PS-2-4

Extended Abstracts of the 2015 International Conference on Solid State Devices and Materials, Sapporo, 2015, pp54-55

Micro-Texture Dependence of the Strength of Electroplated Copper Fine Bumps Used for 3-Dimensonal Integration

Masaru Gotoh, Ken Suzuki and Hideo Miura

Fracture and Reliability Research Institute, Graduate School of Engineering, Tohoku University
6-6-11-716, Aoba, Aramaki, Aobaku, Sendai Miyagi 980-8579, Japan
Phone: +81-22-795-4830 E-mail: masaru.gotoh@rift.mech.tohoku.ac.jp

Abstract

Micro texture dependence of the strength of electroplated copper thin films expected as fine metallic bumps for 3D integration were investigated experimentally. It was found that harness and Young's modulus of the electroplated copper thin films varied from about 1.1 to 1.8 GPa and 110 to 160 GPa, respectively. This fluctuation was due to the strong anisotropy of mechanical properties of copper and the (100)-oriented grains showed smaller value of both Young's modulus and hardness. It is very important, therefore to control the crystallographic orientation of micro bumps to minimize the variation or distribution of their mechanical properties.

1. Introduction

Three-dimensional (3D) integration of silicon microelectronic devices can improve the device performance and realize new device functions. Through Silicon Via (TSV) and fine metallic bumps have been used for 3D integration as the method of the interconnection between a large scale integration (LSI) chip and a substrate or another chip to maximize the packaging density. However, since there is a large mismatch in mechanical properties among materials used for 3D integration, thermal stress and strain should appear in the thermal road. The thermal stress causes not only mechanical failures in the stacked chips but also electronic function shifts of semiconductor devices. It is important, therefore, to minimize it for assuring the reliability of the products.

Electroplated copper thin films have been applied to the TSV and metallic bumps because of its low electric resistivity and high thermal conductivity. As the size of the bumps decreases to several microns order, one bump may consist of a few grains or single crystal. Since the single-crystalline copper has strong anisotropy of mechanical properties such as Young's modulus, the effective mechanical properties of the micro bumps should have wide distribution depending on their crystallographic orientation [1]. Once wide fluctuation of mechanical properties appears in electroplated copper bumps, the local distribution of the residual stress and strain in stacked chips should become complicated, which degrades the long-term reliability of the interconnections in 3D modules. Therefore, the micro texture of the fine bumps should be controlled appropriately in order to assure the long-term reliability.

In this study, nano-indentation tests were performed on the electroplated copper thin films to investigate the fluctuation of the mechanical properties of micro bumps. In addition, we investigated the micro texture of the test locations by using an Electron Back Scatter Diffraction (EBSD) method to clarify the relationship between the mechanical properties and the micro texture, especially crystallographic orientation.

2. Mechanical properties of electroplated copper thin films

Electroplated copper thin films used in this study were prepared as follows. A thin Ta layer (50 nm) as a barrier layer and a Cu layer (150 nm) as a seed layer were continuously deposited on the thermally oxidized silicon wafer by the electron-beam evaporator. The electroplating solution contains 80 g CuO powder, 186 g H_2SO_4, and 1000 ml purified water. The thin film samples were electroplated 5 μm and 45 μm on the copper seed layer under the constant current density of 50 mA/cm^2 at 30^{o}C. After the electroplating, the electroplated films were annealed in pure argon gas at 400^{o}C for 30 minutes.

Mechanical properties of the electroplated copper thin films were measured by using Nano Indenter DCM-SA2 (MTS Corp.) Nano-indentation test was performed on the sample at nine spatial points (3×3, 2 μm spacing) in one set. The displacement resolution and load resolution of the nano-indenter are 0.2 pm and 1 nN, respectively. The strain rate was set to be 0.05 m/s. As a reference for the electroplated films, we measured Young's modulus of single crystal copper with different orientations. Figure 1 shows the depth profile of the Young's modulus of single crystal copper. It is found that the Young's modulus of the (111)-oriented single crystal is the largest, followed by the (110)-oriented and the (100)-oriented sample in order. This crystal orientation dependence of Young's modulus is in qualitative agreement with theoretical estimation based on the elastic stiffness of copper. From this measurement, ani-

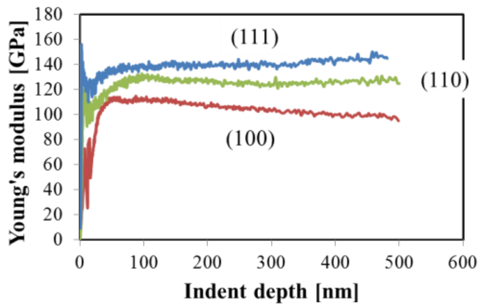

Fig. 1 Anisotropy of Young's modulus of single crystalline copper

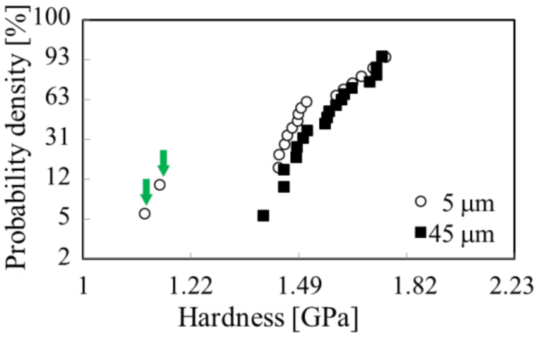

Fig. 2 Distribution of the measured hardness of the electroplated copper thin films

