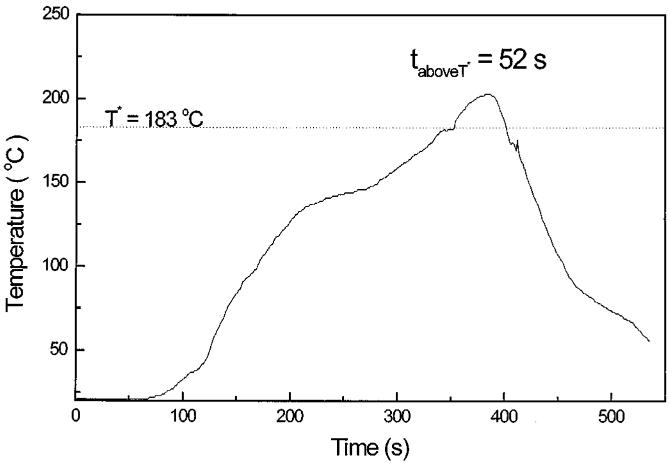


Fig. 1. Measured temperature reflow profile used with the μBGA packages. The time spent above the melting temperature $T* = 183$ °C of the eutectic solder is 52 s.

low viscosity type. It can be seen that even for a misalignment of larger than 50% off the pad centre, the package is still able to self-align. It is interesting that in all cases a small residual displacement toward the side opposite to the sample flow direction of around 20 to 40 μm after reflow can be observed. This displacement can be explained by using the schematic force balance diagram shown in Fig. 3. Since the mounted μBGA samples are reflowed in a compressed air environment, the gas flow produces a viscous drag which can pull the package away from the desired position. In fact, the drag force caused by the gas flow includes both the shear force and the pressure acting on the sides of the package. In this figure, the vertical component of pressure is ignored since it will only affect the stand-off height in between the μBGA and PCB. The force balance is governed by

$$\text{Drag force} + \text{Restoring force} = 0.$$

The slight misalignment of the package in the balance position creates an opposing restoring force to balance the drag force due to the gas flow effect. Therefore, in Figs. 2(a) and 3(a), since the sample flow direction is from left to right, there is a drag force created in the opposite direction, and the solder joints are slightly misaligned to the left. In Figs. 2(b) and 3(b) the drag acts from left to right so the solder joints are slightly off-center to the right. Figs. 4 and 5 show plots of self-alignment against misalignment for the μBGA packages using low viscosity and high viscosity flux respectively. The self-alignment is the distance moved from the initial misalignment to the final equilibrium position. The centering line is a reference line for a solder ball aligned at equilibrium exactly at the pad centre. The upper curve represents the self-alignment results in which the initial misalignment is on the same side as the sample flow direction, while the lower curve represents the self-alignment results in which the initial misalignment is opposite to the sample flow direction. It can be seen that both curves show offset from the centering line. Even when there is no initial misalignment of the package, there is still a displacement from the ideal position. Therefore, the gas flow effect must be considered when using lightweight advanced packages like CSP and flip chip. Comparing Figs. 4 and 5, the viscosity of the flux seems to have

