Effects of Cu Film Texture and Barrier Structure on Cu Grain Growth

Kazuyuki Kohama, Takuya Matsumoto, Kazuhiro Ito, Yasuharu Shirai, Masanori Murakami

1Dept. of Materials Science and Engineering, Kyoto Univ., Yoshida-Honmachi, Sakyo-ku, 606-8501 Kyoto, Japan
Phone: +81-75-753-5482 E-mail: k.kohama@eng.mbox.media.kyoto-u.ac.jp
2The Ritsumeikan Trust, Nakagyo-ku, 604-8520 Kyoto, Japan

1. Introduction
As a Cu wire width reduces to a deep sub-micron scale in ultra-large scale integrated devices, a large resistance-capacitance delay is one of critical material-related issues. One of the primary factors for the increase in electrical resistivity of the Cu wires is the existence of fine Cu grains. Thus, understanding the mechanism of grain growth in Cu films is essential for reducing the resistivity increase.

In the past decades there have been many investigations on grain growth in Cu thin films [1-3], and both Cu grain growth and Cu texture were reported to be affected by a material type of diffusion barrier: Strong (111)-texture was observed in Cu films deposited on barrier materials such as Ta and Ti, in contrast, some (100)-oriented grains in addition to (111)-oriented grains were observed in those on barrier materials such as W and SiO₂. The strong (111)-texture suppressed Cu grain growth, and containing the (100)-oriented grains in the (111) grains facilitated Cu grain growth [1-7]. However, comprehensive and quantitative relationship among the Cu grain growth, the Cu texture and the barrier materials is not clear. Thus, in this study, we comprehensively and quantitatively investigated effects of Cu film texture related with barrier materials on Cu grain growth at room temperature (RT).

2. Experimental Procedures
Single-layer barriers of Ta and TaN with 150 nm in thickness and two-layer barriers (Ta/TaN and TaN/Ta) with 75 nm in thickness of each layer) were deposited on SiO₂/Si substrates in a radio frequency magnetron sputter system, and followed by about 250 nm- or 10 nm-thick Cu films without breaking the vacuum. Those Cu films were also deposited on barrier-less substrates (SiO₂/Si and (112) 0-oriented sapphire). After the deposition, the samples were kept at RT. The Cu surface was observed by focused ion beam (FIB), atomic force microscope (AFM) and scanning electron microscope (SEM)/energy dispersive X-ray spectroscopy (EDX). The resistivity of the Cu films was measured by van der Pauw method. Texture of the Cu films was investigated by X-ray diffraction (XRD) method. The texture was similar to that of the as-deposited Cu grain size. Thus, to facilitate Cu grain growth, it is important to control the α value around 1.0 during grain growth at RT.

3. Results and Discussion

I. Effect of Cu film texture on grain growth (250 nm-thick Cu films)

Figure 1(a) and 1(b) show typical XRD θ-2θ spectra of the (200) and (222) peaks, respectively, for the Cu/SiO₂ sample. Both the (200) and (222) peak areas increased with increasing the keeping time as shown in Fig. 1(c), indicating the Cu grain growth at RT. Similar tendency of keeping-time variation of the peak areas was observed in all the other samples, except for the Cu/Ta sample with the (111)-texture. The horizontal and vertical axes represent the θ value of ~1.0 during grain growth at RT.

The α values and the resistivity of the Cu films on various barriers are shown in Fig. 2 and 3, respectively, as a function of the keeping time. The α values for the as-deposited Cu samples varied with the barrier materials, indicating the texture of the Cu films were affected by the barrier materials. The α values for the Cu/Ta/TaN, Cu/TaN/Ta and Cu/TaN samples decreased with the keeping time, while those for the Cu/Sapphire and Cu/SiO₂ samples increased with the keeping time. The α values decreased with the keeping time for all the samples, indicating the Cu grain growth at RT. However, the residual resistivity reduction rates and the minimum values varied with the barrier materials. The minimum resistivity value of about 2 μΩcm was obtained in the Cu/Sapphire sample (α=0.9).

Based on these results, quantitative relationship among the resistivity, the α value, and the keeping time was summarized in Fig. 4. The resistivity of the as-deposited Cu films varied with the barrier materials. The resistivity decreased with the keeping time for all the samples, indicating the Cu grain growth at RT. However, the residual resistivity reduction rates and the minimum values varied with the barrier materials. The minimum resistivity value of about 2 μΩcm was obtained in the Cu/Sapphire sample (α=0.9).

II. Effect of barriers on Cu film texture (10 nm-thick Cu films)

To clarify how and when the texture of the 250 nm-thick Cu films was determined, texture of the 10 nm-thick Cu films was investigated using the XRD method. The texture was similar to that of the 250 nm-thick Cu films (data not shown). The lateral Cu layer growth was observed in the Cu/Ta and Cu/Ta/TaN/Ta samples using AFM and SEM/EDX. While, Cu agglomeration was observed in Cu/SiO₂, Cu/TaN/Ta and Cu/TaN samples, and morphology of Cu islands became coarse as the α value was larger. Typical AFM images of the Cu/Ta and Cu/TaN samples are shown in Fig. 6. Those indicate that the texture of the Cu films was not produced during grain growth, but was made in nucleation. Also, wettability of the Cu films on various barriers plays a key role for determining the texture. The good wettability made a continuous Cu film on the barrier, and internal stress due to difference of thermal expansion coefficient between the Cu films and substrates may lead to formation of strong (111)-texture.
4. Conclusions
The Cu film texture ($\alpha$ values) could be continuously changed by selection of barrier materials. The Cu grain growth rate and the average grain size can be maximized when Cu films consist of a certain amount of (100)-oriented grains in addition to (111)-oriented grains ($\alpha = \sim 1.0$), regardless of the as-deposited Cu grain size. The average grain size of the sample ($\alpha = \sim 1.0$) was confirmed to be the coarsest. To facilitate Cu grain growth, it is important to control the $\alpha$ value around 1.0 at RT. The texture of the Cu films is concluded to be determined at nucleation, and wettability of the Cu films on various barriers plays a key role for determining the texture.

Acknowledgements
This work was supported by Research Fellowships of the Japan Society for the Promotion of Science for Young Scientists (Kohama). The author (Ito) would like to thank Research Foundation For Materials Science.

References