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Effect of Electroplating on Adhesion between Copper/Titanium and Polyimide in Redistribution Layers and Hybrid Bonding Scheme for Advanced Packaging Applications

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Abstract

We herein present our study on the adhesion between polyimide and titanium/copper after electroplating using a four-point bending system. A polyimide-A sample with low curing temperature shows better adhesion after electroplating; the adhesion of the sample coating on commercial polyimide-B with a higher curing temperature becomes poorer after electroplating. Additionally, The broken surfaces correspond to the adhesion value. This research benefits the development of advanced interconnects and packaging.

1. Introduction

Recently, advanced packaging and 3-D IC technologies have progressed significantly in terms of fabrication. Among these schemes, the quality of redistribution layers, where copper electrical chemical deposition (ECD) process is used, determines the electrical properties. For ECD process, in addition to the characteristics of the copper wire, the interface between the passivation layer and the ECD copper may affect the quality. Moreover, Figure 1 shows the interface between the Ti/Cu layer and the polyimide layer in a hybrid bonding structure is very crucial. Thus, this study focuses on the adhesion properties of the boundary between the ECD copper and the polyimide passivation layer [1].

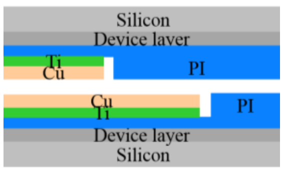

Fig. 1 Illustration of the hybrid bonding

2. Experimental Methods

2.1. Test Sample Preparation

Figure 2 shows the process flow of sample preparation to determine the adhesion between the polyimide layer and the Ti/Cu layer after electroplating. First, a 500-nm-thick silicon oxide was deposited on a silicon wafer by thermal oxidation. Next, the sample was coated on a polyimide layer of approximately 4.5 μm thick. Two kinds of polyimide passivation layers were used in this work. One is the polyimide-like material with a lower curing temperature, called polyimide-A. The other is a commercial polyimide with a higher curing temperature, called polyimide-B. Subsequently, a Ti/Cu seed layer was deposited on the polyimide passivation layer using the sputtering system.

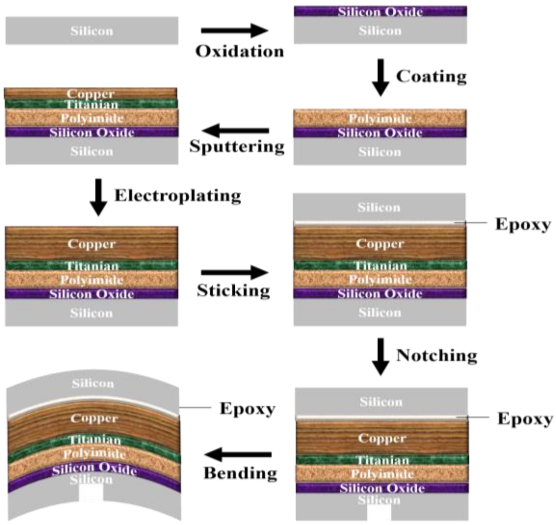

Fig. 2 Process flow of the test sample preparation

Following that, Cu ECD was applied on the whole wafer with different electroplating duration, such as 1, 5, 12, and 24 h. An epoxy was coated on the other wafer to stick to the copper side of wafer to form a sandwich structure. Furthermore, the sample was diced to 7 cm × 0.3 cm. The notch was created in the middle of the sample. Finally, a four-point bending analysis was performed on the sample to obtain the adhesion value. The sample was also checked for any broken surfaces from the scanning electron microscope (SEM) images.

2.2. Four-Point Bending Test

A four-point bending system is widely used for measuring the critical point of a sandwiched thin-film structure to obtain the adhesion strength [2]. When preparing the sample, the notch of the sample can ensure that the crack would begin from the middle. An additional silicon wafer is added to protect the thin-film layers. Figure 3 shows the schematic of the sandwiched structure, the four-point bending system, and the diagram of the measurement. From the distance-loading diagram, the loading value can be extracted through the measurement. From the beam theory, the interfacial fracture energy is calculated using the loading value as follows:

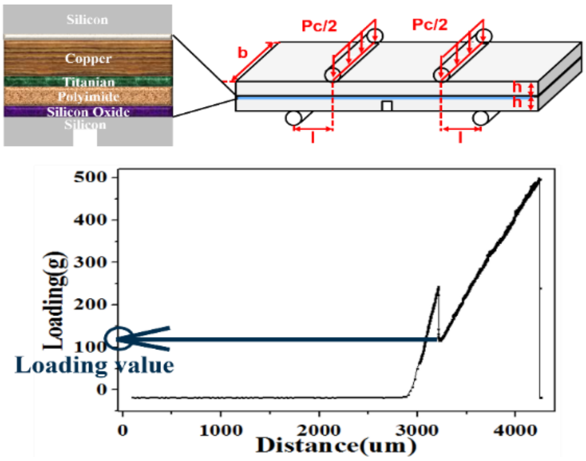

Fig. 3 Schematic of four-point bending system

$$Gc = \frac{21(1-v^2)Pc^2L^2}{16EB^2h^3}$$

where v is Poisson's ratio (0.28 for silicon); Pc is the applied force; L is half the difference between the outer and inner spans (17.5 mm); E is Young's modulus of the silicon substrate (170 GPa); B is the sample width (5 mm); h is half the thickness of the sandwiched sample (625 μm) [3].

