Submicron Au-particle bumps for high-density flip-chip mounting

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Abstract

To perform flip-chip bonding, bumps must be formed on electrodes on the substrate of a chip. Depending on the intended application, various methods, such as soldering, plating, and stud bumping, are used to form bumps. Furthermore, submicron metal particles are used as bonding materials because they easily undergo surface diffusion owing to their high surface energies, thereby resulting in low-temperature sintering. Submicron particles used for mounting are typically mixed with solvents to form a paste. However, these pastes tend to travel up chip walls and cause short circuits between electrodes, making them unsuitable for flip-chip bonding with pitches below several hundred micrometers.

Therefore, we developed a method to form fine Au-particle bumps by combining submicron Au-particle paste with a resist process. The resulting bumps had a porous structure that allowed compression in the direction of pressing without lateral expansion, thereby accommodating the substrate steps and enabling high-density mounting.

In this study, we explored the formation of Au-particle bump shapes that are suitable for various applications. By altering the aperture diameter, pitch, and thickness of the resist patterns, we formed bumps with a minimum diameter of 5 µm and height of 10 µm. However, when the aspect ratio was too high, the bumps collapsed owing to insufficient resist exposure, and when the bump diameter was too large, shape defects such as depressions were observed. These results enabled the selection of appropriate bump diameters and heights according to the size, roughness, and warpage of the electrodes on the substrate.

As electronic devices continue to be miniaturized and integrated, high-density bonding on nonplanar surfaces is required. We aim to utilize the unique advantages of Au-particle bump bonding in applications that require high density and reliability, which has not been possible thus far.

Key words

Au-Particle, Flip-chip Package, High-density bonding, Micro bumps

I. Introduction

From the perspectives of low bonding temperature, high thermal conductivity, and low electrical resistivity, several studies have investigated sintered materials composed of nano- to submicron particles such as Ag and Cu. Conversely, limited research has focused on the use of Au particles as bonding materials, primarily owing to their high costs. However, Au is widely used as a bonding material owing to its superior resistance to oxidation and migration. Therefore, we investigated the use of submicron Au particles as sintering materials [1][2]. Typically, when submicron particles are used for flip-chip mounting, they are mixed with a solvent to create a paste, which is subsequently screen-printed or dispensed. In this study, we proposed a method for forming finer Au particle bumps by combining a submicron Au-particle paste with a photoresist process [3]. The fabrication procedure is illustrated in Fig. 1.

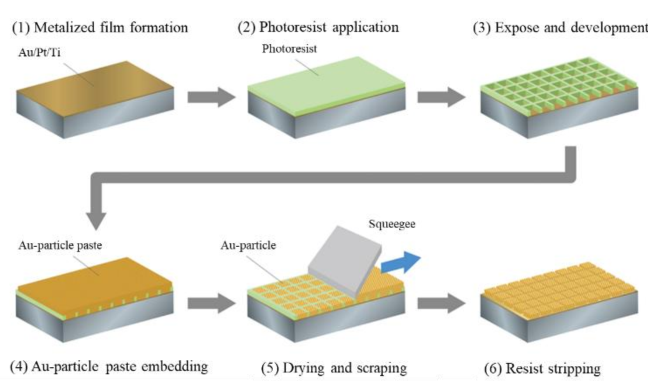


Fig.1 Printing method for Au-particle bumps

(1) Metallize the substrate surface where Au-particle bumps are formed.
(2) Apply photoresist to the substrate surface, adjusting its thickness to match the intended bump height.
(3) Pattern the photoresist by Exposure and development according to the bump geometry.
(4) Apply the Au-particle paste to the prepared resist frame.
(5) Vacuum dry the paste at room temperature to volatilize the solvent, then scrape off the excess Au-particles on the resist utilizing a squeegee.
(6) Heat the sample at 80°C for 10 minutes. Then remove the resist using a stripping solution.

The resulting Au-particle bumps exhibit unique characteristics that are not observed in other materials.

- Fine shape owing to the resist process.
- High reliability attributed to the inherent properties of Au.
- Low temperature sintering property owing to sub-micron particles.
- The porous structure of Au-particle bumps enables them to deform under compressive stress while minimizing lateral deformation.

