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3D Interconnection of Single Micron Pitch by Hybrid Bonding Technology

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Abstract

This paper describes 3D interconnection of single-micron pitch by hybrid bonding technology for 3D LSI of ultra high performance in future. Conventional capillary underfill method has a challenge of filling less than 10-μm gap between chips and bumps. Therefore, we studied hybrid bonding as a promising solution. In this study, we developed fabrication process of the bonding structure of Cu/Sn microbumps with 8 μm pitch and adhesive by combining CMP and O_2/CHF_3 plasma etching, and evaluated design of bonding structure to enable hybrid bonding. The results of hybrid bonding shows that Cu/Sn microbumps were properly jointed with Cu film, and adhesive was filled without significant voids.

1. Introduction

Three-dimensional (3D) integration technologies using through-silicon vias (TSVs) and microbumps provide attractive advantages such as wide bandwidth, low power consumption and so on [1]. Ultra-fine pitch interconnection of less than 10 μm was reported for next generation 3D integration [2]. However, underfill method is a challenge to realize it. In conventional capillary underfill, the filling of the gaps less than 10 μm can be insufficient due to surface conditions and morphology. As an alternative method, wafer level underfill method was proposed [3]. The underfill material was preapplied on the chip before the bonding. However, there are some challenges such as indistinct alignment mark, and resin trapping at bonding interface. They causes misalignment, and reduction of electrical and mechanical reliability of interconnection. Therefore, we focused on hybrid bonding technology that microbumps and insulators was simultaneously bonded [4].

In hybrid bonding, fabrication method and design of bonding structure is important to realize. Several fabrication methods of bonding structure were proposed such as CMP, and diamond bit cutting, photolithography. In this study, we developed fabrication process of the bonding structure of microbumps and adhesive by combining CMP and O_2/CHF_3 plasma etching, and we evaluated design of bonding structure to enable hybrid bonding [5].

2. Experiments

Design of bonding structure

In the hybrid bonding, the bonding structure to bond both microbumps and adhesive is needed. We designed the protrusion structure that the surface of microbump was higher than that of adhesive because adhesive trapping was prevented during bonding. The difference between surfaces of microbumps and adhesive was designed to 200 nm and 400 nm.

Sample preparation

Si chips with Cu/Sn microbumps and Cu film was prepared to evaluate hybrid bonding. The sizes of these were 6 mm x 6 mm and 3 mm x 3 mm, respectively. The thickness of Si chips was 525 μm. Cu/Sn microbumps were fabricated by electroplating on Si. Pure Sn was used for Sn on Cu. Sn was not reflowed to prevent growth of IMC (Intermetallic compound) after electroplating. Ti/Cu seed layer was not removed. The diameter, pitch, and height of Cu/Sn microbumps were designed to 4 μm, 8 μm, 9 μm (Cu/Sn: 3 μm/6 μm). In the counter chip, the Cu film was formed by electroplating on Si. Ti/Cu seed layer was used. The electroplated Cu thickness was 3 μm.

Experimental procedure

Fig. 2 shows process flow of experiments. Firstly, adhesive with SiO_2 filler was spincoated on Si chip with Cu/Sn microbumps. Secondly, adhesive on the microbumps was removed by CMP. The Sn surface was also planarized at the same time. Then, the adhesive with SiO_2 was etched off by O_2/CHF_3 plasma irradiation. The plasma irradiation time was 2 and 4 min to compare with the protrusion structures. The difference between surfaces of microbumps and adhesive was measured by atomic force microscope. Finally, the chip with Cu/Sn microbumps and adhesive was bonded to the chip with Ti/Cu film under the N_2 atmospheric pressure. The surface treatment before bonding was carried out by ArH_2 plasma irradiation. 3 kinds of samples were evaluated; no O_2/CHF_3-plasma irradiated sample, 2 and 4-min irradiated samples. The bonded samples was analized by crosssection obervation and shear test.

3. Results and discussions

Fig. 2 shows SEM images of (a) Cu/Sn microbumps, (b) Cu/Sn microbumps after spincoating of adhesive, (c) Cu/Sn microbumps after CMP of adhesive, and (d) Cu/Sn microbumps after O_2/CHF_3 plasma etching. In the spincoating, top surfaces of microbumps was higher than that of adhesive by adjusting adhesive viscosity and rotation speed. In the CMP, adhesive and Sn was simultaneously planar ized. After the CMP, surface of Sn was 42 nm higher than that of adhesive because of difference of selectively of CMP. In the O_2/CHF_3 plasma etching of adhesive, O_2 and CHF_3 were mixed to etch off the resin and SiO_2 at the same time. The differences between surfaces of microbumps and adhesive of 2 and 4-min irradiated samples were 188 nm and 384 nm, respectively.

