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Crystallinity Dependence of the Strength of electroplated gold thin films Used for Three-Dimensional Electronic Packaging

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Abstract

In this study, the effect of crystallinity, in other words, the order of atom arrangement of grain in electroplated gold thin films on the mechanical and electrical properties was investigated experimentally. The crystallinity of the gold thin films was varied by changing the under-layer material used for electroplating; such as Cr (30 nm) / Pt (50 nm)/ Au (200 nm) and Ti (50 nm) / Au (100 nm). The mechanical properties of the electroplated gold thin films were measured by using a nano-indentation test. It was found that the variation of the crystallinity should have caused the wide variation of mechanical properties of the electroplated gold films.

1. Introduction

Electroplated gold thin films have been used for micro bumps in flip chip packing structures. Since gold has low electrical resistivity, high thermal conductivity and corrosion resistance and low Young's modulus, flexible joints with low mechanical stress and long lifetime can be fabricated by applying fine gold bumps [1]. However, it has been reported that physical properties and micro texture of thin films formed by electroplating vary drastically comparing with those of conventional bulk material, depending on their electroplating process. In addition, since one bump is going to consist of a few grains or a single grain due to the miniaturization of the 3D structures, it shows strong anisotropic mechanical properties because a face-centered cubic crystal essentially has strong anisotropy of physical properties. As a result, there should be the the wide variation of the mechanical and electrical properties of fine bumps. Once wide distribution of physical properties appears in the electroplated materials, the local distribution of the residual stress and strain should become complicated and large local residual stress and strain should cause not only mechanical failures in the stacked chips but also electronic function shifts of semiconductor devices. In addition, it was found that the long-term reliability of micro bumps and interconnections is degraded drastically by porous grain boundaries with a lot of defects because of the acceleration of atomic diffusion along the porous grain boundaries under the application of high current density (electromigration) and high mechanical stress (stress-induced migration). It is, therefore, necessary to clarify the mechanism of the fluctuations of properties of electroplated gold thin films and bumps in order to assure the reliability of the products.

In this study, the effect of crystallinity, in other words, the order of atom arrangement of grains in electroplated gold thin films on the mechanical properties was investigated experimentally. The mechanical properties of the electroplated gold thin films such as Young's modulus were measured by using a nano-indentation test. Also, the micro textures such as crystallinity and crystallographic orientation of gold thin films were investigated by EBSD (Electron Back- Scatter Diffraction) and XRD (X-Ray Diffraction) methods.

2. Sample preparation

Electroplated gold thin films used in this study were prepared as follows. Firstly, 1.5-μm thick SiO_2 layer was deposited on a Si wafer by using Plasma-CVD (Chemical Vapor Deposition). Secondly, the under layers such as a barrier and a seed layers were deposited on the SiO_2. In order to clarify the effect of the order of atom arrangement of the under layers on the micro texture, two different under layer structure were prepared as follows. When Cr was used for a barrier layer, Pt was used for the buffer layer and Au was deposited on the Pt layer as a seed layer for the electroplating by EB (Electron Beam) deposition method. In this under layer structure, 30-nm thick Cr, 50-nm thick Pt and 200-nm thick Au layers were deposited sequentially. The other under layer structure consisted of 50-nm thick Ti and 100-nm Au thick layers formed by EB deposition method. Since the maximum lattice mismatches between stacked layers decreases from about 10% in the Cr/Pt/Au under layer to only 2% in the Ti/Al under layer, the Ti/Al layer structure was expected to improve the order of atom arrangement in the electroplated gold thin films. Next, 1 or 5-μm thick gold film was electroplated on the under layer at the current density of 10 mA/cm^2 using a sulfite-based gold plating solution. Finally, some samples were annealed after the electroplating at 400^oC for 30 minutes in pure Ar gas with heating rate of 20^OC/min. And the annealed samples were cooled down to room temperature (25^OC) under the cooling rate of 20^OC/min after the annealing.

3. Crystallinity of under layers and electroplated gold films

Figure 1 shows the X-ray diffraction patterns of the under layer structures. A strong Au (111) peak was obtained from both gold thin films. There was, however, the clear difference in the peak intensity between the two films. The intensity of the Au (111) peak obtained from the film deposited on the Ti/Au-under layer was about 6 times higher than that on the Cr/Pt-under layer. Figure 2 shows the X-ray diffraction patterns of the 5-μm thick electroplated gold thin films. Regardless of the difference of the under layer structures, the electroplated gold films have a strong (110) orientation while the intensity of (111) peak was the largest in the under layers. Although no clear change of the XRD spectrum was observed when the crystallinity of the under layer showed clear