Prior studies have examined the bonding strength as well as the thermal and mechanical properties of Au-particle bumps [4][5]. In flip-chip mounting, bump geometries must be tailored for specific applications. High-density mounting requires smaller bump diameters; however, if the bump height is inadequate, the compression deformability of Au-particle bumps cannot be fully utilized. Therefore, the objective of this study was to investigate Au-particle bump shapes that are easy to manufacture and suitable for mounting. Specifically, we examined the bump shapes and potential bonding failure by varying the resist pattern aperture diameter and thickness.

II. Experimental Method

A. Submicron Au-particles

The Au-particles were synthesized via a wet reduction method. This process yields Au-particles with diameters ranging from 0.1 µm to 1 µm. However, bumps approximately 10 µm in size are prone to cracking owing to the substantial sintering shrinkage associated with small particles. Conversely, sintering large particles at low temperatures is challenging, as their reduced surface area-to-volume ratio results in a lower surface energy, thereby hindering surface diffusion [6]. Therefore, we controlled the particle size at submicron levels (Mean Volume Diameter 0.4 µm) as shown in Fig. 2. Au particles were mixed with an organic solvent and used as a paste.

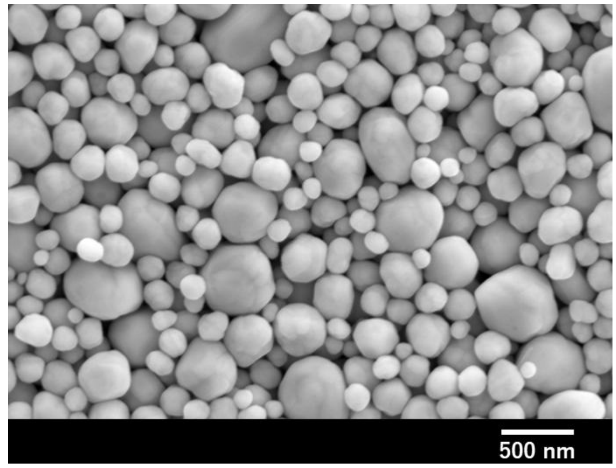


Fig.2 Submicron Au-Particles

B. Substrate

Sputtering was employed to metallize the Si substrate. Ti (50 nm) was deposited as the adhesion layer, followed by Pt (50 nm) as the anti-diffusion layer, and Au (200 nm) as the diffusion-bonding layer. A photoresist coating with thicknesses 10 µm, 30 µm, and 50 µm were applied to the substrate. Bump patterns were fabricated with diameters ranging from 5 to 200 µmφ. Two types of substrates, with and without metallization, were prepared as opposite bonding substrates.

Surface cleaning was performed on both the Au-particle bump forming substrate and competing substrate prior to bonding. Several methods are available for cleaning substrate surfaces, including Ar reverse sputtering, oxygen plasma treatment, and excimer irradiation. In this study, UV cleaning (ASM2001N, ASUMI GIKEN, Limited) was employed owing to its non-vacuum operation, low cost, and suitability for large-area treatment. A UV output of 20 mW/cm² and an irradiation time of 5 minutes were used for the treatment.

C. TCB (Thermo-Compression Bonding)

The fabricated bumps were pressurized and heated employing a flip-chip bonder (M90HF, HiSOL, Inc.), and bump deformation was assessed. Bonding was conducted at 200 °C for 10 seconds under pressures ranging from 20 to 150 MPa. The bonding pressure was controlled such that the target pressure was applied per unit surface area of the Au-particle bumps rather than the entire Si substrate. Cross-sectional observations of selected bump morphologies following bonding were performed using metallized substrates.

Ⅲ. Result

Bump Shape

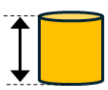
The morphology of the fabricated bumps were observed via confocal microscopy. The length measurement results for the bump shapes are listed in Table 1. Bumps conformed to the geometry of the resist apertures. Representative images of the smallest (5 µmφ/10 µmh) to largest (50 µmφ/50 µmh) bumps structures are shown in Fig. 3(a), (c), (d), and (e). However, as shown in Fig. 3(b), bump collapse was observed for structures with high aspect ratios. Additionally, as shown in Fig. 3(f), a concave top surface was observed for bumps with diameters of 100 µmφ or more. This deformation is likely attributed to the squeegee gouging at the top of the bump during the scraping process.

