

Simultaneous fabrication of a through-glass interconnect via and a bump using dry film resist and submicron gold particles

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Published in Micro & Nano Letters; Received on 5th April 2014; Revised on 28th June 2014; Accepted on 8th July 2014

A process for the simultaneous fabrication of through-glass interconnect vias (TGVs) and gold (Au) bumps using dry film resist and submicron Au particles is proposed. A Ti/Pt/Au layer was sputtered on the top and bottom surfaces of glass vias to improve the adhesion between the glass substrate and submicron Au particles. The submicron Au particles filled the resist holes and glass vias fabricated by photolithography and by the two-electrode method, respectively, and were then sintered. The height and diameter of the fabricated Au bumps were about 20–25 and 200 μm , respectively. The Ti/Pt/Au layer on the surface of the glass substrate was removed by Ar ion milling to isolate each bump electrically. The resistance of a single Au bump and TGV was evaluated using the four-wire ohm method to be about 0.05 Ω . Furthermore, Au bump bonding was demonstrated. Fractured Au bumps and TGVs were observed by scanning electron microscopy after the bonded sample was peeled. It is expected that this fabrication process using a dry film resist and submicron Au particles will be useful in simple packaging processes to form glass interposer substrates or glass integrated circuit chips.

1. Introduction: Recently, miniaturisation, energy savings and increased speed have been required in the field of packaging technology for various devices. Although the wire-bonding method has been used for electric connection between stacked chips, this method can only provide a limited wiring density and can cause signal delays because of the long wiring distance [1–4].

Through silicon via (TSV) interconnect technology for the vertical integration of integrated circuits (ICs) is one of the most promising technologies [5–7]. TSV technology can provide several advantages including a high wiring density, lower energy consumption and fast signal speed compared with conventional wire-bonding methods. However, TSV technology involves two long and complicated fabrication processes: insulating layer formation and conductive material filling.

First, Si has many advantages such as high planarity for flip chip bumping and bonding technologies, good thermal conductivity and good matchability to achieve multiple interconnects between metal layers. However, an additional insulating layer is required to isolate the electrical connects between the TSV and Si, when the Si substrate is used as an interposer material in three-dimensional (3D) feed-through interconnects, and a good electrical isolation layer cannot be fabricated by thermal oxidation or chemical vapour deposition. On the other hand, compared with Si, a glass substrate has good insulating properties, with very high resistivity and lower thermal conductivity, so glass substrates are preferred as the interposer material [7].

Secondly, Cu has received much attention for electric wiring because of its low cost and high conductivity. Cu electroplating is often used to fill in the vias of substrates [5, 6]. However, the conventional process for filling conductive material into the via of the substrate by Cu electroplating has some drawbacks, in that it takes a long time, it is a wet process and it is difficult to control the parameters of the electroplating solution. Therefore a TSV dry filling process using a slurry containing submicron Au particles was proposed by our group [8]. The slurry including the Au particles [9] was uniformly filled into vias with a squeegee under low pressure in a short time. It was found that submicron Au particles were a

very useful material for high-throughput fabrication of TSVs. The resistance of the obtained TSV was 0.11 Ω at a minimum. This is 48 times larger than the theoretical bulk Au resistance for the same size.

In this Letter, we propose a technique for the simultaneous fabrication of through-glass interconnect vias (TGVs) and Au bumps using dry film resist and submicron Au particles. Compared with liquid-type resist, dry film resist has a more even thickness and is easy to laminate on substrates with holes. The dry film resist holes were fabricated over the glass vias by photolithography, and then submicron Au particles were filled and sintered in the via and hole. The diameter of the Au bumps was larger than that of the TGVs so that the interspace between the glass substrate and the submicron Au particles could be sealed when the Au particles shrink during sintering. The Au bumps fabricated from the sintered submicron Au particles were flexible, so alignment of the heights of the Au bumps was not required.

2. Experimental procedure: The fabrication process for the bump and TGV structures is shown in Fig. 1. First, a 200 μm -thick glass substrate was prepared and vias were fabricated in the substrate using the two-electrode method. The diameters of holes in the top and bottom surfaces were about 70 and 40 μm , respectively.

