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Room-Temperature Cu Microjoining Using Ultrasonic Bonding of Cone Shaped Bump

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1. Introduction

Three dimensional (3D) LSI technology is attracting a great deal of attention since it reduces computing energy and provides wide function. In the 3D-LSI technology, TSVs (through silicon via) and microjoining are the keys to realize high density I/Os [1,2]. Owing to the low resistivity and superior electro-migration tolerance, Cu is widely used as the materials for TSVs and bump electrodes. The bonding of Cu-Cu bumps usually requires a temperature around 350°C [3] and a time as long as several tens of minutes. On the other hand, many of the materials like III-V compounds or flexible plastic substrate which are important candidate materials for heterogeneous system are hard to be integrated at afford such a high temperature. Many researchers have investigated to lower the bonding temperature of Cu by surface modifications using such technology as those listed in Table I. However, reducing bonding temperature still remains a challenge [4,5]. The surface activated bonding (SAB) [6] and the mechanical calking technology [7] using pairs of cone shaped bump and slit electrode enabled bonding at room temperature. However, SAB requires processing in a high vacuum environment. The mechanical calking offers bonding in the ambient air. But it has a drawback in terms of process cost because it requires additional photolithography to form the slit electrode.

To overcome the drawbacks in the existing technology of Cu microjoining, we propose ultrasonic bonding of cone-shaped Cu bump. In this work, it is shown that room temperature Cu-Cu bonding is realized by this technology.

2. Experimental

Test element groups having daisy chains of Cu cone-shaped bumps were prepared by using the process described elsewhere [7]. In brief, the cone-shaped Cu bump was formed by the sequence of seed layer (TiW/Cu), photolithography using a chemically amplified photoresist, and electroplating of Cu. The seed layer was removed by wet chemical etching using a $KHSO_4$ solution and a H_2O_2 solution to remove TiW and Cu, respectively. The counter electrode was also made of Cu using electroplating while it was simply of planar type. Figure 2 shows the scanning electron microscopy images of the cone-shaped Cu bumps and the counter electrodes. The pitch was 20 μm and the diameter at the bottom of the cone-shaped bump was about 10 μm. Prior to bonding, the surface of the bump and the counter electrode was cleaned with $KHSO_4$ and CH_3COOH in sequence to remove the contaminations at the surface which contain mainly C and O.

3. Results and Discussion

The bonding was carried out in the ambient air at room temperature under the ultrasonic condition shown in Table. II. The initial pressing force started at 0.25 gf/bump and then increased to 1 gf/bump in 0.5 sec. During this time, the amplitude of ultrasonic was held at a constant value in the range 0.9-1.2 μm. The whole bonding was finished in a total time of 1.5 sec.

During the bonding process, we encountered a problem of misalignment between the two chips, which we have not experienced in bonding of Au bumps. Intensive study has shown that the cause of the misalignment is due to the hardness of Cu. In other words, when ultrasonic vibration is applied, the cone-shaped bump flicks the counter electrode together with the chip before bonding starts. To solve this misalignment problem, we introduced two techniques: One is to thicken the counter electrode from 1μm to 3μm. The other is to reduce the amplitude of ultrasonic vibration to a moderate value which is about 1μm. By applying these techniques, the misalignment was reduced from over 5μm to about 2μm.

Fig. 4 shows the results of daisy chain test carried out on a test chip having 11000 bump connection nodes. We can see that the all nodes are connected without failure in bonding. From the slope of the daisy chain resistance, the resistance of each connection node, which includes resistance of metal wiring, is 45 mΩ. This value is low enough for wide application. Figure 5 shows cross-section showing a part of the daisy chain. It clearly demonstrates, as was expected, the top end of the cone-shaped bump was deformed to form intermetallic bonding with the counter planar bump.

3. Conclusions

Through the electrical test and cross section observation of bonding samples, we have shown that Cu-Cu microjoining can be performed at room temperature by using the ultrasonic bonding of cone-shaped bump. The misalignment problem caused by the fact that Cu is much harder other electrode metals such as Au can be constrained by optimizing ultrasonic vibration condition. 11000 pins on a chip has been completely connected with a reasonably low resistance, which strongly demonstrate the potential of this technology for 3D LSIs.