Table 1 The length measurement results for the bump shapes

(a)

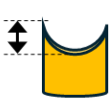
Bump Diameter (µm)			
Resist Aperture Diameter (µm)	Resist thickness (µm) 10	30	50
5	4.6	4.9	*collapse*
10	9.8	10.2	*collapse*
20	19.3	19.8	23.5
30	29.1	29.5	33.9
40	39.2	39.7	44.9
50	49.0	49.6	54.7
100	100.9	100.1	102.7
200	*concave*	200.0	201.6

(b)



Bump Height (µm)			
Resist Aperture Diameter (µm)	Resist thickness (µm) 10	30	50
5	10.5	33.2	*collapse*
10	10.7	33.8	*collapse*
20	11.1	33.4	51.8
30	11.1	32.8	50.6
40	10.6	32.8	49.7
50	10.4	32.9	50.1
100	9.8	32.8	49.4
200	*concave*	33.3	48.1

(c)



Bump top Concavity (µm)			
Resist Aperture Diameter (µm)	Resist thickness (µm) 10	30	50
5	0.6	0.9	*collapse*
10	0.6	0.9	*collapse*
20	0.9	0.8	1.2
30	1.1	1.1	1.5
40	1.4	1.5	1.9
50	2.1	1.9	2.9
100	9.1	2.6	2.8
200	*concave*	7.4	6.0

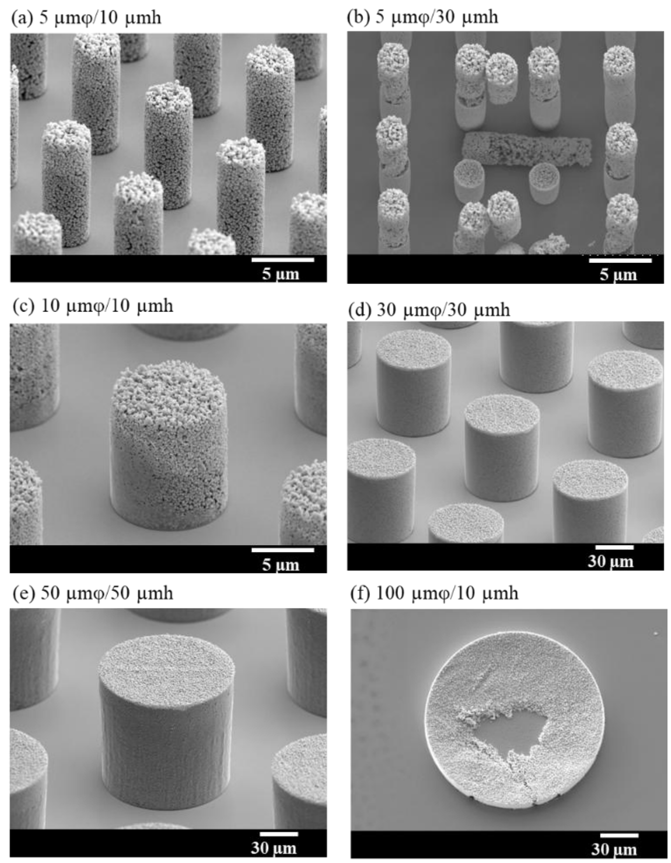


Fig.3 Fabricated Au-particle bumps

Bump shape deformation

The bump morphology following thermo-compression bonding (TCB) on non-metallized substrates was observed employing digital and confocal microscopes, as shown in Fig. 4. The cross sections before and after bonding are presented in Fig. 5.

These results confirm that the bumps deformed primarily in the vertical direction up to approximately 50 MPa with negligible lateral spreading. Furthermore, the bumps exhibited vertical deformation at a consistent rate irrespective of their aspect ratio. However, for 20 µmφ/30 µmh shape with a high aspect ratio, the bump height and diameter changed substantially under high pressure (150 MPa). This is attributed to non-uniform deformation, where the bumps bent instead of compressing linearly. For bumps with even higher aspect ratios, such as 10 µmφ/30 µmh, a mode of bump collapse was observed following compression.

