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A Low Temperature Process of Bonding Fine Pitch Au/Sn Bumps in Air

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1. Introduction

High requirement for electronic products is driving demand for high density interconnection. Flip chip technology becomes virtually the only viable IC assembly for high I/Os beyond 2000, high electrical performance, and high reliability [1]. In optoelectronic packaging and microwave device production, Au-Sn metallization system, belonged to hard solders, are popularly utilized due to the high strength, high melting point, good wetting behaviors especially in fluxless application, and resistance for thermal fatigue compared with conventional lead-tin solder system [2-4]. In order to realization of high density package by Au-Sn flip chip structure, low temperature bonding method should to be applied, since conventional methods such as soldering require high temperature, which induce to not only the degradation of bonding accuracy, the damage of components but also higher energy consumption and associated costs. Although many works have been done for trying to reduce the temperature, the bonding temperature of Au-Sn was remained above 200°C [2-4]. Contrast with conventional liquid bonding processes, a solid state bonding method called surface activated bonding (SAB) is reported for Au-Sn flip chip bonding. The procedure of the SAB method starts with activating surfaces by a dry process such as argon plasma pretreatment in a certain vacuum condition, and then the activated surfaces are brought into contact directly with a certain contact pressure. A strong covalent bond is formed due to the atomic forces between the mated surfaces.

In the previous investigations [5], the SAB method has been proved to bond various types of materials successfully together at room temperature or lower temperature than the conventional techniques. In principle, the SAB method needs a vacuum environment to prevent the activated surfaces from being oxidized. Conventional processes [2-4] of Au-Sn bonding also require environments such as H_2 or N_2 to inhibit oxidation. Previous studies [5-7] show the possibility of bonding even in air due to the limited oxide growth of activated surfaces. The purpose of this study is to develop a novel process for 30 µm pitch Au-Sn bonding at 100°C-200°C for the first time.

2. Experimental

4908 Au pads on the Si chip in correspondence with 4908 Au/Sn bumps on the Si substrate were fabricated. The bump and pad size is 20 µm with a square shape, and the pitch size is 30 µm. The pads on the Si chip were produced by electroplating 1 µm Au. On the Si substrate, a 5 µm thick Au layer was electroplated first, and then a 4 µm thick Sn layer was deposited on top of the Au. The samples have daisy chains and four point Kelvin structures. There are two pairs of daisy chains designed in order to check the short condition. In the peripheral area, corresponding sets of probing pads were fabricated for the electrical connection checking to the bonded samples by four point test method.

The bonding experiments were carried out by using a SAB flip chip bonder. The precision of alignment, mounting, and parallelism accuracy of this bonder may reach to sub-micron level. The bonding procedure starts with irradiating the substrate and the chip by Ar RF plasma (100W) for 2 min in the pretreatment chamber for activating sample surfaces under 7.5 Pa pressure. After that, the samples were transferred into the bonding chamber, and then alignment and bonding were performed at 100°C, 150°C, and 200°C by a certain load for 30s in air. The bonding interfaces were observed by using scan electron microscope (SEM) and electron probe micro-analyzer (EPMA).

3. Results and Discussion

30 µm pitch Au/Sn bumps are successfully bonded with Au pad together at 100°C, 150°C, and 200°C by SAB method in air. The bond yield reaches to 100%. The influence of Ar plasma pretreatment, temperature, and bonding pressure were investigated.

Contact Pressure

Certain contact pressure can flatten rough surfaces and destroy the re-oxidized layer grown on the activated surfaces after Ar plasma pretreatment to make two bonded surfaces contact sufficiently. But too larger pressure will induce to electrical short, and smaller pressure will induce to electrical open in fine pitch flip chip bonding. Therefore a suitable bonding pressure should be used at different bonding temperature. The experiments were carried out by using 0.4 gf/bump, 1 gf /bump, 2 gf /bump, 4 gf /bump, and 8gf/bump contact pressure separately. By checking the resistance of the daisy chains and four point structures, it is found that the suitable pressure is around 4 gf/bump at 100°C, 2 gf/bump at 150°C, 1 gf/bump. The tensile strength of bonded samples is above 10 MPa. Increasing the contact pressure, the bonding strength has no obvious change at the same bonding temperature. It is because more deformation has no contribution to increase the bonding strength but induces electrical short between the neighboring connections.