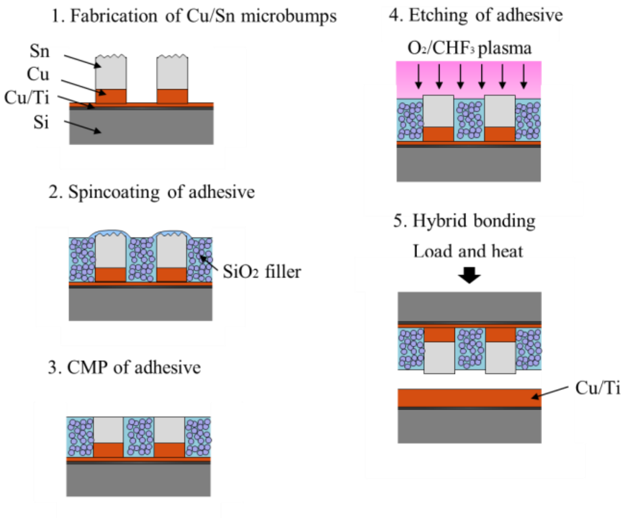

Fig. 1 Process flow of experiments.

In the bonded sample without etching of adhesive, it was observed that adhesive was trapped at the Cu-Sn interface between Cu/Sn microbumps and Cu film in some area. On the other hand, in the bonded sample with etching of adhesive for 2 and 4 min, these samples were properly bonded at the interface between Cu/Sn microbumps and Cu film. The cross sectional SEM image of the bonded sample with etching of adhesive for 4 min was shown in the Fig. 3. In addition, adhesive also was bonded without significant gap. The shear strength was 17.9 MPa.

4. Conclusions

We studied on 3D interconnection of single-micron pitch by hybrid bonding technology for 3D LSI of ultra high performance in future. We developed fabrication process of the bonding structure of Cu/Sn microbumps with 8 μm pitch and adhesive by combining CMP and O_2/CHF_3 plasma etching. In addition, design of bonding structure to enable hybrid bonding was evaluated. The results shows that the difference between surfaces of microbumps and adhesive was needed more than 200 nm to achieve without resin trapping. And, The cross section SEM observation also shows that Cu/Sn microbumps were properly jointed with Cu film, and adhesive was filled without significant voids.

Acknowledgements

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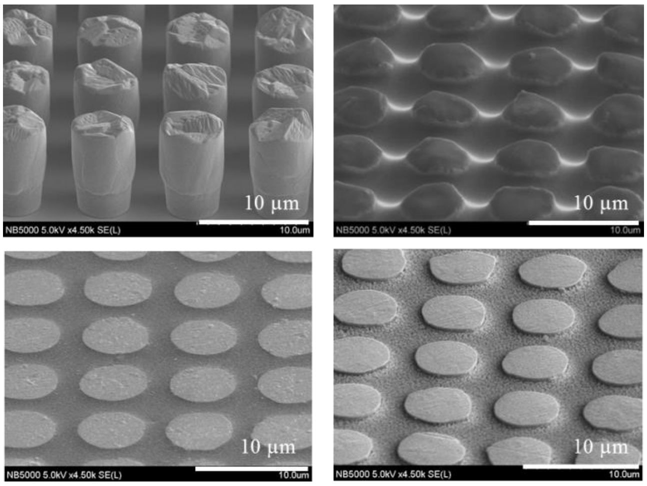

Fig. 2 SEM images of (a) Cu/Sn microbumps, (b) Cu/Sn microbumps after spincoating of adhesive, (c) Cu/Sn microbumps after CMP of adhesive, and (d) Cu/Sn microbumps after O_2/CHF_3 plasma etching.

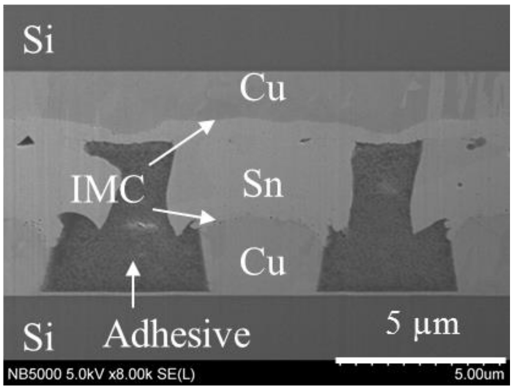

Fig. 3 Cross sectional SEM images of the bonded sample with etching of adhesive for 4 min.

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