Novel Bumping Material for Solder-on-Pad Technology

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A novel bumping material, which is composed of a resin and Sn3Ag0.5Cu (SAC305) solder power, has been developed for the maskless solder-on-pad technology of the fine-pitch flip-chip bonding. The functions of the resin are carrying solder powder and deoxidizing the oxide layer on the solder power for the bumping on the pad on the substrate. At the same time, it was designed to have minimal chemical reactions within the resin so that the cleaning process after the bumping on the pad can be achieved. With this material, the solder bump array was successfully formed with pitch of 150 µm in one direction.

Keywords: Maskless bumping, solder-on-pad (SoP) technology, Sn3Ag0.5Cu solder, resin.

I. Introduction

Flip chips can be found in nearly every popular consumer and server application because flip-chip packaging technology becomes cost-effective in the 200 to 700 pin count range [1]. To increase their manufacturability and reliability, solder-on-pad (SoP) technology was introduced to obtain a higher standoff height than the conventional Ni/Au or organic solderability preservative (OSP) pad surface finishes used for flip-chip substrates [2]. The conventional approach was the stencil printing process using solder paste. However, it was not suitable for the fine-pitch bumping of 150 µm and less than 150 µm. The proposed technologies were solder jetting, controlled collapse chip connection new process (C4NP), electro-plating, micro-ball placement, super solder, and so on. Each technology has its own disadvantages, such as expensive equipment, low throughput, and environmental problems.

In this letter, we propose a novel bumping material for SoP technology. The basic idea is similar to the solder bump maker (SBM), which is based on the rheological behavior of the solder in resin [3]-[5]. However, the major component of the resin in the SBM was epoxy, the solder of which has a low-melting-point, making the SBM inapplicable to the SoP technology. To resolve those problems, we adopted the Sn3Ag0.5Cu (SAC305) solder and developed a new resin which can endure high temperature process so that a cleaning process can be performed after the bumping process. This SBM with SAC solder has the same features as the SBM with low-melting-point solder [3]. The characteristics of the resin with and without solder were analyzed using differential scanning calorimetry (DSC) and a dynamic mechanical analyzer (DMA). The wetting behavior of SAC305 solder in the resin on Au finish and Cu finish electrodes was observed. Finally, an SAC solder bump array with pitch of 150 µm in one direction was formed using the SBM with SAC, and its morphologies were characterized.

II. Materials and Experiment

1. Materials

The resin used consists of a polymer matrix, a deoxidizing agent, and additives. The polymer matrix carries the solder powder during the bumping process. The heat-resistant polymer matrix was chosen to have little property change

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during the high temperature process. The deoxidizing agent and additives reduce the oxide layer on the solder powder. The mixing ratio between the polymer matrix, deoxidizing agent, and additives was precisely designed according to the amount of oxide in the solder powder. The chemical reactions between the components in the resin were designed to be minimal because the chemical reactions might make the cleaning process impossible. As in the SBM, the solvent was not applied to the resin to prevent the out-gassing from the resin during the bumping process. For bumping process, an SAC305 solder powder was mixed with the resin.

2. Experiment

A dynamic DSC and DMA (torsional parallel plate) with a heating rate of 10°C/min were conducted using the resin with and without the SAC solder [4] for characterization of the chemo-rheological phenomena. The specification of the distribution of the solder diameters was type 6 according to the standard [6]: smaller than 5 µm, 5 µm to 15 µm, 15 µm to 20 µm, and larger than 20 µm with weight percentages of 1.62%, 87.23%, 9.14%, and 2.01%, respectively. The volumetric mixing ratio between the resin and solder powder was 7:3 [3].

For the investigation of compatibility between the SAC solder and the resin, the wetting phenomena of an SAC solder ball with a diameter of 0.76 mm in the resin was observed. For bumping using the SBM with SAC, an under-bump metallization (UBM) pad array with pitches of 150 µm in the horizontal direction and 190 µm in the vertical direction on a PCB substrate was prepared. The UBM structure was electroless nickel and immersion gold (ENIG). The pad design was solder mask defined (SMD). The thickness of the SBM with SAC on the PCB substrate was controlled to be 170 µm with a guide tape on the PCB substrate. After printing the SBM with SAC on the PCB substrate, the device under test (DuT) was reflowed at 260°C for 20 s on an IR oven. Then, the DuT was rinsed with a solvent and ultrasonicated to remove the resin, along with the remaining solder powder in the resin that did not wet on the UBM.