Acknowledgements

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Table I Cu-Cu bonding of references

Bonding Method	Temperature of Bonding (Annealing)	Bonding Ambient	Ref. No.
Thermo-compression	375°C	Vacuum	3
HCl Cleaning+ Thermo-compression	400°C	Dry N_2	4
SAM protection+ Thermo-compression	250°C	Vacuum	5
Surface activated bond-ing	RT	High vacuum	6
Mechanical calking with cone-shaped bump	RT	Air	7

Table II. Profile of bonding process

Name of the parameter	Initial value	Slope time	Target value	Hold time
Pressing force	0.25 gf/bump	0.5 sec	1 gf/bump	1 sec
Amplitude of ultrasonic	0.9 μm		1.2 μm	

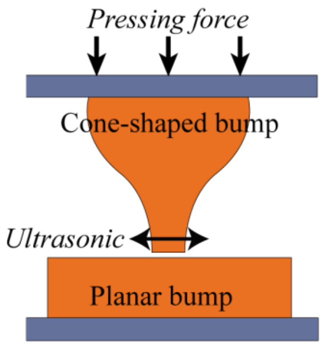

Fig. 1 Scheme of Cu-Cu bonding in room-temperature using cone-shaped bump and planar bump by ultrasonic.

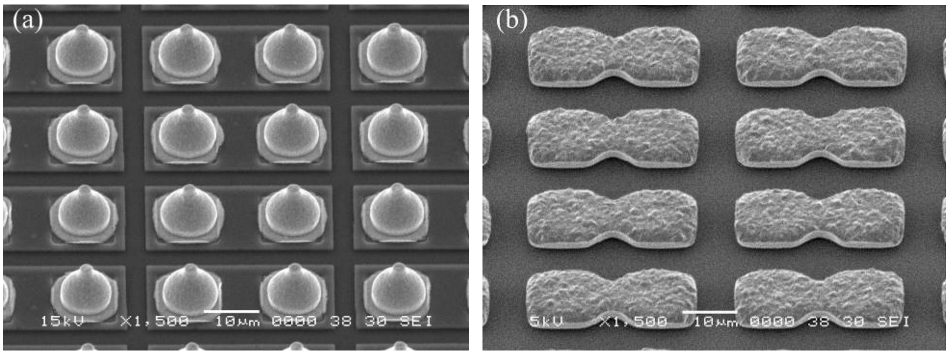

Fig. 2 Scanning electron microscopy images of (a).Cone-shaped bump array and (b).Planar bump array on silicon substrates. Both electrodes were made of Cu.

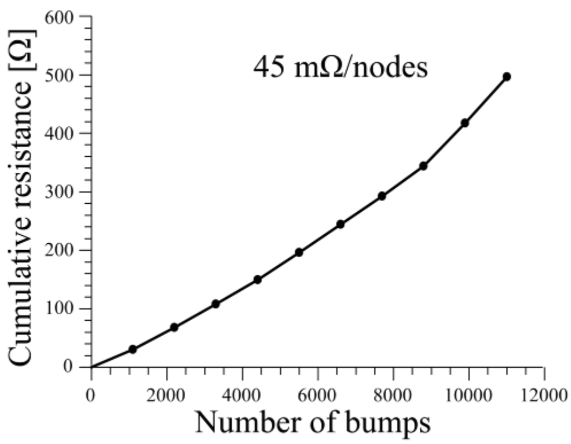

Fig. 4 Daisy-chain test result shows that all 11000 pins on chip connected with an average resistance of 45 mΩ/node.

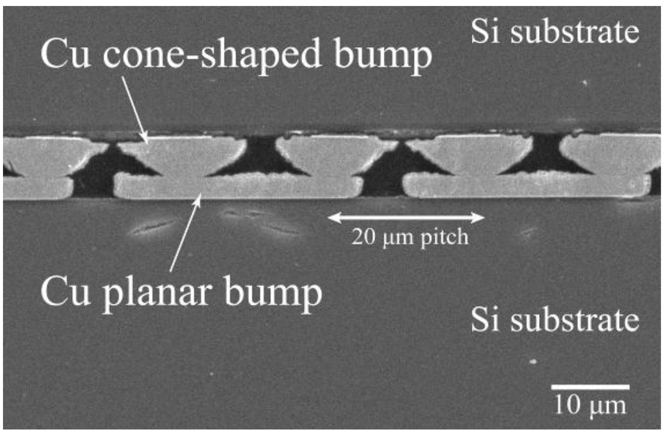

Fig. 5 Cross section image taken from scanning electron microscopy shows the Cu cone-shaped bump deformed to bond to planar bump.