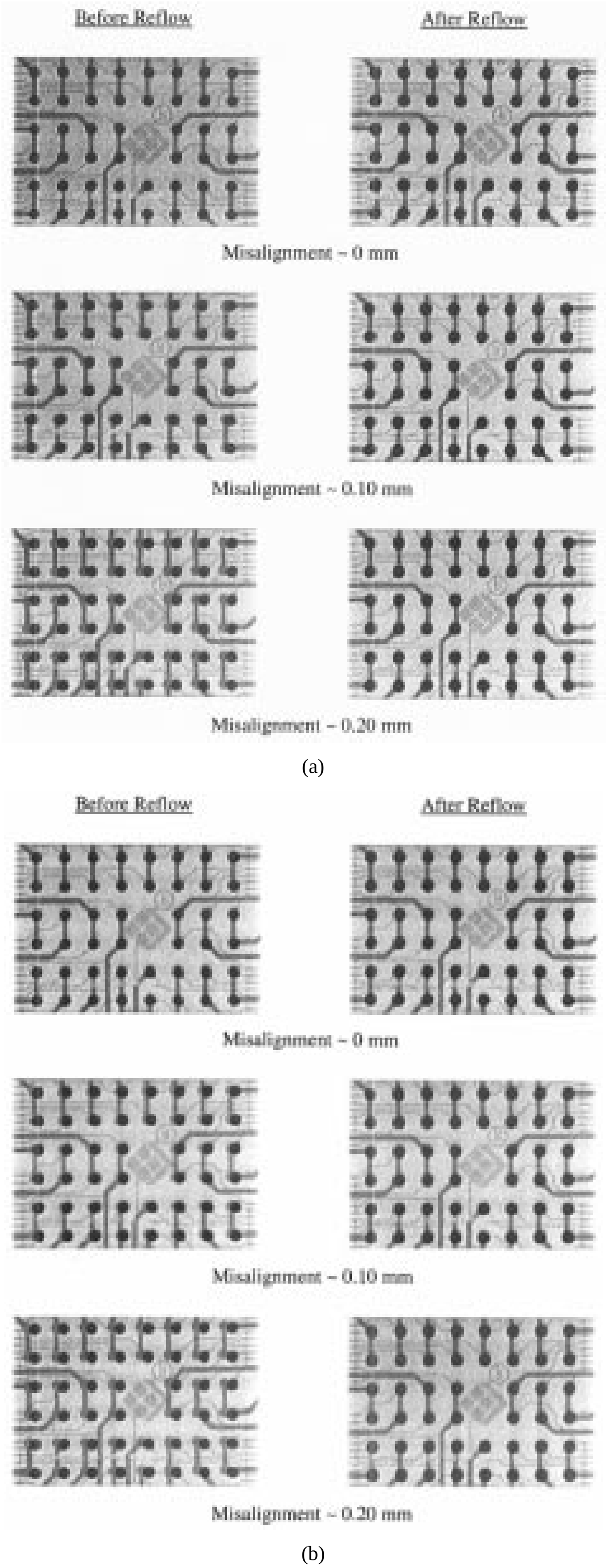


Fig. 2. X-ray inspection pictures of μBGA samples with various misalignments before and after reflow, in which (a) the sample flow direction is from left to right and (b) vice versa.

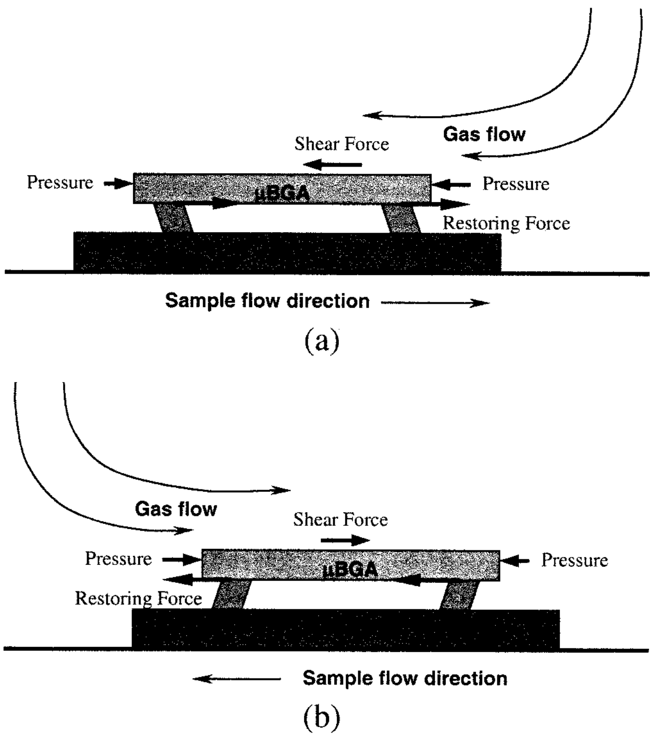


Fig. 3. Schematic force balance diagram of the μBGA package during reflow, in which (a) the sample flow direction is from left to right and (b) vice versa.