III. Results and Discussion

Figure 1 shows the measured DSC thermograms for both of a new resin and a SBM with SAC. As in [3], the endothermic peak at around 100°C for the resin was caused by the melting of the deoxidizing agent. The chemical reactions occurred above about 220°C, and their heat of reactions decreased from 128.4 J/g to 23.65 J/g compared with those in the previous paper. The heat generated from the chemical reactions was designed to be of a small quantity to provide the thermal stability above the melting point of SAC305 solder to the SBM with SAC. To reduce the reactions, the amount of the deoxidizing agent was carefully decreased. The SBM with SAC showed melting of the solder at 220°C during heating. It was noted that the chemical reactions started above 170°C in the SBM with SAC. It was thought that the solder powder plays the role of a catalyst so that the chemical reactions in the resin occurred at lower temperature with the solder powder [7]. The heat of the chemical reaction above 170°C was measured as 17.55 J/g.

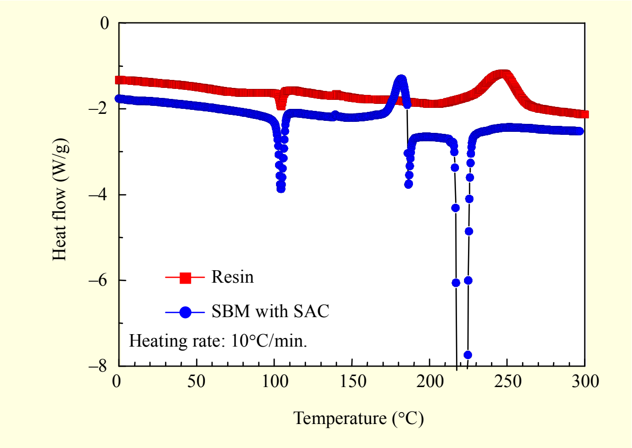


Fig. 1. Dynamic DSC scan with 10°C/min for both of new resin and SBM with SAC.

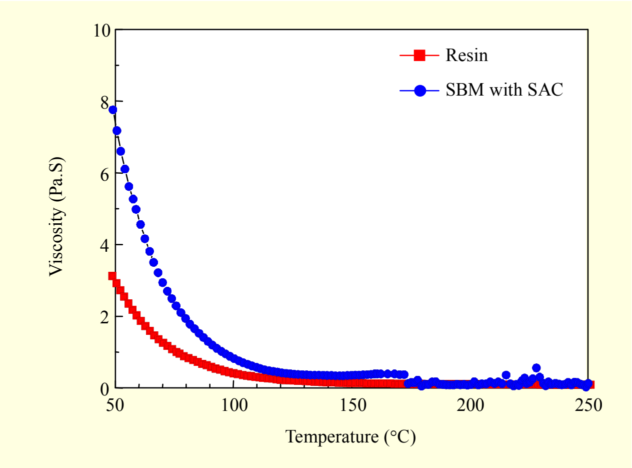


Fig. 2. Dynamic DMA scan with 10°C/min for both resin and SBM with SAC.

The viscosity of both modified materials was measured as shown in Fig. 2. Their behaviors were observed to be similar to that of the SBM, that is, showing decreasing viscosity with temperature. Several differences, however, were noted. First, the SBM with SAC showed a much smaller viscosity compared with the SBM with low-melting-point solder.

Second, the viscosity change of the SBM with SAC was relatively continuous with temperature because the viscosity of the SBM with SAC was low enough before melting of the deoxidizing agent and solder powder. Above the melting point of solder powder, the SBM with SAC showed a viscosity of about 0.1 Pa.S which is sufficiently low for the wetting and coalescence of molten droplets of solder on the UBM.

