The reliability of COF Joints with Tin Bumps and Non-Conductive Adhesives for Image Sensor Module Application

Chang-Bae Lee, Jin-Gu Kim, and Young-Do Kweon
Advanced PKG Group, Corporate R&D Institute, Samsung Electro-Mechanics Co., LTD
314, Meatan 3-Dong, Yeoungtong-Gu, Suwon, Gyunggi-Do, Korea

Kyoung-Moo Harr and Young-Ho Kim*
Division of Materials Science & Engineering, Hanyang University, Seoul, 133-791, Korea
*E-mail: kimyh@hanyang.ac.kr

Abstract

We developed a low cost and low temperature chip-on flex(COF) bonding technology by using Sn bumps and non-conductive adhesive(NCA) for image sensor device. Two types of Sn bumps, square and hemispherical bumps, were fabricated. Sn bumps were formed sequentially by electroplating and then were reflowed to form the hemispherical bumps. Device with Sn bumps was bonded with flexible-printed circuit board(F-PCB) using NCA at 180℃ after the NCA was dispensed. To evaluate the reliability of the COF joints, a thermal cycling (TC) test, high temperature storage (HTS) test, and temperature and humidity (T&H) test have been performed. The bondability and reliability of joints were evaluated by measuring the contact resistance of each bump. The electrical test showed that COF bonding was successful with no failed bumps, and the contact resistance of COF joints was very low about 10mΩ per bump. After aging treatment at 150℃ slightly increased the contact resistance. But failed COF joints were not observed before and after aging treatment. The reliability of COF joints fabricated using hemispherical bumps was good more than that of joint with square Sn bump. NCA trapping in the interface between bump and pad had an influence on the reliability of COF joints. The results of our experiments were successfully performed in application for the temperature sensitive devices such as image sensor module.

Key word: Hemispherical Bump, Contact Resistance, Thermal Cycling Test, High Temperature Storage Test, Temperature & Humidity Test

Introduction

Recently, flip chip technology has been increasingly used due to its high packaging density, good electrical performance, and excellent reliability in many applications [1]. The pad size and pitch size of chips get smaller and finer because of further miniaturizations and integration of electronic components. Various interconnecting methods are suggested as an alternative technique. Integrated chips with high density often provide a solution for the shrinkage of product size and weight. In response to the current requirements, we have recently developed a low temperature flip chip bonding technology using Sn bumps and a non-conductive adhesive [2] [3].

In this technology, the half-dome shaped Sn bumps were formed on a chip and Sn bumps on a chip were bonded to the pads of a substrate with NCA by thermo-compression method. This technology has been successfully applied to the chip-on glass (COG) bonding. We extended this technology to COF bonding and a new COF bonding method using NCA and Sn bumps was developed for image sensor packaging applications, because the Sn bumps have smaller hardness than that of Au bumps. In general COF bonding method using a NCA has been developed which provides a simple and engaging solution for fine pitch interconnection. Also, Au stud, electroless Au/Ni and electroplated Au bumps have been used in this technology. However, this technology failed to meet the increasingly demanding requirements of low cost and high reliability, sensitive to bump height, especially. Therefore, we utilized the plastic deformation of reflowed Sn bump during bonding. The Sn bump has been several advantages than Au bump, it has low yield strength, bump geometry flexibility, and low cost. Besides, Sn bumps easily forms by electroplating, bump geometry is easily controlled, alloying to control the properties of bumps is easy, and the metallurgical bonding in the interface between Sn bumps and metal pad is possible.

In this study, two types of Sn solder bumps were fabricated. The square bumps were formed by electroplating, and the hemispherical bumps were formed by reflow after electroplating. We compared the bondability and reliability of COF joints fabricated using two types of solder bumps. In the case of the COF joints with square bump, it has been observed that NCA trapping occurred at the interface between Sn bumps and the bond pad. The NCA trapping of joints may increase the contact resistance and induce the electrical failure. But, the hemispherical bumps were effective to decrease NCA trapping [3] [4]. Therefore, the Sn bumps used in this study were electroplated and reflowed.

