Novel Maskless Bumping for 3D Integration

Kwang-Seong Choi, Ki-Jun Sung, Byeong-Ok Lim, Hyun-Cheol Bae,
Sunghae Jung, Jong-Tae Moon, and Yong-Sung Eom

A novel, maskless, low-volume bumping material, called solder bump maker, which is composed of a resin and low-melting-point solder powder, has been developed. The resin features no distinct chemical reactions preventing the rheological coalescence of the solder, a deoxidation of the oxide layer on the solder powder for wetting on the pad at the solder melting point, and no major weight loss caused by out-gassing. With these characteristics, the solder was successfully wetted onto a metal pad and formed a uniform solder bump array with pitches of 120 µm and 150 µm.

Keywords: Maskless bumping, solder bump maker (SBM), low-melting-point solder

I. Introduction

As the data capacities used by consumers have increased, market demand for high-density, high-speed, high-performance, and low-cost electronic components has also tremendously expanded. In view of packaging, interconnection technologies are migrating from wire bonding to flip-chip technologies, as the latter can cope with market requirements. For three-dimensional (3D) silicon stack chips, flip-chip technologies can be a particularly good solution for chip-to-wafer or chip-to-chip bonding processes [1]. It was reported that for 3D integration, low-volume, lead-free solder interconnects are more desirable because of the need to minimize the wiring length between chips, increase the heat dissipation, and shrink the design rules for the use of silicon [2].

In this letter, we propose a novel, maskless, low-volume bumping material, called solder bump maker (SBM), which is based on the rheological behavior of the solder in a resin. The resin we used is distinguished as having low viscosity around the melting point of the solder, a deoxidizing capacity of the oxide layer on the surface of the solder, and no out-gassing related with solvents during the bumping process. 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 Sn-58Bi solder in the resin on Au finish and Cu finish electrodes was observed. Finally, a Sn-58Bi solder bump array was made using the SBM, and its morphologies were characterized.

II. Materials and Experiment

1. Materials

The resin used consists of an epoxy-based thermoset, a deoxidizing agent, and additives. The epoxy carries the solder powder during the bumping process. The oxide layer on the solder powder was deoxidized by a deoxidizing agent and additives. The mixing ratio between the epoxy, deoxidizing agent, and additives was precisely designed according to the amount of oxide in the solder powder. The solvent was not applied to the resin in order to prevent out-gassing from the resin during the bumping process. For the bumping process, a Sn-58Bi solder powder was mixed with the resin.

2. Experiment

For characterization of the chemo-rheological phenomena, a dynamic DSC and DMA (torsional parallel plate) with a heating rate of 10°C/min were conducted using resin with and without the Sn-58Bi solder [3]. The distribution of the solder diameters was as follows: smaller than 5 µm, 1.62% weight percentage; 5 µm to 15 µm, 87.23%; 15 µm to 20 µm, 9.14%; and larger than 20 µm, 2.01%. The volumetric mixing ratio

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Kwang-Seong Choi (phone: +82 42 860 6033, email: kschoi@etri.re.kr), Ki-Jun Sung (email: skmagici@etri.re.kr), Byeong-Ok Lim (email: limbo@etri.re.kr), Hyun-Cheol Bae (email: hcbae@etri.re.kr), Sunghae Jung (email: csh63352@etri.re.kr), Jong-Tae Moon (email: jtmoon@etri.re.kr), and Yong-Sung Eom (email: yseom@etri.re.kr) are with the Convergence Components & Materials Research Laboratory, ETRI, Daejeon, Rep. of Korea.

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between the matrix and solder powder was 70:30.

