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Investigation of Low Temperature Cu Pillar Thermosonic Bonding for 3D Integration Applications

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Abstract

In this paper, the effect of ultrasonic vibration for low temperature Cu pillar bonding is investigated with excellent mechanical and electrical properties in 3D integration. The development is successfully achieved under the conditions of 220 ^{0}C bonding temperature with 10 minutes bonding time at ambient atmosphere.

1. Introduction

In respond to the increase the density of signal I/O counts, fine pitch flip chip Cu pillar bonding used to achieve not only large number of vertical interconnections but also outstanding electrical characteristics for 3D integration applications [1-2]. However, direct Cu-to-Cu thermocompression bonding usually requires the conditions with high temperature (up to 350 ^{0}C) and strong compression force which may degrade the device performance and lead to serious misalignment issue [3].

In this work, Cu pillar associating with thermosonic bonding and diffusion soldering simultaneously is researched to develop conditions with lower temperature, lower bonding force and shorter bonding time. This research is conducted in ambient atmosphere instead of high vacuum condition. Constructively, this approach is able to establish mechanically robust interconnections and to meet the thermal budget for most devices.

2. Experimental Methods

The schematic diagram and specification of flip chip Cu pillar bonding test structure are shown in Fig. 1, and the upper chip area with 14 x 14-array Cu pillars is 3 x 3 mm^2. The bonding process is designed under the conditions with variable parameters such as bonding temperature, bonding force, ultrasonic power, ultrasonic time and bonding time in order to investigate how these parameters affect the bonding strength. As shown in Fig 2, the design of the experiment is conducted in a sequence in such that the parameters are based on the results from the previous shear test. After the thermosonic bonding process, shear test is carried out to evaluate the bonding strength. The test structure with the strongest bond is further tested on its electrical measurement and reliability.

3. Results and Discussion

Shear Strength

Table I shows the shear strength results along with the five parameters mentioned in section 2. From the results, the strongest shear strength is approximately 45 MPa, under the condition of 220 ^{o}C of bonding temperature, 25 N of bonding force, 15 W of ultrasonic power, 4000 ms of ultrasonic time and 10 min. of bonding time. It is found that the bonding strength and each parameter are in positive correlation. However, extremely high ultrasonic power and excess bonding time degrade bonding strength. The high ultrasonic power results in mighty ultrasonic vibration assisting the ruptures of the natural oxide layer at the bonding interface. This is to boost the Cu/In interdiffusion and formation of intermetallic compounds (IMCs) as shown in Fig. 3. However, the high ultrasonic power also causes serious dislocation and deformation of the structure. Excess bonding time may form thicker IMCs which degrade the quality and strength of the bond [4].

Electrical Measurement and Reliability Test

The designed structures of Kelvin structure and Daisy chain (N=6) were fabricated for electrical characteristic measurement and reliability tests including temperature cycling test (TCT, JESD22-A104C, -65~150 ^{o}C 500 cycles) and unbiased highly accelerated stress test (UB-HAST, JESD22A-118, 130 ^{o}C/85% relative humidity for 96 hours). The resistance of each structure was measured with applied current sweeping from -100 to 100 mA.

Fig. 4 shows the measured specific contact resistance of Kelvin structure. The results show approximately 35% variation lower than the original value while keeping a low and stable resistance in the range of 10^{-8} Ω-cm^2 for both TCT and UB-HAST. Fig. 5 shows the measured resistance of Daisy chain remains consistent during current sweeping. In addition, the results of resistance measured after TCT and UB-HAST deviate in a very small range (<2%) as compared to the original one. To summarize, the results investigated by these two design prove that the Cu-In interconnect of Cu pillar structure is thermally stable and able to withstand high moisture environment.

4. Conclusions

With the assistance of ultrasonic vibration and diffusion soldering, flip chip Cu pillar bonding was successfully achieved with the bonding strength above 45 MPa under the condition of low temperature (220 ^{o}C) and short bonding time (10 min.). Besides that, bonding force (25 N) can be much lower as compared to thermocompression bonding, resulting in less mechanical stress to substrate and component which is an advantage if the materials used are susceptible to deformation or crack. The reliability examination demonstrate that the Cu-In bonded interconnection of the Cu pillar bonding structure has great electrical characteristics and reliability, and shows excellent potential for 3D integration applications.

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References

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Table I The results of shear test with variable parameters.

