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Low Temperature Cu to Cu Direct Bonding in Atmosphere Environment Using Pillar-Concave Structure in 3D Integration

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Abstract

In this paper, low temperature Cu-Cu direct bonding using Cu pillar and Cu concave structure is realized under atmosphere pressure. The result shows void-free at contact area with high bonding quality at a bonding temperature of 150°C for 10 min. Based on the well-bonded result, Cu pillar-concave bonding structure could be a feasible technology and scheme to achieve low temperature Cu-Cu direct bonding under atmosphere pressure in 3D integration.

1. Introduction

In recent years, the scaling of electronic devices follows Moore's Law, while the physical limitation of devices is expected to encounter soon. Three-dimensional integrated circuits (3D IC) have then been developed to drive Moore's law forward [1-2]. Cu-Cu direct bonding is one of the key technologies in 3D integration. However, traditional Cu-Cu bonding requires high bonding temperature and high vacuum environment [3-4]. The roughness of Cu surface is another bonding bottleneck.

To achieve low temperature Cu-Cu direct bonding under atmosphere pressure, a special bonding structure is proposed. Figures 1(a) and 1(b) illustrate the Cu pillar-concave bonding structure before and after bonding. The diameter of Cu pillar lies between the opening size of Cu concave and the bottom size of Cu concave. As shown in Fig. 1(c), Cu pillar initially contacts at only four points with the Cu concave leading to the deformation of Cu pillar, which is caused by the high stress during bonding process. The initial no contact areas between Cu pillar and Cu concave are considered as the exhaust vents in order for the air to escape from the bottom of Cu concave during bonding process, leading to a seamless Cu-Cu direct bonding.

2. Experimental Methods

The procedure of this approach began with the deposition of Ti/Cu seed layer using a sputtering system. Then, photoresist was utilized to define the pitch and the size of Cu pillar. Afterwards, Cu electrical chemical deposition (ECD) was applied. On the other hand, Cu concave was sputtered using the same system as the Ti/Cu seed layer. After that, photosensitive polymer was used to build up the concave shape [5] and cured to optimize the sidewall angle followed by the ECD process. Images of Cu pillar and Cu concave are shown in Fig. 2. With the chip size of 1.25 mm * 2.5 mm, the diameter and pitch of Cu pillar are 13 and 30 μm, respectively.

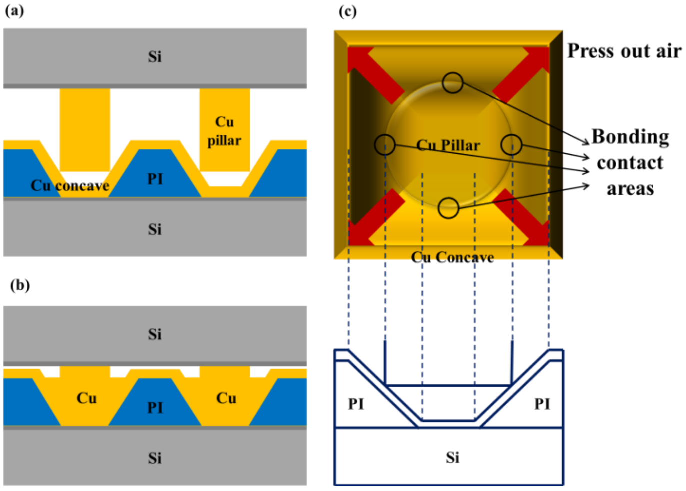

Fig. 1 The illustration of Cu pillar-concave direct bonding structure (a) before bonding, (b) after bonding; and (c) top view of Cu pillar-concave structure

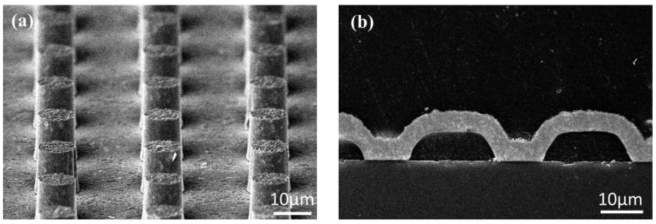

Fig. 2 SEM images of (a) Cu pillar (b) Cu concave

3. Results and Discussion

The concave sidewall angle is one of the important bonding parameters in Cu pillar-concave structure. Figure 3 shows that the simulation during the bonding process at 24° and 54°, respectively. The result indicates that when the sidewall angle is at 24°, smaller stress would be generated due to the larger contact area during the bonding process and the stress is spread uniformly, allowing it to only be produced at the corners leading to less deformation. On the contrary, the sidewall angle at around 54° shows that pillar and concave contact at a small point, which produces higher stress. The higher stress can spread to the whole Cu pillar, resulting in larger deformation.