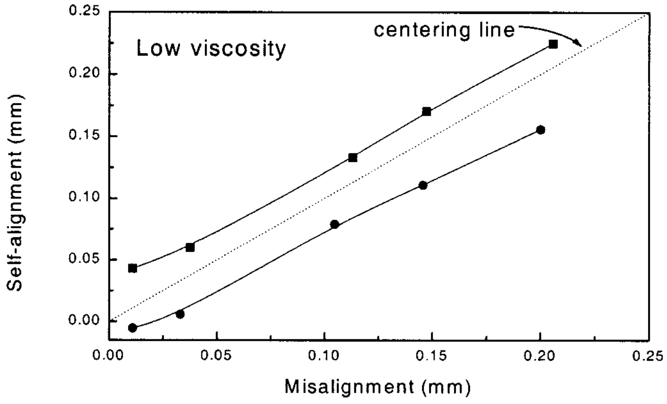


Fig. 4. The relationship between self-alignment and misalignment of μBGA samples using low viscosity flux. The centering line indicates perfect self-alignment.

no effect on the self-alignment of the μBGA packages. However, it is known that the higher the flux viscosity, the lower the defect rate at reflow. This has been attributed to the fact that it is more difficult for a component to move through a high viscosity flux during board preparation, handling and initial reflow [6]. In addition, it can be seen that the greater the misalignment, the greater the self-alignment. Theoretically, increasing the misalignment will lead to increase the restoring forces that move the package toward the balanced position [7], and thus increase the distance moved to the desired balance position, i.e., restoring force ∝ self-alignment ∝ misalignment.

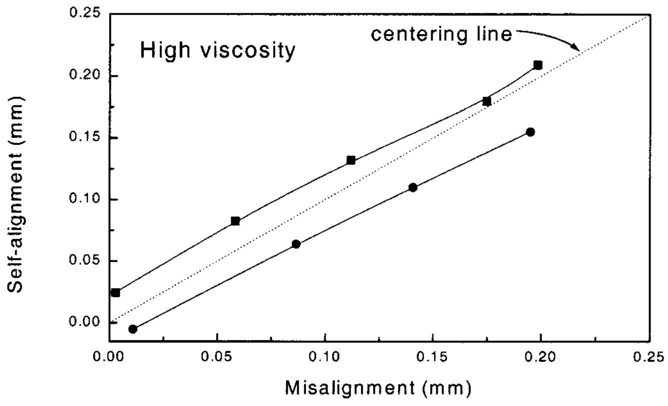


Fig. 5. The relationship between self-alignment and misalignment of μBGA samples using high viscosity flux. The centering line indicates perfect self-alignment.

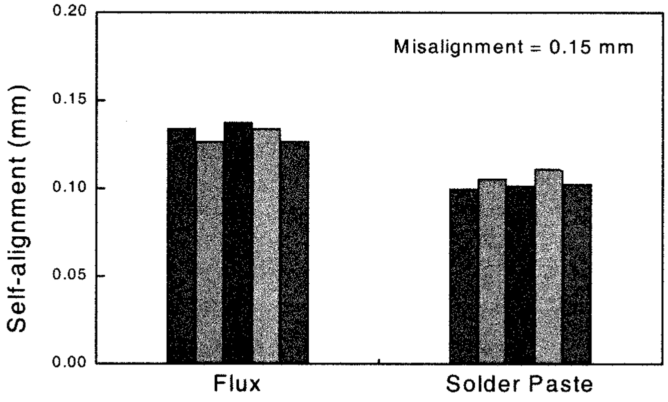


Fig. 6. Comparison between self-alignment of two groups of samples using flux and using solder paste, for an initial misalignment of 0.15 mm.