Secondly, an Au layer was formed on the glass substrate by sputtering to improve the adhesion between the submicron Au particles and the surface of the glass substrate. Si/Ti/Pt/Au substrates were prepared by the deposition of a Ti layer on an Si substrate, followed by the deposition of an Au layer.

Next, 38 μm -high dry film resists (PH-3038, Hitachi Chemical) were laminated on the top and bottom surfaces of the glass substrate by a roller. The laminate temperature was under 115°C. Then, a resist hole pattern was fabricated by photolithography. A total of 100 resist holes were fabricated in a 10 \times 10 array. The resist hole diameter was 200 μm , the height was 38 μm and the pitch between bumps was 500 μm . These parameters matched the corresponding dimensions of the glass vias in the glass substrate.

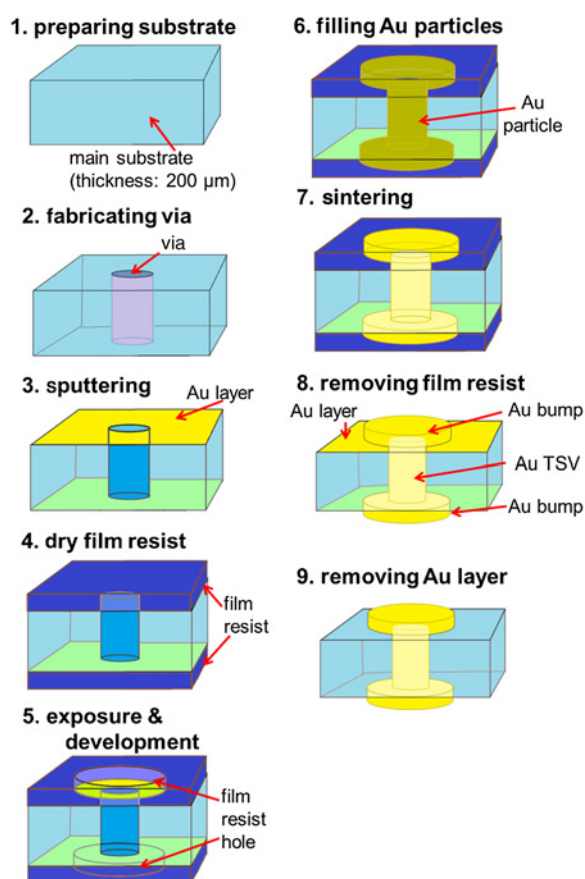


Figure 1 Fabrication process for the integrated structure including a TGV and Au bump on a glass substrate

The via structures in the dry film resist and glass substrate were like a letter 'I' in form, so we call this structure the 'I structure.'

After the dry film resist holes were fabricated, submicron Au particles were filled in the vias. An Au slurry (AuRoFUSE™, TANAKA KIKINZOKU KOGYO K.K.) was coated on the top surface of the glass substrate and vacuumed from the bottom surface through a paper filter so as not to collapse at the bottom bump. When the vias were filled to capacity, the sample was heated at 110°C on a hotplate for 1 h. After this sintering process, dry film resists were stripped in acetone solution.

Finally, the Ti/Pt/Au layer on the surface of the glass substrate was removed by Ar ion milling to isolate each bump electrically.

The fabricated I structures in the glass substrate were observed by scanning electron microscopy (SEM) and optical microscopy. Furthermore, to investigate the flexibility of the Au bumps, bump–bump bonding was demonstrated. Finally, the resistance of a single I structure was measured using the four-wire ohm method.