Experimental Procedure

To satisfy the demands of the fine pitch, 100㎛ pitch bumps were fabricated. For thin UBM (Under Bump Metallization) stacks, thin films of Ti (50㎚), Cu(1㎛), Au (50㎚), Ti (50㎚) were sequentially deposited onto SiO_2/Si wafer using a DC magnetron sputtering system. The top Ti layer acts as a ball limiting metallurgy during soldering and bottom Ti layer act as a seed layer forming solder bumps by electroplating as well as the adhesion layer. Metal lines for measuring the contact resistance of the COF joints were formed with photolithography and a wet chemical etching method. Also, to fabricate Sn bump, via openings with 60*60㎛ size were formed by patterning thick PR (Photo resist) and then, Sn/Cu bumps were formed on the patterned metal lines by electroplating after the top Ti layer was removed, the the thickness of Sn and Cu was about 5 and 15㎛, respectively. To fabricate the hemispherical bumps, electroplated Sn/Cu bumps were reflowed in a RTA(Rapid thermal annealing) system under a forming gas (95 vol% N_2 + 5 vol% H_2) atmosphere at 275℃ for 5sec, and the flux was not used. After the reflow process, the seed of bottom Ti layer was removed to separate each bump for contact resistance measurement.

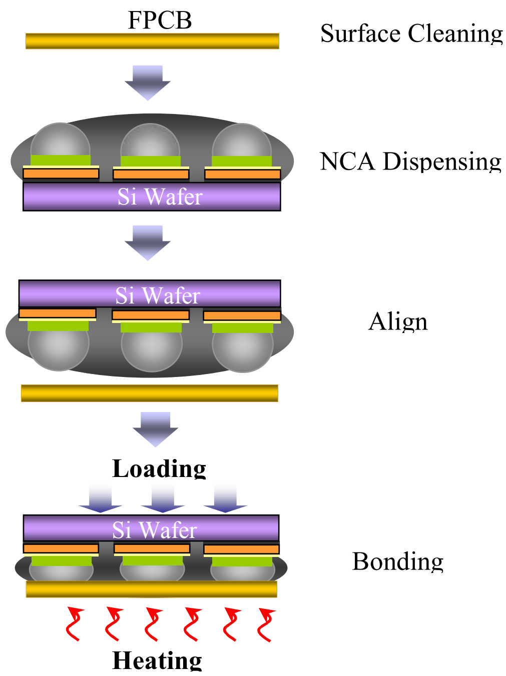


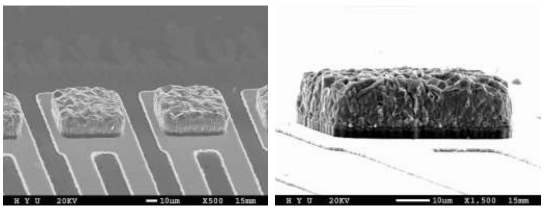
Fig. 1 Schematic diagram of the COF bonding process flow

Figure 1 shows the COF bonding process flow and bonding temperature profile. Double side F-PCB consists of 12㎛ of polyimide and two 25㎛ Cu foils. Before bonding process, the Cu surface of F-PCB was cleaned in a 10% H_2SO_4 solution for 30sec. The bonding process was performed at 180℃ under 90 Mpa by using a thermo-compression bonder after NCA was dispensed over the reflowed Sn bumps on the chip, and the NCA was simultaneously cured at same temperature. After bonding, the contact resistance of each joint was measured by four point probe method. The

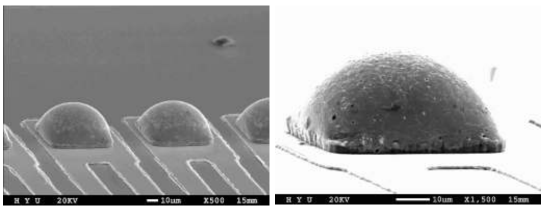
COF joints with the contact resistance larger than 100mΩ were regarded as failed joints. The contact resistance was measured after completion of each test condition and more than 200 points were measured at each condition. To evaluate the reliability of the joints, a thermal cycling (TC) test(condition: 150℃, ~1000hr), high temperature storage (HTS) test(condition: -25℃ /+125℃, ~1000cycles), and temperature and humidity (T&H) test (85℃/85%RH, ~1000hr) have been performed. The microstructure of joints before and after reliability test was characterized through the SEM (Scanning electron microscopy) and EDS (Energy dispersive spectrometry) analysis.