B. Effect on Self-Alignment Using Flux and Solder Paste

Fig. 6 shows a bar chart of the self-alignment of two groups of samples using flux and solder paste at a misalignment level of 0.15 mm. This figure shows that the self-alignment using flux is larger than that using solder paste. Based on the simple-estimation formulas [8], the restoring force $f_s(P)$ is a function of misalignment P as follows:

$$f_s(P) = \frac{\pi}{2}\gamma(r_c+r_s)\left\{\frac{P+r_c-r_s}{[(P+r_c-r_s)^2+h^2]^{1/2}} + \frac{P-r_c+r_s}{[(P-r_c+r_s)^2+H_c^2]^{1/2}}\right\} \quad (1)$$

$$H_c = \frac{3V}{\pi(r_c^2+r_cr_s+r_s^2)} \quad (2)$$

where γ is the surface tension coefficient, r_c the package pad radius, r_s the board pad radius, h the height of solder joint, and V the solder volume. If γ, r_c, r_s, h, and P are all fixed, an increase in solder volume V will lead to a reduction in the restoring force f_s. By adding solder paste to the board pad, the total solder volume per joint will be slightly increased at reflow. As a result, the addition of solder paste reduces the restoring force and thus the self-alignment.

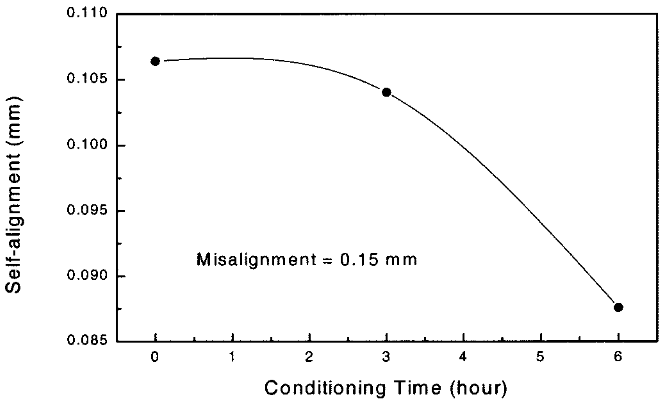
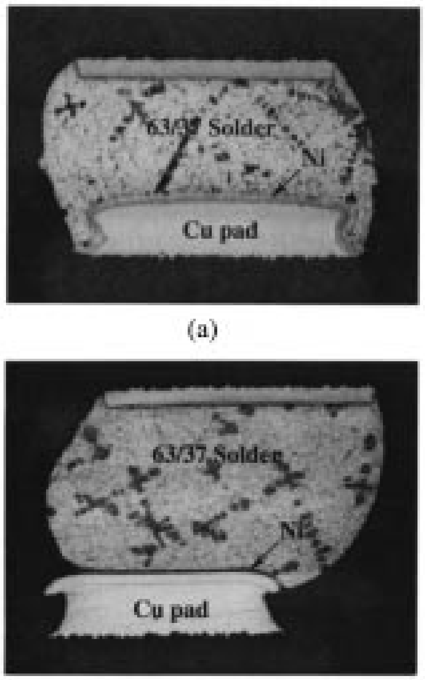


Fig. 7. Self-alignment against conditioning time for solder paste conditioned at 25 °C and 85% RH humidity.


