Surface Topography and Microstructure of Copper Plating Machined with Single-Crystal Diamond Tool

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Abstract. This study investigates the surface characteristics of copper plating machined with a single-crystal diamond tool. The surface topographies of the machined samples were evaluated using WLI and AFM. PSD analysis showed that copper plating is smoother than oxygen-free copper at spatial frequencies below 2×10^4 mm^{-1}. Although the PSD of copper plating was the highest above 2×10^4 mm^{-1} due to its sand-like texture, this did not significantly affect its RMS roughness. Microstructural analysis using EBSD and XRD revealed that the copper-plated surface consists of fine crystalline grains, likely responsible for the observed texture. These results indicate that copper plating can be smoothly machined and is suitable for use in optical components.

1 Introduction

Copper plating can be accurately machined using a single-crystal diamond tool, making it a promising material for optical surfaces [1]. However, few studies have investigated the characteristics of the machined copper-plated surface in detail. The aim of this study is to clarify the characteristics of copper surfaces machined by a single-crystal diamond tool. To this end, copper-plated surfaces were turned using the tool, and their surface topographies were evaluated using surface profilers. Moreover, the microstructure of the machined surfaces was analyzed to investigate the relationship between microstructure and surface topography.

2 Method

The workpieces made of copper plating, oxygen-free copper, and NiP plating were prepared. They were turned using an ultraprecision turning machine with a single-crystal diamond tool. The workpieces were finish-turned with a depth of cut of 2 μm. The resulting surfaces were measured using a white light interferometric microscope (WLI)

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and an atomic force microscope (AFM). The microstructure of the machined surfaces was analyzed using electron backscatter diffraction (EBSD) and X-ray diffraction (XRD).

3 Results and discussion

The surface of oxygen-free copper observed over an area of 140 × 105 μm^2 using WLI revealed crystal grains with boundary steps of approximately 5 nm. In contrast, the surfaces of copper plating and NiP plating were smooth, with no observable crystal grains. Figure 1 shows the Power Spectral Density (PSD) curves calculated from the surface profiles. As shown in Fig. 1, the PSD of oxygen-free copper tends to be the highest among the three materials, while those of copper plating and NiP plating are similarly low.

The results of the 1 × 1 μm^2 area measurements obtained by AFM are as follows. The surface of the copper plating exhibited a sand-like texture, while the surface of oxygen-free copper showed many tiny holes. The RMS roughness of the copper-plated surface (1.72 nm) was smaller than that of oxygen-free copper (2.32 nm). The surface of the NiP plating was smooth, with an RMS roughness of 1.50 nm. Figure 2 shows the PSD curves calculated from the surface profiles. As shown in Fig. 2, the PSD of oxygen-free copper is the highest at spatial frequencies below 2 × 10^4 mm^{-1}, likely due to the presence of tiny holes. The PSD of copper plating is highest at spatial frequencies above 2 × 10^4 mm^{-1}, which is thought to result from the sand-like texture. Since the RMS value of copper plating is small, it was found that the PSD at these high spatial frequencies does not significantly affect the RMS value. From Figs. 1 and 2, it can be concluded that copper plating is smoother than oxygen-free copper at spatial frequencies below 2 × 10^4 mm^{-1}.

The surface microstructure of the machined copper plating was analyzed using EBSD and XRD. A grain map over an area of 6 × 6 μm^2 was obtained by EBSD, revealing that the surface consisted of fine crystalline grains. Furthermore, XRD analysis confirmed that there was no amorphous region on the surface, and the average grain sizes for various crystal orientations ranged from 20 to 47 nm. Therefore, the sand-like texture observed on the machined copper plated surfaces is likely due to the presence of these microcrystalline grains.

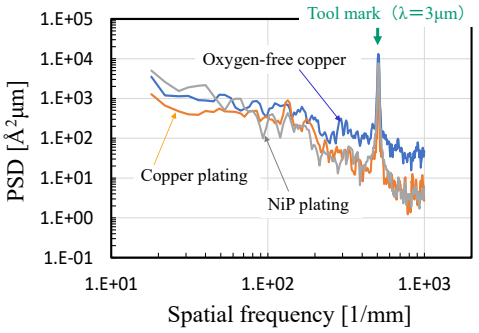

Fig. 1. PSD Curves for various turned surfaces measured with WLI.

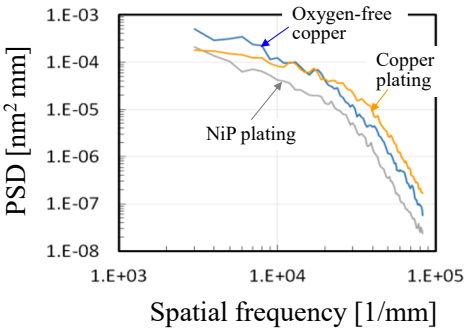

Fig. 2. PSD Curves for various turned surfaces measured with AFM.

References

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