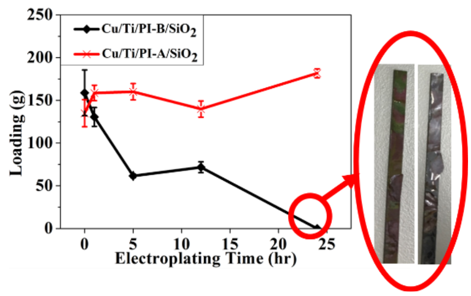

Fig. 4 Optical microscope image corresponding to the adhesion result

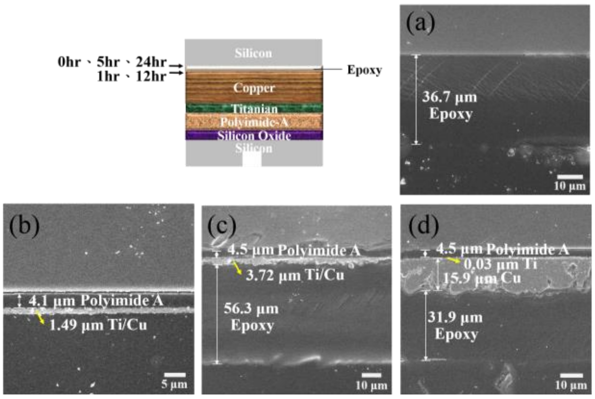

Fig. 5 Cross-sectional SEM images of polyimide-A sample of the broken surface under (a) 1 hr (top silicon) (b) 1 hr (bottom silicon) (c) 5 hr (d) 24 hr electroplating

3. Results and Discussion

The experiment compares the adhesion values between different polyimides and electroplating duration. The adhesion value measured by the four-point bending system is shown in Fig. 4. The result shows that the adhesion strength is almost the same before electroplating. After electroplating, the adhesion of polyimide-A remains the same because the silane inside improves the adhesion. However, the loading value of the commercial polyimide-B gradually decreases. Furthermore, after 24-h electroplating, all the commercial polyimide-B samples are delaminated because of its poor adhesion.

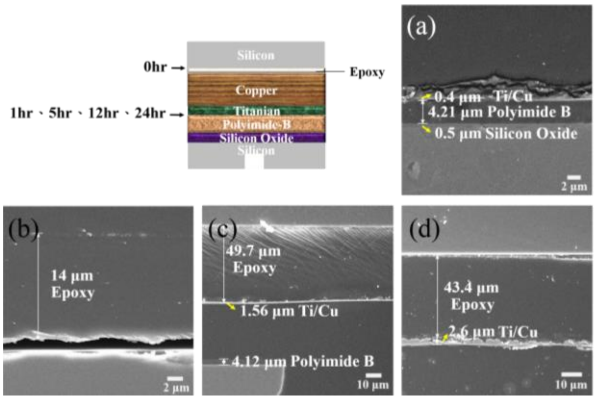

Fig. 6 SEM images of the broken surface of polyimide-B samples under (a) 0 hr (bottom silicon) (b) 0 hr (top silicon) (c) 1 hr (d) 5 hr electroplating

Moreover, the image of polyimide-A in Fig. 5 shows that the broken surface is on one side or the other side of the epoxy under 0, 1, 5, 12, and 24 h of the electroplating process. This means that the adhesion between the Ti/Cu layer and the polyimide layer is much better than those measured by four-point bending system. Nevertheless, the SEM image of polyimide-B in Fig. 6 without electroplating is different from the others under 1, 5, 12, and 24 h of electroplating. This is because the adhesion between the Ti/Cu layer and polyimide layer becomes poorer after electroplating. Therefore, a broken surface appears at that interface. The electroplating process may cause the interface degradation between the titanium and polyimide-B layers. The silane coupling agent can form bridges between the titanium and polyimide-like thin films. Therefore, it can effectively prevent the titanium layer from an oxidation–reduction reaction during the electroplating process.

4. Conclusions

The adhesion performance after the electroplating procedure between the Ti/Cu layer and polyimide layer is discussed herein. Polyimide-A has better adhesion compared with polyimide-B because of the silane contained in polyimide-A. Furthermore, the broken surface is on the surface between the metal and polyimide layers if the adhesion strength degrades. Otherwise, the broken surface will be on one side of the epoxy layer interface. These results can be applied to the fabrication of the re-distribution layers and 3-D ICs.

Acknowledgements

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