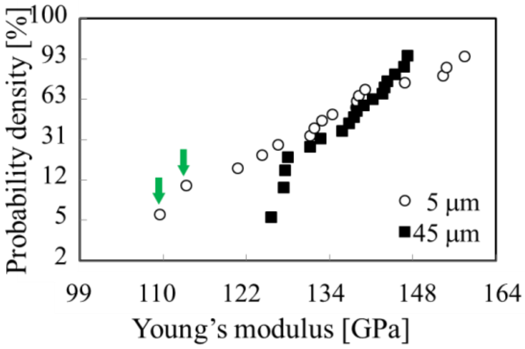

Fig. 3 Distribution of the measured Young's modulus of the electroplated copper thin films

sotropy of mechanical properties of copper was confirmed by the nano-indentation test and the fluctuation of mechanical properties depending on the crystal orientation should appear in polycrystalline electroplated copper micro bumps.

Figure 2 and 3 show the distribution of Young's modulus and hardness of the 5-μm and 45-μm-thick electroplated samples, respectively. The values in these figures were defined as the measured value at the depth of 100 nm from the surface. The mechanical properties of both samples were found to fluctuate significantly. In particular, the 5-μm-thick sample had two measurement points with significantly smaller hardness and Young's modulus. As a result, the hardness varied from 1.12 to 1.75 GPa and Young's modulus varied from 110 to 160 GPa in the 5-μm-thick sample. This remarkable fluctuation strongly depends on the position where the indenter was contacted.

3. Micro texture and mechanical properties

The actual micro texture around the indentation location was investigated by using EBSD method. Figure 4 shows the inverse pole figure (IPF) map and the distribution of grain boundaries of the test location. The distribution of crystal orientation appeared in the local micro texture. The micro structure of 5-μm-thick film had fine grains and large distribution of crystal orientation. Therefore, the variation of mechanical properties of 5-μm-thick film was wider than that of 45−μm-thick film.

Table 1 summarizes the local distribution of the measured mechanical properties of the film. The measured results show a large variation of mechanical properties depending on the orientation of each grain. For the 5-μm-thick film, Young's modulus and the hardness are found to be small values at the indentation positions 1 and 2. The IPF map as shown in Fig. 4 indicates that the positions of 7 and 8 were located in the grain with (100) orientation. The values of Young's modulus at these positions are almost equal to that of the (100)-oriented single crystal, as shown in Fig. 1. Therefore, the observed spatial fluctuations of mechanical properties in the electroplated copper thin films were due to the distribution of crystal orientation.

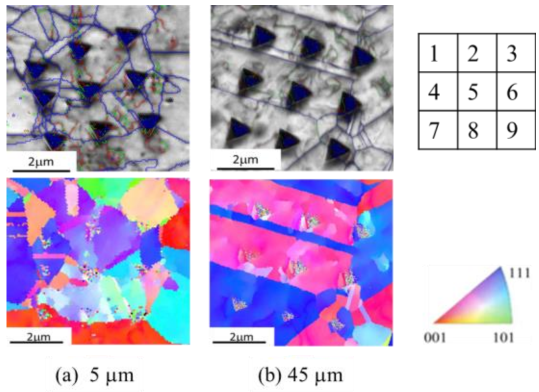

Fig. 4 Distribution of grain boundaries and IPF map in the test regions: (a) 5-μm thick film, (b) 45-μm-thick film

Table 1 Distribution of the measured mechanical properties of the test regions

Hardness/Young's modulus [GPa]

(a) 5 μm

1	1.49/139	2	1.50/120	3	1.44/139
4	1.49/135	5	1.71/126	6	1.45/133
7	1.12/110	8	1.15/113	9	1.65/124

(b) 45 μm

1	1.52/128	2	1.60/127	3	1.74/147
4	1.58/127	5	1.57/125	6	1.72/131
7	1.49/139	8	1.50/143	9	1.62/144

4. Conclusions

The hardness and Young's modulus of the electroplated copper films varied depending on their crystal orientation. It is very important to control the crystal orientation of micro bumps to minimize the variation or distribution of their mechanical properties.

Acknowledgements

This research activity has been supported partially by Japanese special coordination funds for promoting science and technology, and Tohoku University.

References

[1] F. Endo, R. Furuya, K. Suzuki, H. Miura, The Institute of Electronics, Information and Communication Engineers, J96-C(11), 400-408, 2013-11-01.