Figure 3 shows the wetting angles of an SAC305 solder ball within the developed resin on Au and Cu finish electrodes without applied pressure on the solder ball. Wetting angles of the solders on each electrode were 10.9° and 23.3°, respectively, which means that the resin enabled the reduction of the oxide layer on the solder ball and that of the Cu pad, which led to the wetting of the solders regardless of the surface finish, showing the versatility of the resin. Compared with the wetting angle of the resin reported, the solders in the new resin exhibited smaller wetting angle by 5° to 7° [3].

Figure 4 shows SEM and cross-section images of the SAC305 solder bump arrays formed on a PCB substrate using the SBM with SAC. The diameter of pads was 79 μm. The average height was about 28 μm, similar to that of the solder resist.

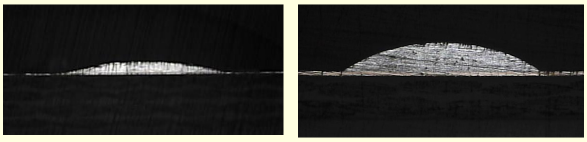
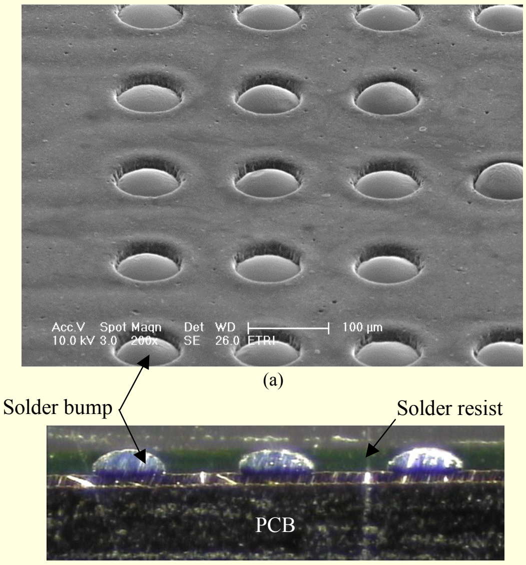

(a) (b)

Fig. 3. Wetting angles of SAC305 solder ball within resin on (a) Au and (b) Cu finish electrodes.



(b)

Fig. 4. (a) SEM image and (b) cross-section of formed SAC305 solder bump arrays.

The mechanism of the maskless bumping for SoP technology was the same as that reported previously [3]: the interactions between the force of gravity and the surface tensions among the resin, molten droplets of solder, and surface finish of the electrodes on the substrate. The only difference is in the materials: solder and polymer matrix. Since the melting-point of SAC305 solder is about 220°C, several points about the properties of the polymer matrix should be redesigned. First, the polymer matrix needed to be heat-resistant so that properties such as viscosity did not change during the bumping process. Next, the chemical reactions of the polymer matrix with the oxidizing agent were designed to be reduced because they can make the cleaning process impossible and decrease the capacity of deoxidizing agent. To achieve these purposes, the amount of the deoxidizing agent was carefully controlled. We checked how many radicals of the polymer matrix interact with the agent so that the limited chemical reactions can occur during the mixing and bumping process. As observed in Fig. 1, the heat of the chemical reactions above 170°C was about 18 J/g, which is so small that there is no difficulty in the cleaning process. The limited chemical reactions between the polymer matrix and the deoxidizing agent were considered crucial because they can prevent the phase separation between them during the mixing and the bumping process.

For the stable flip-chip bonding process, the height of the bumps comparable to that of the solder resist is not desirable. The solder powder specification was determined considering the five-solder-ball rule [2]. However, the low profile solder bump came from the low wetting angle of the solder ball in the resin as shown in Fig. 3. To increase the wetting angle, the surface tension between the solder and resin should be controlled or the UBM metallization needs to be changed to Cu finish, which will be the subject of our future work.

IV. Conclusion

Novel, maskless SAC305 solder bumping material has been developed for SoP technology. Its chemo-rheological properties were measured, and from the results, it can be concluded that the resin can provide the environmental conditions for the bump formation with SAC305 solder powder.

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