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10-μm-Pitch In-Au Microbump Interconnection by Chip Self-Assembly with Excimer Lamp Irradiation for 3D LSI Applications

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1. Introduction

Chip-to-wafer stacking using known good dies (KGDs) is thought to be a promising 3D integration method in terms of production yield and throughput. It has a high production throughput because, except for KGD assembly, chip-to-wafer 3D integration can proceed at the wafer level. However, chip-to-wafer 3D integration suffers from a trade-off between assembly throughput and alignment accuracy due to sequential stacking with conventional pick-and-place assembly. To overcome this problem, we have developed multichip self-assembly techniques using liquid surface tension as a driving force to precisely align KGDs in batch processing for advanced chip-to-wafer 3D integration [1]-[4]. In the present paper, we demonstrate flip-chip self-assembly of chips with 10-μm-pitch metal microbump electrodes on wafers with the same microbump design as the chips. We employ In-Au as a microbump material because In-Au microbumps can be bonded at low temperatures below 200ºC. To realize a high alignment accuracy, a new surface modification technique with a 172-nm excimer lamp is introduced to selectively hydrophilize chip bonding areas. We compare the electrical characteristics of the resulting microbump daisy chains produced by self-assembly with those obtained by conventional mechanical alignment.

2. Experimental

Fig. 1 shows the process flows for fabricating chips and wafers with In-Au microbump electrode arrays with 3 and 0.3 μm in In and Au thicknesses. The chips and wafers are fabricated by the lift-off technique [5]. After microbump formation, chip bonding areas and the surrounding hydrophobic areas are formed by using conventional photolithography. Then, a very thin (~ 5 nm thick) fluorocarbon film is deposited on the surrounding areas. Another lift-off process is then performed to define the hydrophobic areas. Then, each wafer is irradiated with extravital ultraviolet light from an excimer lamp (Ushio Electric UER, NEX-4V-172; wavelength: 172 nm; intensity: 10 mW/cm^2) with a distance of about 1 mm from the lamp window to the wafer surface in an N_2 atmosphere with O_2 at a concentration of < 3%. The process flow for flip-chip self-assembly is shown in the bottom of Fig. 1. Here, we employed 1-μl ultrapure water as an intermediate liquid for self-assembly. In the self-assembly processes, chips are manually placed on the liquid droplets using tweezers. Thermal compression follows precise chip alignment after the chips are released and then the liquid droplets are evaporated. The bonding conditions are as follows: bonding load of 60 N/chip, bonding temperature of 200ºC, and heating time of 5 min.

3. Results and discussion

Fig. 2 shows the relationship between the excimer lamp irradiation time and the water contact angles of both the bonding areas and the surrounding areas. The contact angles of the surrounding areas decrease slightly to nearly 100º after 5-s irradiation and to about 90º after 20-s irradiation, whereas the contact angles of the chip bonding areas decrease remarkably by excimer lamp irradiation over the same time period. After excimer lamp irradiation for 5 s or longer, the water contact angles of the bonding areas remain constant at approximately 20º. Fig. 3 shows photomicrographs of the resulting chip and wafer and an SEM image of 10-μm-pitch In-Au microbump arrays on the chip.

Fig. 4 shows the dependence of the alignment accuracy on the wetting contrast between bonding and surrounding areas. The alignment accuracy increases dramatically with increasing wettability contrast (i.e., the difference in the water contact angles of the bonding and surrounding areas). The wettability contrast is maintained above 85º, which is sufficiently high to give a high alignment accuracy of within 2 μm. On the other hand, a low wettability contrast of less than 40º results in large misalignment of over 40 μm. Self-assembly experiments revealed that the alignment accuracy depends strongly on the wettability contrast between the hydrophilic bonding areas and the surrounding hydrophobic areas. 5 × 4 mm chips with 10-μm-pitch In-Au microbumps are self-assembled to a wafer as shown in Fig. 5.

Fig. 6 (a) shows cross-sectional SEM images of the resulting daisy chain patterns consisting of In-Au microbumps with a width/pitch of 5/10 μm after self-assembly and following thermal compression at 200ºC. This figure clearly shows that a pair of In-Au microbumps formed on both chips and wafers are tightly bonded together and that a daisy chain is formed. Fig. 6 (b) shows a comparison of self-assembly and mechanical alignment to evaluate the I-V characteristics and the chain resistances. This figure shows daisy chains consisting of 2,500 In-Au microbumps with a width/pitch of 5/10 μm. Chips with the In-Au microbumps have resistances of 208 mΩ/bump for mechanical alignment and 164 mΩ/bump for self-assembly. A slight difference in the resistances could be due to different alignment accuracies, especially in θ direction.