Results & Discussion

The Sn bumps with the fine pitch of 100㎛ were successfully fabricated by photolithography and electroplating process. Figure 2 shows the SEM micrographs of the Sn bumps formed on the metal traces for measuring the contact resistance. As shown in Fig. 2(a), the electroplated Sn bumps were square with dimensions of 60*60㎛ and the surface of square Sn bumps were relatively rough. After reflow, the bump morphology changed from a square shape to a hemispherical shape in order to reduce surface energy and the surface of the reflowed bump became very smoother than that of square bump. (see Fig. 2 (b)) The height of bump was about 20㎛ before reflow, increased to about 29㎛ after reflow.



(a) Square Sn bump



(b) Hemispherical Sn bump

Fig. 2 SEM micrographs of Sn bump before (a) and after reflow process (b).

Figure 3 shows the cross sectional SEM micrographs of the COF joints. All joints were successfully bonded and no joint failed electrically. The average value of the contact resistance of the hemispherical bumps (~10 mΩ) was lower than that of the square bump (~17 mΩ). The Sn bumps were deformed plastically during bonding, especially, in the case of hemispherical bumps, which were originally about 29㎛ tall, were severely deformed. The uniformity of bump height is a significant factor in the overall electrical performance of COF joints [5]. But, in the present study, non-uniform bump height can be compensated by easy deformation of the soft Sn bumps. As shown in Fig. 3(b), a continuous layer of Cu_6Sn_5 intermetallic compound at the interface between the Sn bump and Cu pad of the F-PCB, as well as at the interface between the Sn bump and the Cu UBM was identified by EDS analysis. The interface between the Cu_6Sn_5 and solder displays a scalloped morphology. But Cu_3Sn intermetallic was not found because of the short reaction time. The formation of intermetallic compound layer, it is desirable to achieve a good metallurgical bond. Therefore, the relatively low contact resistance of the COF joints results from the good metallurgical bonding, in addition to the good contact allowed by the easy plastic deformation of Sn.

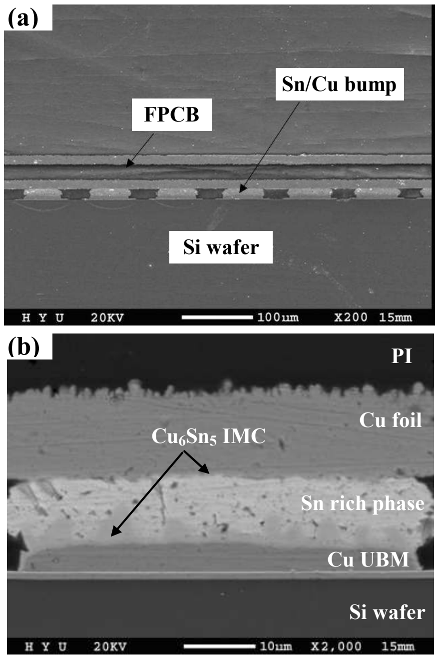


Fig. 3 SEM micrographs of COF joint.

Figure 4 shows the cross sectional SEM micrographs of the COF joints with square bump. As shown in Fig. 4, it can be clearly seen that NCA trapping is observed at the interface between the Sn bump and Cu bond pad. The NCA trapping was ascribed to the rough surface and the flat bump geometry of the square bump (see Figs. 2(a) and (b)). On the contrary to this case, in the COF joints with the hemispherical Sn bump initiated point contact with the Cu pad during initial bonding process, and the NCA was easily squeezed out of the interface with additional pressure [6]. It can be seen from the result of the contact resistance and cross-sectional SEM micrographs observation, that the higher contact resistance of the COF joints with the square Sn bumps was due to NCA trapping in the interface of COF joints. Before and after the reliability test, the contact resistance of each bump was measured using the four-point probe method. For each read point, more than 200 joints were measured for each condition. The test results, which are listed in Table 1, show that the contact resistance of the square bump and hemispherical bump was 15.2 − 18.3 mΩ and 8.6 − 10.6 mΩ, respectively before the reliability test. And then, after test, the contact resistance increased slightly with increasing time and test cycle. All the joints with hemispherical bump were passed the criterion of reliability test for the given test condition. Meanwhile, in the case of COF joints with squared bump, the contact resistance values were larger than 100 mΩ in a few COF joints after TC and T&H test.