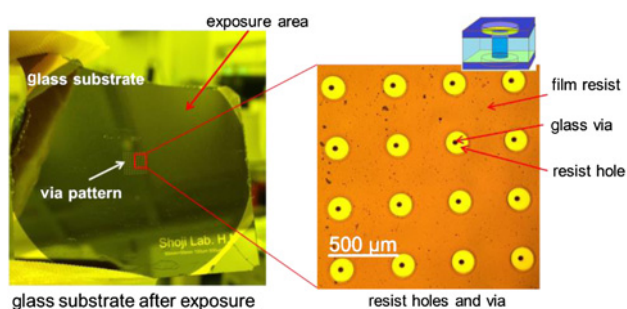


Figure 2 Fabricated pattern of resist holes on glass vias

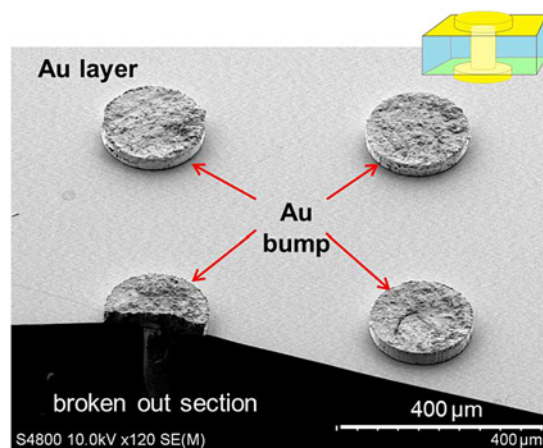


Figure 3 Top-view SEM image of fabricated I structures after removal of dry film resist

3. Results and discussion: Fig. 2 shows optical images of the resist and glass via pattern after UV exposure and development. Lamination of the dry film resist was clearly achieved, and the glass vias were exactly centred in the resist holes.

The fabricated Au bump structures are shown in Fig. 3. The Au bump diameter was 200 μm, and the pitch between bumps was 500 μm. This bump pattern is the same as the pattern of the fabricated holes. The dry film resist was removed completely, and no sub-micron Au particles existed on the surface of the glass substrate.

Fig. 4 shows the cross-sectional SEM images of a single I structure. The height of the Au bump is about 20–25 μm, which is lower than the height of the resist holes, 38 μm. This discrepancy seemed to be because the compactness of the submicron Au particles shrank during sintering. Furthermore, the observation of the interface between the glass substrate and the I structure shows that the adhesion between the submicron particles and the Au layer on the glass substrate was good.

These results indicate that the use of dry film resist for via pattern formation and filling in the vias with submicron Au particles are very useful methods for simple simultaneous fabrication of Au bumps and TGVs. Whereas in previous work the TSVs varied widely in shape, all bumps and TGVs were almost uniform.

Fig. 5 shows an optical microscope image of the Au bumps and TGVs in the glass substrate from the bottom surface of the glass

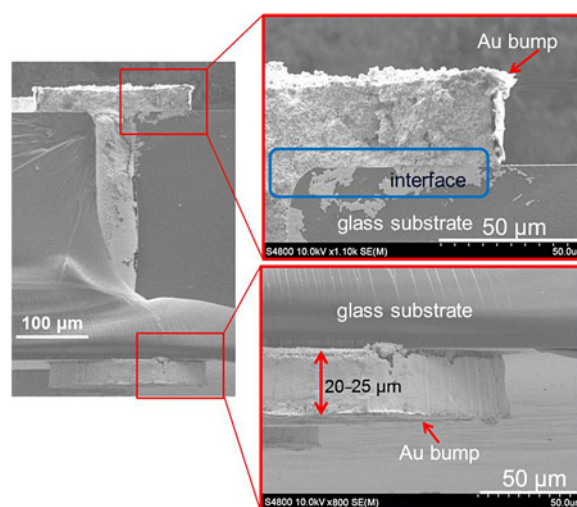


Figure 4 Cross-sectional SEM images of fabricated I structures and interface between the structure and the glass substrate

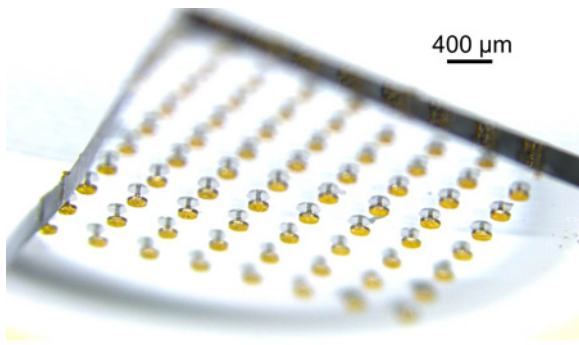


Figure 5 I structures consisting of TGVs and Au bumps after removal of the Au layer on the glass substrate

substrate after Ar ion milling. The Ti/Pt/Au layers on both sides of the glass substrate were removed successfully, and each I structure was isolated electrically. The TGV structures and the bottom sides of the Au bumps on the top surface of the glass substrate could be observed.