63/37 Solder
Ni
Cu pad
63/37 Solder
Ni
Cu pad

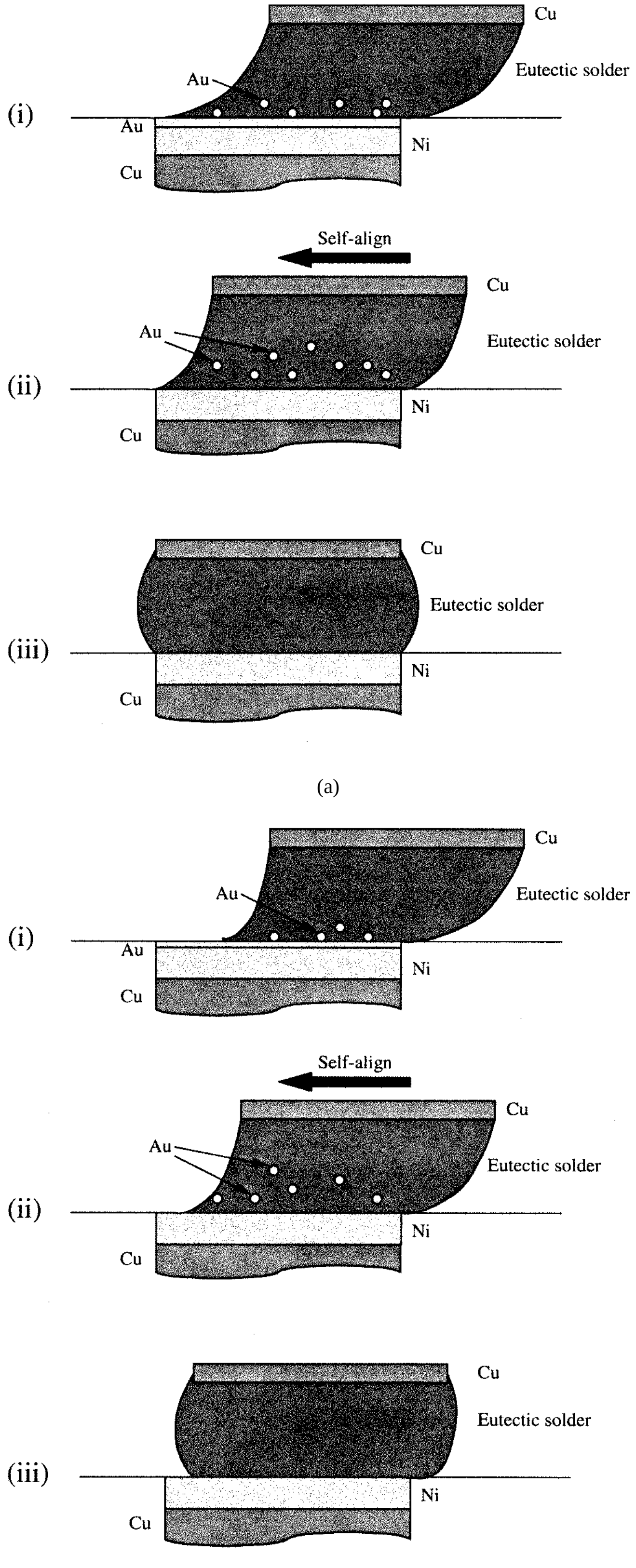
(a)

(b)

Fig. 8. Optical micrographs of cross sections of μBGA solder joints using (a) a pad of copper plated with nickel and 1000 Å gold flash on top and (b) a pad of copper plated with nickel and 100 Å gold flash on top.

C. Effect of Time Exposed to the Environment on Self-Alignment

Fig. 7 shows a plot of self-alignment against conditioning time for solder paste conditioned in a humidity chamber. In this experiment, we first stencil the solder paste onto the board pads and then condition these test boards in the temperature and humidity chamber at 25 °C and 85% RH. After removal from the chamber the boards are loaded with μBGA packages and reflowed. From Fig. 7, it may be seen that the self-alignment is only slightly reduced after the first 3 h conditioning but drops greatly after 6 h. In fact, as solder paste is worked and exposed to the environment, solvent evaporates and moisture from the air is absorbed [9]. As a result, the fluxing ability of