Fixed Condition	Temperature	---			220 °C			220 °C			220 °C			220 °C		
	Bonding Force	25 N			---			25 N			25 N			25 N		
	Ultrasonic Power	15 W			15 W			---			15 W			15 W		
	Ultrasonic Time	4000 ms			4000 ms			4000 ms			---			4000 ms		
	Bonding Time	5 min.			5 min.			5 min.			5 min.			---		
Test Parameter		Temperature(°C)			Bonding Force(N)			Ultrasonic Power(W)			Ultrasonic Time(ms)			Bonding Time(min.)		
		180	200	220	15	20	25	10	12.5	15	1000	2000	4000	5	10	20
Shear Strength (MPa)	Min	2.8	2.9	19.6	6.1	4.9	19.6	6.5	8.3	19.6	3.7	14	19.6	19.6	33	21.4
	Max	6.1	11.1	36.7	27	26.7	36.7	23.7	20.3	36.7	25.4	14.3	36.7	36.7	45.6	40.3
	Mean	4.0	5.8	27.2	15	16.6	27.2	14.4	13.2	27.2	13.9	15.4	27.2	27.2	39.8	28.9
	Std. Dev.	1.8	4.6	6.0	10.8	9.7	6.0	5.8	4.8	6.0	9.0	5.6	6.0	6.0	6.3	6.9

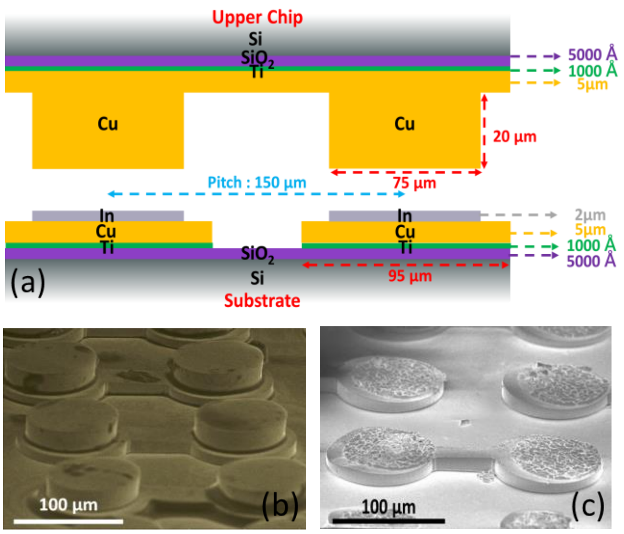

Fig. 1 (a) Schematic diagram of bonding test structure and (b) the SEM images of 75-μm diameter, 20-μm height Cu pillar and (c) corresponding Cu pad coated with 2-μm-thick Indium.

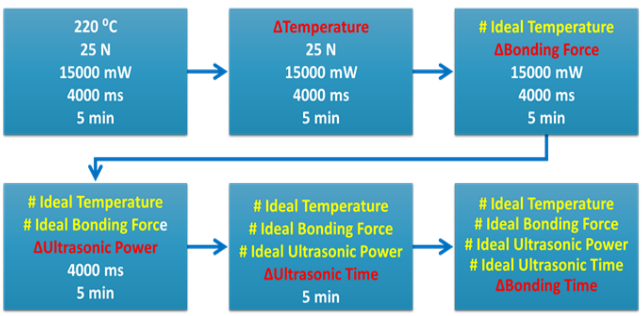

Fig. 2 The design of experiment for Cu pillar thermosonic bonding with variable parameters.

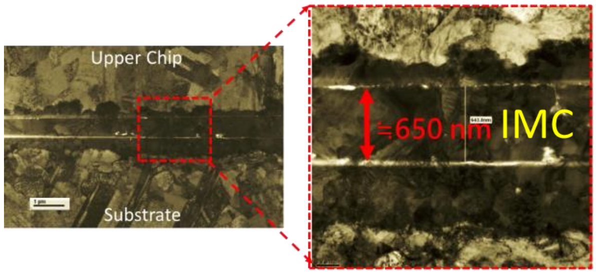

Fig. 3 The cross-sectional TEM images of the bonding interface where Cu pillar bonded to corresponding In-coated Cu pad.

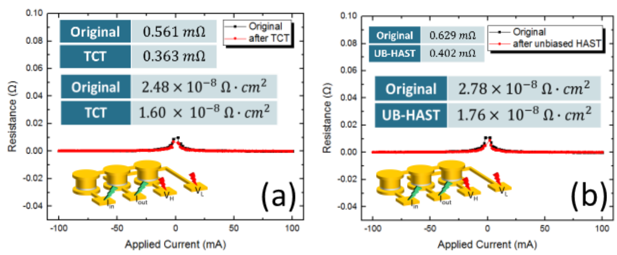

Fig. 4 The measured resistance of Kelvin structure after (a) TCT and (b) unbiased HAST reliability test.

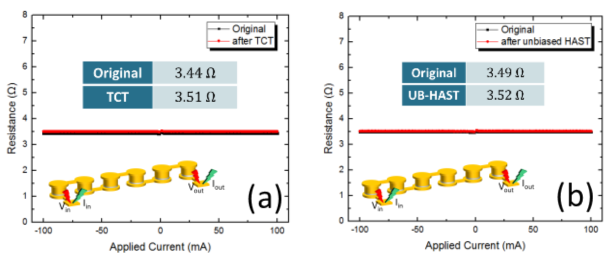

Fig. 5 The measured resistance of Daisy Chain after (a) TCT and (b) unbiased HAST reliability test.