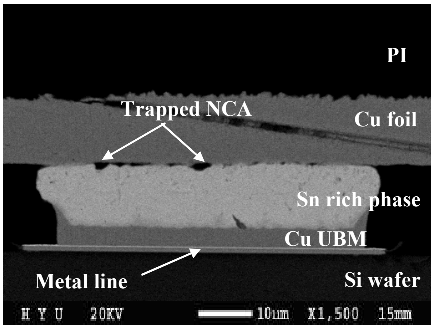


Fig. 4 SEM micrograph of COF joint with square Sn bump.

Table 1. The contact resistance value and failure rate of the COF joints before and after reliability test.

Test	Condition (hr, cycle)	Square bump		Hemispherical bump	
		ACR*	FR**	ACR*	FR*
HTS	0 hr	16.2	0	10.6	0
	250	19.1	0	8.2	0
	500	21.0	0	10.0	0
	1000	22.8	0	12.0	0
TC	0 cycle	15.2	0	9.5	0
	200	20.1	0	15.2	0
	500	23.1	0	16.0	0
	1000	30.2	1.5	17.6	0
T&H	0	18.3	0	8.6	0
	250	21.7	0	14.6	0
	500	25.2	0	17.1	0
	1000	31.1	3.4	19.4	0

ACR*: Average contact resistance (mΩ), FR**: Failure rate (%)

Besides, the failure rate of the square bump was 1.5% and 3.4%, respectively, after TC and T&H test. The NCA was trapped in the interface between the Sn bumps and Cu bond pads in the COF joints with square bump, as shown in Fig. 4. Some failed COF joints are attributed to the NCA trapping. It is well known that the trapped NCA suffered a volume change due to the temperature change during TC test, besides the NCA absorbed moisture and expanded in the T&H test. [6] The result of these phenomena during reliability test degraded the interface and increased the contact resistance, however, a small amount of trapped NCA did not have a great influence on contact resistance due to good metallurgical bonding in the interface between the Sn bumps and Cu bond pads.

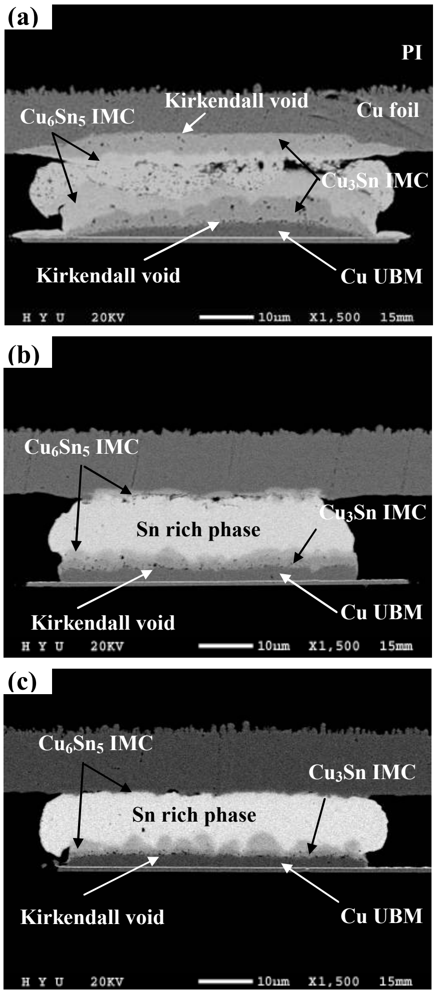
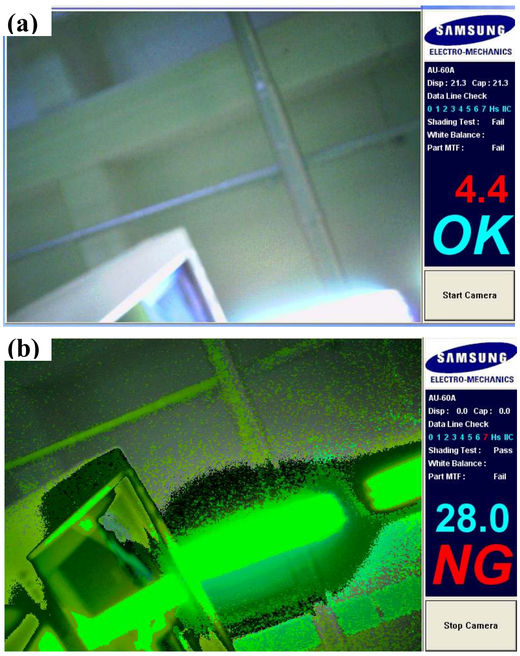


