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Au Bump Interconnection with Ultrasonic Flip-chip Bonding in 20 μ m pitch

Kazumasa Tanida, Mitsuo Umemoto, Ryoichi Kajiwar, Yoshihiro Tomita, Yukiharu Akiyama
and Kenji Takahashi

Association of Super-Advanced Electronics Technologies (ASET)
Electronic System Integration Technology Research Department, Tsukuba Research Center
1-6, Sengen 2-chome, Tsukuba, Ibaraki 305-0047, JAPAN
Phone: +81-298-60-2400 / Fax: +81-298-58-6177 / E-mail: tanida@si3d-aset-unet.ocn.ne.jp

1. Introduction

Nowadays three-dimensional (3D) stacked LSI technologies are studied extensively [1]. The 3D chip stacking that realizes the shortest wiring length between the chips is one of the most important technologies [2]. Figure 1 shows a cross-section of 3D stacked LSI structure. The exposed electrodes are allocated in 20- μ m-pitch on the back surface of the each device, and the copper electrodes are formed through the Si devices in 50 μ m thickness. The superfine flip chip bonding technologies in 20- μ m-pitch on through hole electrodes is the elemental technology for the 3D stacked LSI.

As for the advanced metallurgical bonding technology, the low temperature bonding process is desired [3] because of the influence of the temperature to the bonding accuracy and the damage of the thin Si device. Ultrasonic flip-chip bonding (UFB) process [4,5] is expected to be a practical solution for the issues, and we have presented that the process has a possibility to be applied in the interconnections of the through-via electrodes with Au micro-bumps [6]. However, the bonding mechanisms and optimization have not been enough studied yet.

In this paper, the results of the experiments are introduced regarding with the atomic level analysis of the bonding interface of the UFB and conventional thermo-compression bonding utilizing the electroplated Au micro bumps in 20- μ m-pitch.

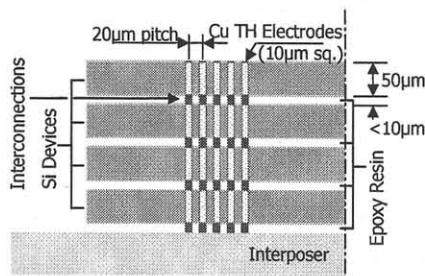


Fig. 1 Chip-stacking 3D LSI structure.

2. Experiment

Figure 2 shows the structure of the chip-on-chip (COC) sample for the evaluations. The Au micro-bumps were allocated around the periphery of the Si chip and interposer. The number of the bump was 1844, and the bump size was 12- μ m-square/7.5- μ m-height. The bumps were etched 30nm in depth as surface cleaning by argon sputtering before bonding. The bonding conditions are summarized in Table 1.

As the evaluation of the UFB bondability, the relationship between the bonding condition and the deformation ratio of

the bump was evaluated by measurement on the bump height after the treatment by the focus ion beam (FIB). As more detailed analysis, the bonding interface was analyzed by the scanning electron microscopy (SEM), electron diffraction (ED) and the transmission electron microscopy (TEM). As for the thermo-compression bonding [7], the bonding interface was analyzed with electron backscatter patterns (EBSP).

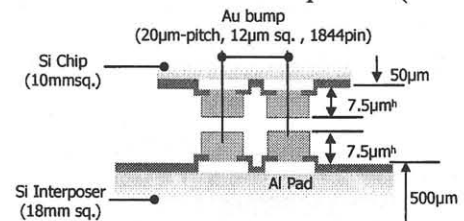


Fig. 2 COC structure for evaluation on UFB.

Table 1 UFB bonding conditions.

Description	UFB	Thermo-compression
Bonding Force	15, 20, 27 N	24.5 N
Amplitude	3.0, 4.5, 6.0 μ m	N.A.
Frequency	50 MHz	N.A.
Bonding Time	300 ms	7 s
Tool Temperature	150 °C	350 °C
Stage Temperature	150 °C	350 °C

3. Results and Discussion

Optimum conditions of UFB

Figure 3 (a) shows the results of the measurement on the Au bump deformation ratio. In the figure, the "Requirement" was the theoretical amount of modification in order to connect all bumps, which took the bump height distribution into consideration. As the results, in case of 15 N, the deformation ratio was not increased according to the ultrasonic amplitude. On the other conditions, the deformation ratio was increased according to the bonding force and the ultrasonic amplitude. As the reason, the decrease of the transmission of the oscillation due to the friction between tool and Si chip was considered [6]. In low bonding forces, the oscillation was not transmitted effectively. Therefore, as the optimal bonding conditions to obtain the sufficient bump deformations, the bonding force was set to 20 N, and the tool amplitude was set at 3 μ m. Figure 3 (b) shows the SEM micrograph at the cross section analyzed by FIB. As shown in the figure, no damage was found at the Al pads and the under bump metallurgies.