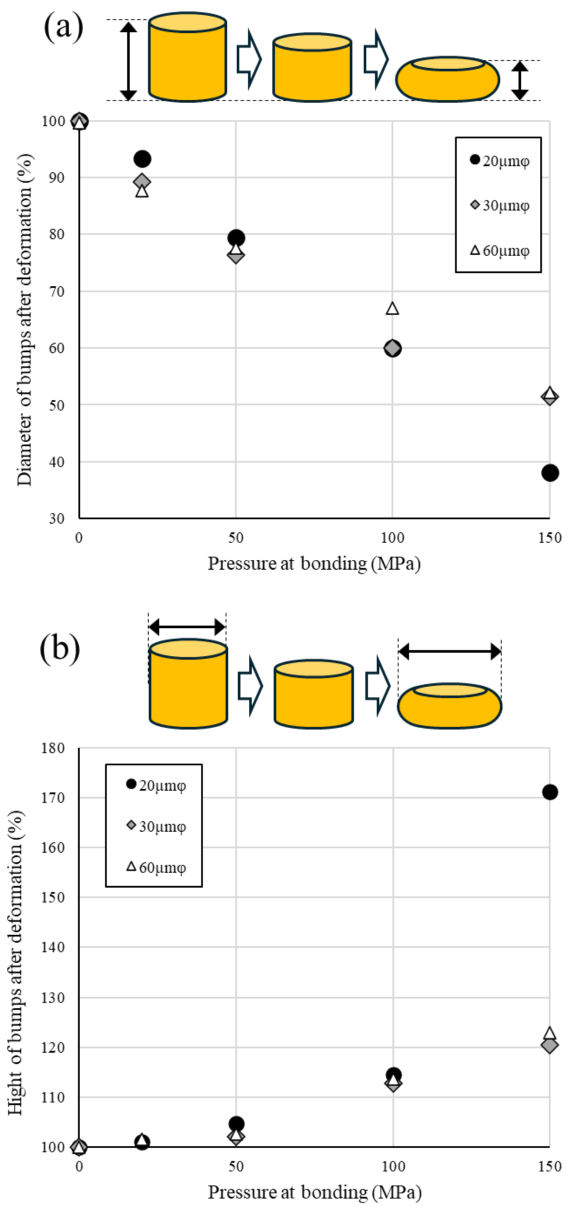


Fig.4 Bump deformation rate
(a) Height, (b) Diameter

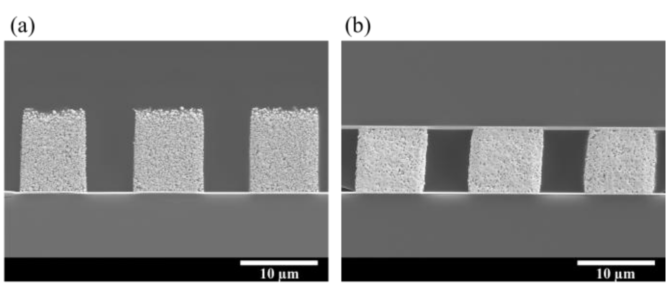


Fig.5 Cross-section of Au-particle bumps (10 μmφ/10 μmh):
(a) Before TCB
(b) After TCB_200℃, 10 seconds, 50 MPa

Ⅳ. Conclusion

The key findings of this study are as follows:

- Bumps with a minimum diameter of 5 μmφ/10 μmh were successfully fabricated. The study demonstrated that Au particles can be embedded into the resist aperture across aperture diameters ranging from 5 to 200 μmφ, even when the aspect ratio exceeded 2. However, wide apertures results in pronounced concavity during scraping, and an excessively high aspect ratio causes the bumps to collapse prior to bonding.
- During TCB, the Au-particle bumps exhibited similar deformation, across different geometries. However, bumps with aspect ratios extremely high either collapsed during bonding or exhibited bending after compression.

These results indicate that Au-particle bumps with diameters ranging from 5 to 50 μmφ and aspect ratios of 1.5 or less are suitable for formation and mounting.

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