For the investigation of compatibility between the Sn-58Bi solder and the resin, the wetting phenomena of a Sn-58Bi solder ball with a diameter of 0.76 mm in the resin was observed. The electrodes were made of an electro-plated Au and Cu finish on a laminated FR-4. For bumping using the resin mixed with Sn-58Bi solder powder, under-bump metallization (UBM) pad arrays with pitches of 100 μm, 120 μm, 150 μm, and 200 μm on a silicon substrate were prepared. The UBM structure was made of Ti/Ni/Au. The thickness of the SBM on the silicon substrate was controlled to be 120 μm with a guide tape on the silicon substrate. After printing the SBM on the silicon substrate, the device under test (DuT) was reflowed at 200°C for 60 s in an oven. Then, the DuT was rinsed with a solvent and ultrasonicated to remove the uncured 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 results for both the resin and SBM. The glass transition temperature T_g was observed at −16.5°C for both materials. The endothermic peaks were observed at around 100°C for both materials, and chemical reactions then started above 150°C in the resin and 120°C in the SBM. The SBM showed melting of the solder at 140°C during heating. This implies that the oxide layer on the solder powder was effectively reduced by the deoxidizing agent. We infer that the endothermic peak at around 100°C was caused by the melting of the deoxidizing agent. The effect of the chemical reactions above 150°C on the properties of the resin was investigated by reheating the resin. The T_g of the resin during reheating was −8.8°C, which was considered too small an increase to change the properties of the resin, compared with the T_g of the resin during the first heating. Therefore, it was expected that the residual resin and solder powder that was not wetted on the UBM after the bumping process could be easily removed using a cleaning process.

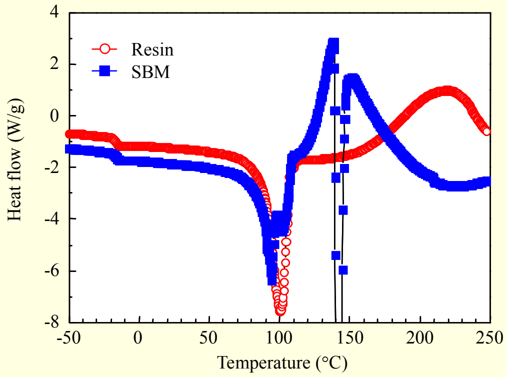


Fig. 1. Dynamic DSC scan with 10°C/min for both resin and SBM.

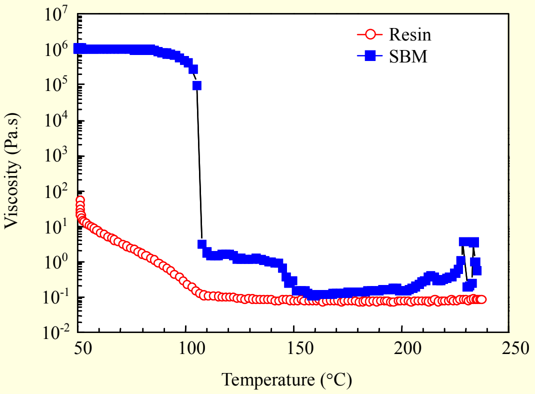
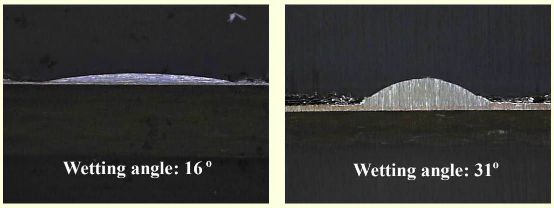


Fig. 2. Dynamic DMA scan with 10°C/min for both resin and SBM.

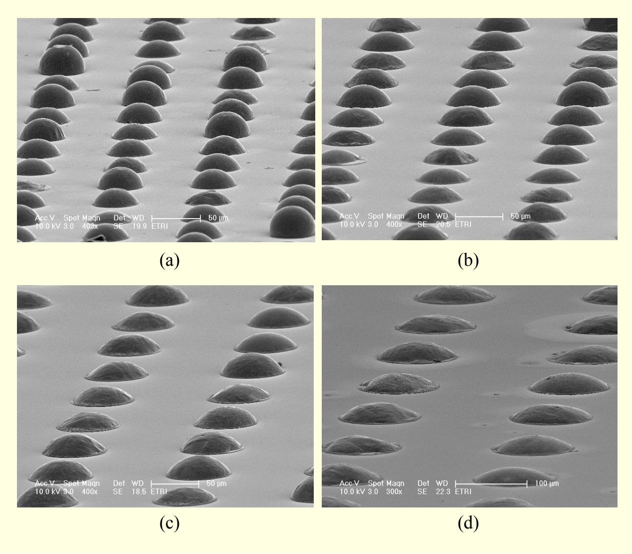
The viscosity of both materials was measured as shown in Fig. 2. Across the entire temperature range, the SBM showed higher viscosity than the resin. It was clear that the high viscosity of the SBM was caused by the presence of the solder powder. The viscosity of the resin continuously decreased up to 110°C and kept at about 0.1 Pa.s. A dramatic decrease in the SBM viscosity was observed twice during the increase of temperature, at 110°C and 140°C. We infer that the first decrease was caused by the melting of the deoxidizing agent. The second was clearly induced by the melting of the solder powder because the viscosity of the SBM decreased at 140°C. We conclude that the viscosity of the SBM at around 200°C, which was the bumping temperature, is sufficiently low for the wetting and coalescence of molten droplets of solder on the UBM.