Fig. 5 SEM micrographs of the interface between the Sn bump and Cu UBM (or Cu bond pad on FPCB) after reliability test: (a) HTS, 1000 hr, (b) TC, 1000 cycle and (c) T&H, 1000 hr

Figure 5 shows the SEM micrographs of the COF joints after the various reliability testing. The microstructure of the COF joints after reliability tests were characterized using the SEM combined with EDS. From Fig. 5 (a), it can be seen that the Cu_3Sn intermetallic formed between Cu bond pad and Cu_6Sn_5 intermetallic after the HTS test. The Cu_3Sn intermetallic formed at the interface between Cu and Cu_6Sn_5 intermetallic through the interdiffusion of Cu and Sn atoms during test. In addition, kirkendall voids were observed at the interface between Cu_3Sn intermetallic and Cu pad (UBM). The interface between the Cu_6Sn_5 intermetallic and Sn bump displays a scalloped morphology and After significant TC and HTS test, the interface between the intermetallic compound and Sn bump becomes smoother, which is expected from the thermodynamic driving force, favoring the minimization of surface area. The COF joint was composed of Sn-rich phase, Cu_6Sn_5 and Cu_3Sn intermetallic compound. As shown in Figs. 5 (b) and (c), the duplex structure of Cu_6Sn_5 and Cu_3Sn intermetallic compound were found in the COF joint, and kirkendall voids were observed at the interface between the Cu_3Sn intermetallic and Cu UBM. The Cu_3Sn intermetallic formed at only the interface of bottom (chip side) in the joint. On the other hand, the Cu_3Sn intermetallic formed at the interface of the bottom and upper side (chip and Cu bond pad on F-PCB) in the COF joints after HTS test. However, after the T&H test, the layer of Cu_6Sn_5 intermetallic was very thin because of lower temperature condition.



Fig, 6 The test image of image sensor module after reliability test (T&H): (a) hemispherical bump and (b) square bump.

We applied the COF bonding method to image sensor module, the process condition of bumping and CMOS image sensor assembly was processed in the same conditions which were used for test vehicle. Figure 6 shows the test image of image sensor module after reliability test. In this study, we obtained promising results, the test images acquired using CMOS sensor with hemispherical Sn/Cu bumps have a good image quality, as shown in Fig. 6 (a), and the same results were obtained in TC test. Otherwise, in the case of CMOS sensor with square Sn/Cu bump, results from function test show that the image sensor worked not well, as shown in Fig. 6(b). It can be seen from the test results (see Fig. 4 and Table 1), that failed COF joints are attributed to the NCA trapping.

Conclusion

We developed a low temperature COF bonding technology for the temperature sensitive devices such as image sensor module. Si test chip with reflowed Sn bumps was successfully bonded with F-PCB substrate at 180℃. The results are summarized as follows:

(1) The Sn/Cu bumps with 60*60㎛ square-shaped were fabricated successfully by electroplating process.

(2) The contact resistance value of COF joints with hemispherical bump was about 10mΩ and after reliability test, the contact resistance was kept almost constant with test time, no failed bump was observed. Relatively low contact resistance was due to easy plastic deformation of the Sn bumps and good metallurgical bonding in the interface. Besides, a small amount of trapped NCA did not have a great influence on contact resistance due to good metallurgical bonding in the interface between the Sn bumps and Cu bond pads.

(3) As the result of this study, the COF bonding method using the Sn/Cu bumps and NCA to CMOS image sensor was performed very successful.

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