(i)
Cu
Eutectic solder
Au
Au
Ni
Cu
Self-align
(ii)
Cu
Eutectic solder
Au
Ni
Cu
(iii)
Cu
Eutectic solder
Ni
Cu
(i)
Cu
Eutectic solder
Au
Au
Ni
Cu
Self-align
(ii)
Cu
Eutectic solder
Au
Ni
Cu
(iii)
Cu
Eutectic solder
Ni
Cu

(a)

(b)

Fig. 9. Schematic diagrams depicting the process of self-alignment of the package for (a) a 1000 Å-Au/Ni/Cu pad and (b) a 100 Å-Au/Ni/Cu pad. Stage (i) is the initial wetting reaction of eutectic solder and Au thin layer on the Au/Ni/Cu board pad; stage (ii) is the dissolution of Au into the eutectic solder and self-alignment to the desired position; and stage (iii) is the final position of the solder.

the solder paste will be degraded, affecting the self-alignment of the μBGA packages.

D. Effect of Different Au Thickness Coating of Test Board Pad on Self-Alignment

Fig. 8 shows optical micrographs of cross sections of solder joints using (a) a board pad of copper plated with nickel and about a 1000 Å thin layer of gold on top, and (b) a board pad of copper plated with nickel and about a 100 Å thin layer of gold flash on top. The initial misalignment of the μBGA packages for these two figures is 0.20 mm. The self-alignment of the μBGA package shown in Fig. 8(a) is very good and the μBGA package is almost aligned to the centre of the board pad even though the initial misalignment was larger than 50% off the pad centre. However, in Fig. 8(b), it can be seen that the self-alignment is much worse. Closer inspection reveals that the solder has not wet the pad properly. In our previous work of wetting dynamic experiment [10], it is found that the spreading of molten solder on 1000 Å Au layer pad is faster than that on 100 Å Au layer pad. In order to have a clear interpretation, the effect of different degree of spreading on the self-alignment of the package is illustrated by the diagrams in Fig. 9(a) and (b) for the 1000 Å Au layer pad and the 100 Å Au layer pad, respectively. There are three stages. The first stage (i) is the reactive wetting of the eutectic solder on the Au thin layer in the initial stages of reflow following the action of the flux on the surfaces to be joined. However, since the spreading of molten solder on 100 Å Au layer pads is much slower, the effective board pad surface area that can be wetted by the molten solder may be smaller. That is, the molten solder may not wet the whole area of the 100 Å Au layer pad due to the slow spreading of molten solder. In the meantime, the thin Au layer starts to dissolve into the molten solder. The second stage (ii) shows the very thin Au layer dissolving into the eutectic solder exposing the Ni surface to the eutectic solder at the interface. At the same time, the package self-aligns to the desired position. Actually, in Fig. 9(b), the restoring force for the solder joints using 100 Å Au layer pads will be reduced due to the smaller board pad surface area that can be wetted by the molten solder. As a result, the change of equilibrium condition will cause less better self-alignment of the package using 100 Å Au layer pad, which is shown in stage (iii) of Fig. 9(b).

IV. CONCLUSION

In summary, we have made a detailed study of the self-alignment of μBGA packages. It is found that a μBGA package can still self-align even for an initial misalignment of larger than 50% off the pad centre. It is found that the gas flow during reflow causes a small residual displacement of the package away from the ideal position due to drag forces. The flux viscosity seems to have no effect on the self-alignment of the μBGA package. The use of solder paste is found to slightly reduce the self-alignment ability due to the increase in solder joint volume during reflow. Exposure of the solder paste to conditioning at 25 °C and 85% RH for 6 h significantly reduces the self-alignment. This is attributed to evaporation of solvent and absorption of moisture leading to the degradation of solderability and thus reduction in the self-alignment of the package. Finally, we have observed less better self-alignment for 100ÅAu/Ni/Cu board pads. The probable cause is the reduction of restoring forces due to slow spreading of the molten solder on the pad surface.

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