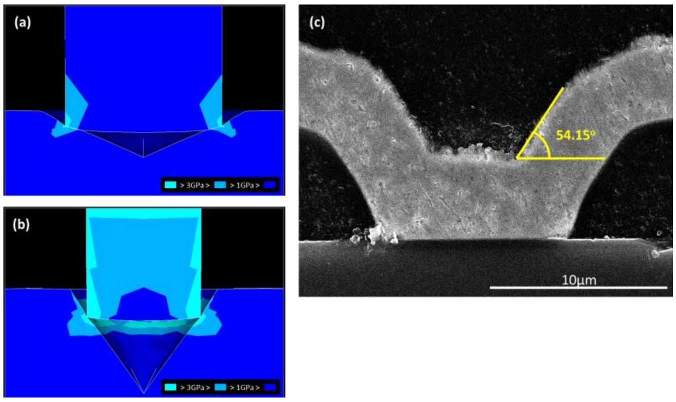

Fig. 3 The simulation image of Cu pillar-concave with different sidewall angle of (a)24° (b)54°

According to the simulation results, the sidewall angle of Cu concave is controlled at around 54° for the bonding process, as shown in Fig. 3(c). Figure 4 shows the SEM cross-section images of Cu pillar-concave direct bonding at different bonding temperatures for 10 min. At 150 and 200 °C, Cu pillar fills up the concave and forms a well-bonded interface. Cu from pillar and from concave would diffuse mutually and uniformly. However, a conspicuous bonding crack can be observed under 100 °C for 10 min. It means that under the lower bonding temperature condition, Cu grain requires more stress to release the energy to induce Cu atom diffusion. Annealing after bonding process [6] can provide additional energy to reduce the bonding interface cracking. In addition, different shapes of pillar-concave bonding structure are taken into consideration to increase the stress per unit contact area as another way to improve the bonding outcome, which is shown in Fig. 5.

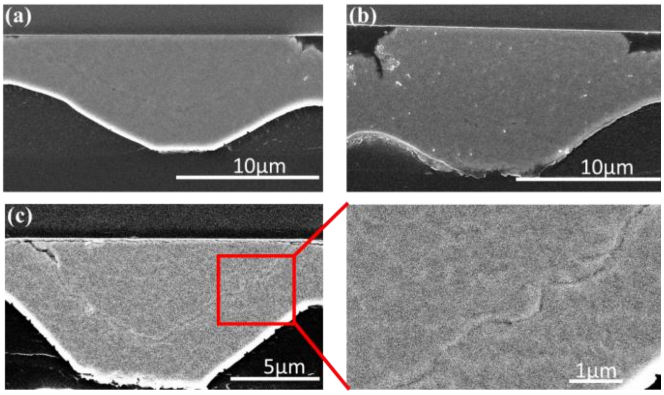

Fig. 4 Cross-sectional SEM images of bonded structure under (a) 200 °C for 10 min (b) 150 °C for 10 min (c) 100 °C for 10 min

4. Conclusions

In this paper, a pillar-concave structure designed for Cu-Cu bonding has not only successfully achieves low temperature bonding but also realizes the bonding process under atmosphere pressure. The high bonding quality and void-free bonding result are demonstrated under 150 °C for 10 min. When the bonding temperature is lower than 100 °C for 10 min, the bonding interface could be found with an obvious crack. Therefore, in addition to annealing process, using different shapes of pillar-concave bonding structure, which is used to increase the bonding stress, is a solution to realize lower temperature bonding condition under atmosphere environment.

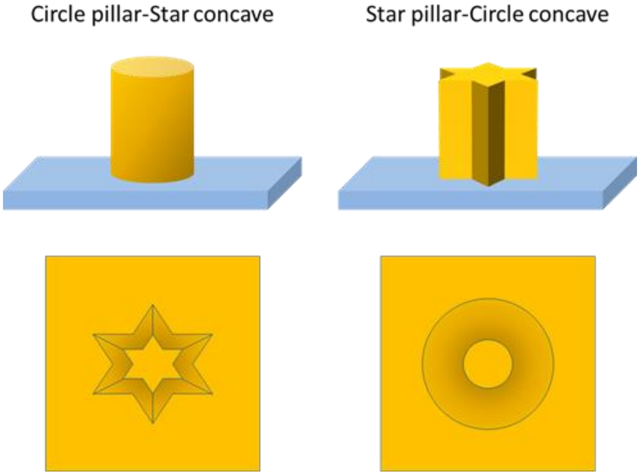

Fig. 5 Concept of Cu pillar-concave bonding structure sheme with different shapes for increasing high stress

Acknowledgements

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