Acknowledgements

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References

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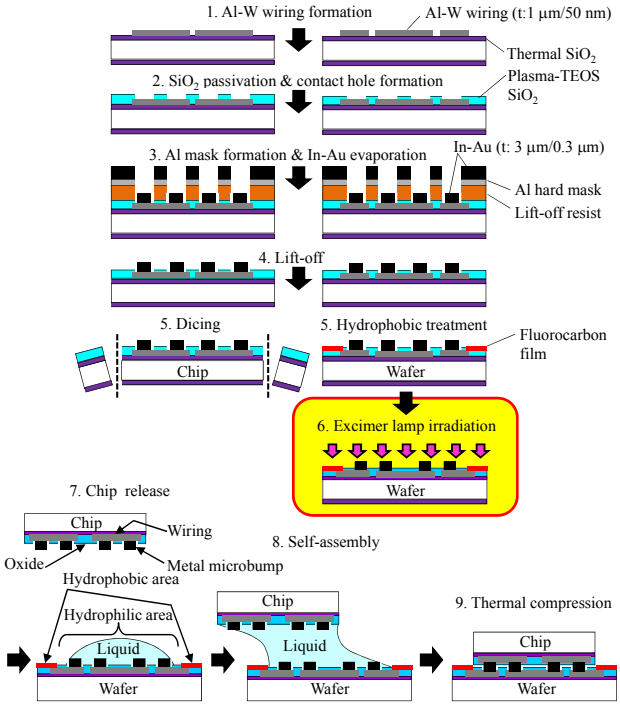

Fig. 1 Fabrication processes of chips/wafers with In-Au microbumps and a self-assembly flow.

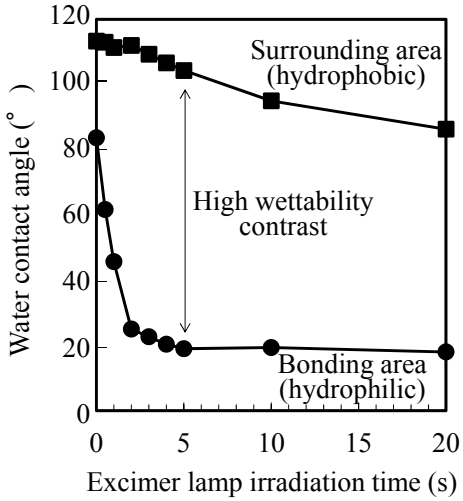

Fig. 2 Effect of excimer exposure time on water contact angle on bonding/surrounding areas.

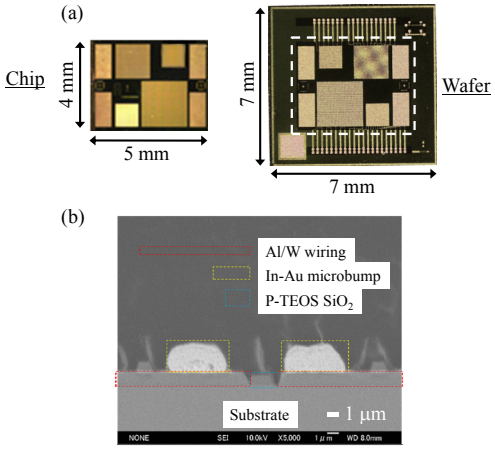

Fig. 3 Photos of a chip and a wafer and SEM cross-section of 10-μm-pitch In-Au microbumps.

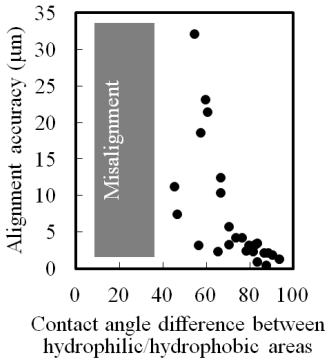

Fig. 4 Relationship between wettability contrast and alignment accuracy.

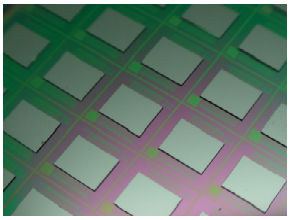

Fig. 5 A photo of self-assembled chips on a wafer.

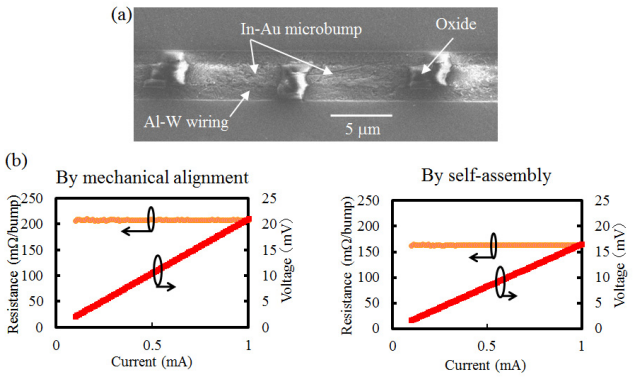

Fig. 6 (a) SEM cross-section of a daisy chain formed with 10-μm-pitch microbumps after self-assembly and (b) comparison of I-V data between self-assembly and mechanical alignment.