The resistance of a single I structure was 0.05Ω , as shown in Fig. 6. This value is about 25 times larger than the theoretical bulk Au resistance of the same size. The theoretical resistance was calculated using expression (1), as follows

$$R = \rho L / A \quad (1)$$

In (1), R is the resistance [Ω], ρ the electrical resistivity [$\Omega \cdot \text{m}$], L the length [m] of the wire and A is the cross-sectional area [m^2]. It is considered that the electric properties of the TGV were improved because the Au bumps worked very well as seals and as connections in the interspace between the glass substrate and the TGV fabricated with submicron Au particles.

Fig. 7 shows the SEM and optical images of two fractured Au bumps and a TGV after bonding and peeling. The bonding pressure was 62.4 MPa, and the bonding temperature of 300°C was held for 40 min.

The Au bumps changed in shape and became integrated. The peeled area was inside of the TGV, and the Ti/Pt/Au layer was bonded to the Au bump. These results indicate that no alignment of the heights of the bumps is needed, because the heights of the bumps decrease during bonding. Furthermore, the Ti/Pt/Au layer was very good at improving the interface between the glass and the submicron Au particles.

4. Conclusion and future work: In this Letter, we have proposed a simple process for the simultaneous fabrication of Au bumps and TGVs using dry film resist and submicron Au particles. Glass

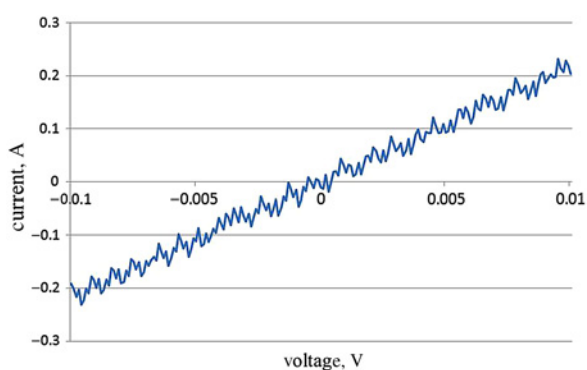


Figure 6 I-V characteristic of a single fabricated I structure

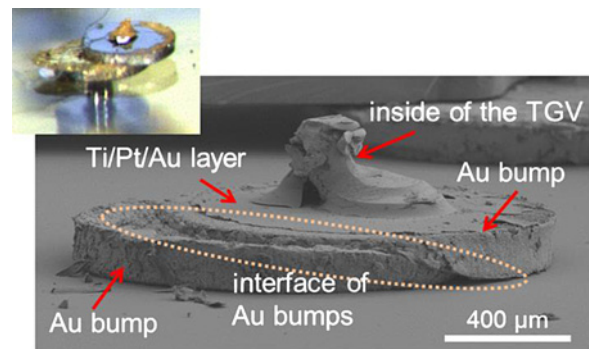


Figure 7 Au bump, Ti/Pt/Au layer and TGV after a structure bonded at 300°C was peeled

vias were fabricated using the two-electrode method. A Ti/Pt/Au layer was sputtered on the glass surface. Dry film resist was laminated with a manual roller, and resist holes were developed by photolithography. The $20\text{--}25 \mu\text{m}$ bumps and TGV structures were fabricated at the same time by sintering the submicron Au particles. The Ti/Pt/Au layer on the surface of the glass substrate was removed by Ar ion milling to isolate each bump electrically. The resistance of a single structure was about 0.05Ω . Finally, Au bump bonding was achieved by holding the structure at 300°C for 40 min with a pressure of 62.4 MPa. This fabrication method will be very useful for various applications of glass interposers or glass IC chips.

In the future, we are planning to demonstrate this fabrication process with a smaller Au bump and TGV pattern to achieve a high packaging density, and we plan to evaluate air leakage efficiency of the top and bottom surfaces for hermetic devices.

5. Acknowledgments: This work was partly supported by the Japan Ministry of Education, Culture, Sports, Science and Technology (MEXT), a Grant-in-Aid for Scientific Basic Research (S) No. 23226010, Specially, Promoted Research ‘Establishment of Electrochemical Device Engineering’ and a Grant-in-Aid for the Cooperative Research Project Nationwide Joint-Use Research Institute on Advanced Materials Development and Integration of Novel Structured Metallic and Inorganic Materials from MEXT. The authors acknowledge the support from the MEXT Nanotechnology Platform Support Project of Waseda University.

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