Ar Plasma Pretreatment

The results of resistance test were listed in Tab.1. The flip chip assembly with 100% yield is achieved in the bonding with Ar plasma pretreatment for 2 minutes, no matter to be bonded at which temperature. However, some of the connections opened in the bonding without Ar plasma pretreatment at 100°C and 150°C. Although no open circuit happened in 200°C, the resistance is much larger than the one with Ar plasma pretreatment. It elucidates that Ar plasma pretreatment is an essential step of the low temperature SAB bonding for Au-Sn. Ar plasma pretreatment can remove the oxides and contaminants and get the activated surfaces. Without Ar pretreatment, the initial oxides and contaminants become a barrier layer between the two surfaces in the bonding.

Table I Electrical resistances

Ar Time	2 min			0 min		
Temp.	Resistances of a single connection (unit: mΩ)					
	No.1	No.2	No.3	No.1	No.2	No.3
100°C	6.1	24.9	18.6	70.6	open	180.1
150°C	4.3	4.5	4.3	open	open	27.7
200°C	4.9	4.9	5.1	11.5	182.6	5.4
Temp.	Resistances of daisy chains (unit: Ω)					
	No.1	No.2	No.3	No.1	No.2	No.3
100°C	16.9	17.0	15.9	41.5	open	open
150°C	15.5	15.8	15.2	19.0	open	open
200°C	15.3	16.1	16.3	21.6	41.4	18.9

Temperature

Au and Sn can interdiffuse even at room temperature, about 2.5 μm Au-Sn intermetallic compounds (IMCs) appeared between Au and Sn in Au/Sn bumps before bonding. As a result, about 2 μm Sn layer left on the top of Au/Sn bumps. The sequence of IMCs is AuSn, $AuSn_2$ and $AuSn_4$ from the Au side of Au/Sn bumps. The interconnections bonded at 100°C, 150°C, 200°C with suitable contact pressure after Ar plasma pretreatment for 2 min were observed on the cross section by SEM and EPMA, as shown in Fig. 1. Au-Sn diffusion phases appear in the bonding interfaces. As shown in Fig. 1 (a1, a2), a lot of Sn remained in the bonding at 100°C, but it is hardly to be detected in the case of 150°C and 200°C showed in Fig. 1 (b1, b2), and (c1, c2). In the bonding at 100°C and 150°C, the sequence of IMCs formed from the bonding interface is AuSn, $AuSn_2$ and $AuSn_4$ from Au pad side, which is symmetrical to that of the diffused phases in Au/Sn bump before bonding. More one phase, $AuSn_5$, emerges between AuSn phase and Au at 200°C. Temperature may soft the bonding materials and accelerates the diffusion rate of Au and Sn. Insufficient diffusion at the bonding interfaces of bonding at 100°C results the relatively lower tensile strength and larger resistance. In such case, the diffusion degree may be increased by extending the bonding time or annealing after bonding.

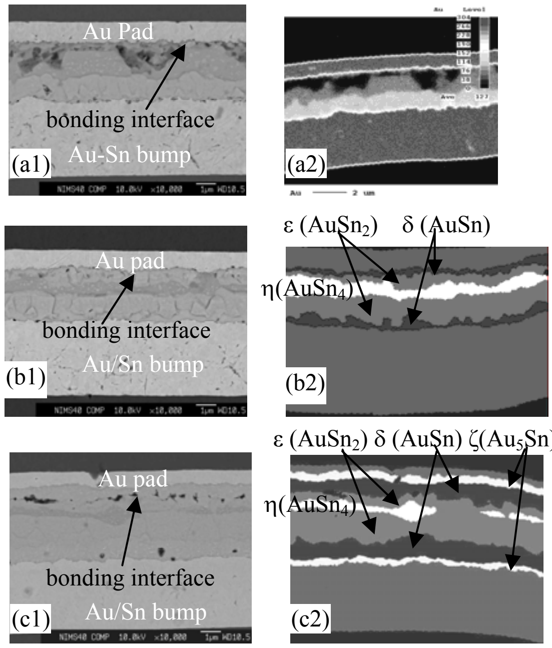

Fig. 1 The interfaces at cross section bonded at (a) 100°C: (a1) SEM image, and (a2) EPMA image of Au distribution; (b) 150°C: (b1) SEM image, and (b2) EPMA image; (c) 200°C: (c1) SEM image, and (c2) EPMA image.

4. Conclusions

A low temperature bonding method for assembling fine pitch Au-Sn flip chip is successfully developed for the first time by the SAB method at 100°C-200°C in air. The bond yield can reach to 100%, and the bonding strength can reach to more than 10 MPa. Ar plasma pretreatment is a prerequisite factor to the bonding.

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