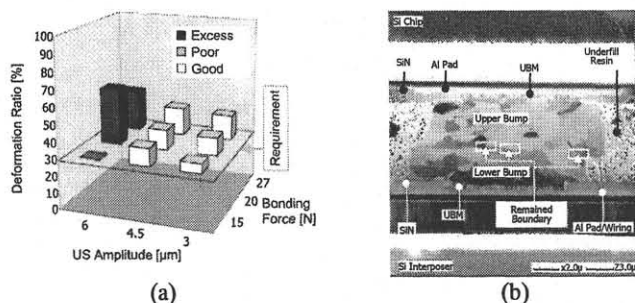


Fig. 3 (a) Relationship between bonding condition and deformation ratio of Au bump. (b) SEM micrograph of micro joint analyzed by FIB (20 N/3 μm).

Analysis of UFB interface

Figure 4 shows the TEM and ED pattern near the bonding interface and the grain boundary in the same bump. As shown in the figure, the different direction lattice patterns were crossed at the bonding interface on atomic level as the grain boundary in the same bump. Figure 5 shows the schematic diagram of lattice pattern observed in detail at the bonding interface and the grain boundary. As shown in the figure, some vacancies and dislocations were observed frequently near the bonding interface. It suggests that the bonding interface of UFB forms a discontinuous boundary that no diffusion is observed. As the results, the atomic level solid phase bonding is considered to be the dominant mechanism of UFB process.

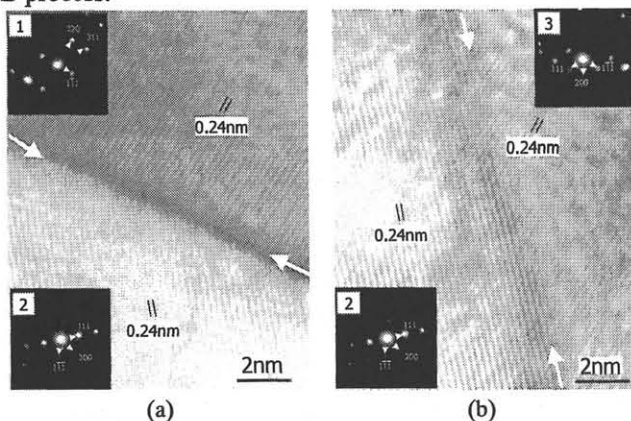


Fig. 4 TEM and ED analysis results of (a) bonding interface, (b) grain boundary (20 N/3 μm).

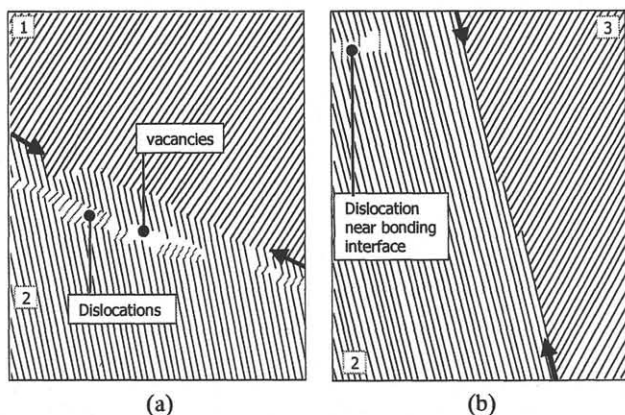


Fig. 5 Schematic diagram of lattice pattern of (a) bonding interface, (b) grain boundary.

Analysis of thermo-compression bonding interface

Figure 6 shows the orientation map of a bump acquired by EBSP. The dotted line was drawn by connecting small voids, which illustrates the estimated boundary of upper and lower bumps. The line crosses the large grain located at the center of bumps. The result indicates that solid phase diffusion is the governing mechanism of thermo-compression bonding.

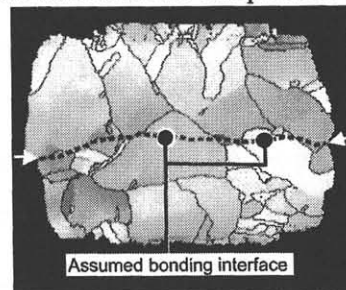


Fig. 6 Orientation map of thermo-compression bonded bumps.

4. Conclusion

As the low temperature bonding process, the UFB process was evaluated on the COC structure utilizing the electroplated Au bumps in 20- μm -pitch. And as low bonding profile, the bonding temperature was set at 150°C.

The following results were obtained.

- (1) The relationship between the bonding conditions and deformation of the Au bumps was found out. The basic conditions were set as the bonding force at 20 N and the amplitude at 3 μm . No damage was found at the Al pads and the under bump metallurgies. Therefore, the possibility of the Au bump interconnection in 20- μm -pitch by the UFB process was found out.
- (2) The solid phase bonding interface at atomic level was obtained by the UFB process, although some vacancies and dislocations were observed near to the bonding interface. The orientation geometry was apparently different from that of thermo-compression bonding, which showed solid phase diffusion across the boundary.

Acknowledgments

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