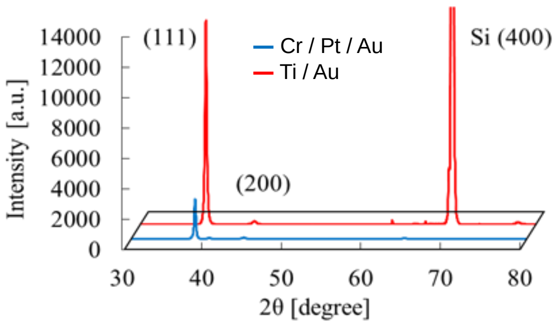

Fig. 1 XRD spectrum of under layer thin films

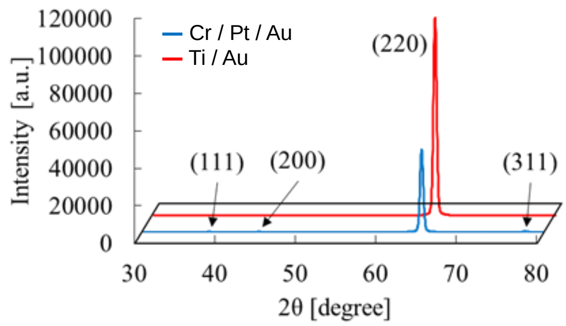

Fig. 2 XRD spectrum of electroplated gold thin films

difference, the cross-sectional texture of the electroplated gold thin films varied drastically depending on the crystallinity of the under layer as shown in Fig. 3. The electroplated gold film on the Au/Pt/Cr consisted of random distribution of grains such as fine columnar grains and coarse grains. On the other hand, the cross-sectional structure of the gold thin film electroplated on the Au/Ti under layer consisted of two layers. There was a thin interfacial layer with the thickness of a few hundred nm, which consisted of a series of a single-crystal grain. Fine columnar grains with the length longer than 4 μm grew on the interfacial layer. Therefore, the micro texture of the electroplated gold thin film varied drastically depending on the crystallographic structure of the under layer used for electroplating.

In order to clarify the crystallinity of the electroplated gold thin films more in detail, EBSD analysis was applied as shown in Fig. 4. Figures from 4(a) to 4(d) show IQ (Image quality) maps of the gold electroplated thin films, and the blue area in the color IQ map indicates the low IQ value area with a lot of defects, while the red area indicates the high IQ value end high quality area. Average IQ value of the gold thin film electroplated on the Au/Pt/Cr under layer was about 5000 and that on the Au/Ti layer was about 5400. After annealing at 400^{O}C, the average grain size increased drastically and the crystallinity of the electroplated gold thin films improved. From the EBSD analysis, both average IQ values of the gold thin films electroplated on the Au/Pt/Cr and that on the Au/Ti under layer increased to about 5800. Figure 5 shows the Weibull plots of mechanical properties of the electroplated gold thin films. Young's modulus fluctuated significantly from 79 GPa to 113 GPa depending on the under layer and heat treatment, in other words, the order of atom arrangement affected the distribution of Young's modulus. Therefore, controlling the order of atom arrangement of under layer is important for controlling the distribution of Young's modulus.

4. Conclusions

The crystallinity of grain of electroplated gold thin films varied drastically depending on the order of atom arrangement in the under layer and annealing after the electroplating. The distribution of the mechanical properties also changed drastically. Therefore, it was confirmed that the control of the order of atom arrangement in the under layer used for electroplating is indispensable for improving the crystallinity and reliability of the electroplated gold thin-film interconnections.

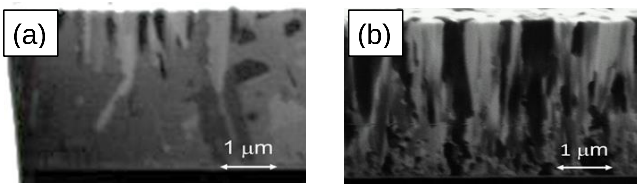

Fig. 3 Cross-sectional micro texture of the 5-μm thick electroplated gold thin film (a) on Au/Pt/Cr under layer and (b) on Au/Ti under layer

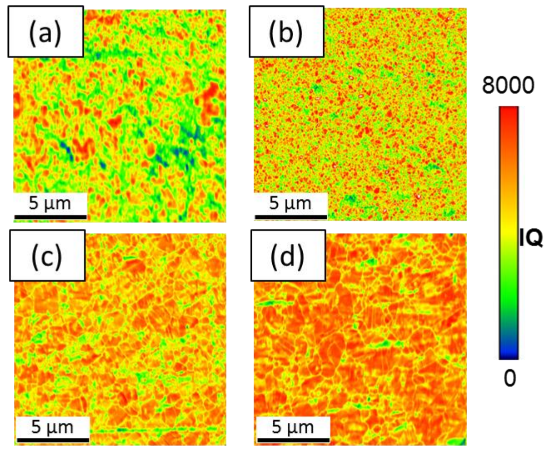

Fig. 4 IQ maps of the top surface of the electroplated gold thin films: (a) As-electroplated on the Au/Pt/Cr under layer, (b) As-electroplated on the Au/Ti under layer, (c) After the anneal (on Au/Pt/ Cr) (d) After the anneal (on Au/Ti)

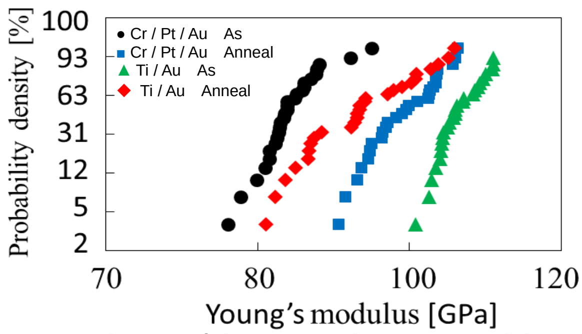

Fig. 5 Distribution of the measured Young's modulus of the electroplated gold thin films

Reference

[1] N. Tanaka, Y. Yoshimira, T. Naito, C. Miyazaki, Y. Nemoto, M. Nakanishi, T. Akazawa, Electronic Components and Technology Conference, (2005), pp.788-794.