Figure 3 shows the wetting angles of a Sn-58Bi solder ball within the developed resin on the Au and Cu finish electrodes without applied pressure on the solder ball. The wetting angles of the solders on each electrode were 16° and 31°, respectively, which means that the resin enabled the wetting of the solders regardless of the surface finish, showing the versatility of the resin.



(a) (b)

Fig. 3. Wetting angles of the Sn-58Bi solder ball within the resin on (a) Au and (b) Cu finish electrodes.



(a) (b)

(c) (d)

Fig. 4. SEM images of formed Sn-58Bi solder bump arrays with pitches of (a) 100 μm, (b) 120 μm, (c) 150 μm, and (d) 200 μm.

SEM images of the Sn-58Bi solder bump arrays formed using the novel bumping material are shown in Fig. 4. The solder bump arrays with pitches of 120 μm and 150 μm showed a relatively uniform bump shape. The array with the pitch of 100 μm exhibited irregular solder bumps with excessive and insufficient solder volumes. Those with 200 μm showed bumps with insufficient volume. The aspect ratio of the solder bumps, which is defined as a ratio between bump height and diameter, ranged from 0.17 to 0.28 depending on the pad diameters.

The mechanism of the maskless, low-volume bumping with novel material utilized the force of gravity and the interaction of the surface tensions between the three components: the resin, molten droplets of solder, and surface finish of the electrodes on the substrate. The most important interaction between the resin and solder was the deoxidization of the oxide layer on the solder powder by the deoxidizing agent in the resin. The melting of the solder powder, as shown in Fig. 2, and the wetting experiments verify the effect of the deoxidizing agent. Another important interaction was the low viscosity of the resin above the melting point of solder, which enabled the molten droplets of solder to aggregate on the gold finish on the electrodes. This was achieved through the design of the components in the resin with minimized chemical reactions between them as observed in Fig. 1 [3]-[5]. One of the factors controlling the volume of the solder bumps was the distribution of solder powder in the resin. For a specific pad size, it was thought that there was an optimum distribution of solder powder diameters. From the bump formation shown in Fig. 4, the ratio of the pad diameter to the average solder powder diameter ranged from 6 to 7 for the uniform bumps. If the ratio was larger than this, additional solder powder was occasionally necessary to make uniform bumps, requiring an increase of processing time. The processing time of the resin was limited because of the curing of the epoxy-based thermosetting material. If the resin is cured, the cleaning process is considerably difficult. Therefore, because of the limited processing time and temperature, a solder bump with an insufficient volume was observed when the pad size was much larger than the average powder diameter. On the contrary, if the ratio was smaller, a relatively large solder ball contributed a solder bump with high-volume in some cases, and in other cases, the molten droplets of solder were consumed by the adjacent electrodes so that solder bumps with insufficient volume formed. One solution to enhance the uniformity of the bumps is to use solder powder with a narrow diameter distribution, which will be the subject of our future work.

IV. Conclusion

Maskless, low-volume Sn-58Bi solder bumps with pitches of 120 μm and 150 μm for 3D integration were developed. For that purpose, a deliberate design for a novel material was performed, that is, a deoxidizing of the oxide layer on solder powder, maintaining low-viscosity above the melting point of solder without out-gassing. With the proposed SBM, a simplified, low-cost process for a fine-pitch bump can be attained.

References

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