Achievement of Super-Smooth Surface of Cu by Abrasive-Free CMP Utilizing Vacuum Ultra-Violet Light

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Abstract

Copper (Cu) substrates have been conventionally finished by the chemical-mechanical polishing (CMP) method with abrasives for obtaining the super-smooth surface. The method, however, has serious problems such as contaminations and scratches caused by the abrasives. To overcome the problem, the abrasive-free polishing (AFP) method utilizing vacuum ultra-violet (VUV) light irradiation and electrolyzed water was applied to the finishing process after the Cu-CMP. As the experimental results, the super-smooth surface less than 1 nm Ra (average roughness) in the macro area 500 µm square, and 5 nm Ry (peak-to-valley value) in the micro area 10 µm square can be achieved.

1 Introduction

In recent years, the bonding technology of a thin film of dissimilar material by utilizing the intermolecular bonding force on the substrate has been newly developed [1]. The bonding technology requires nanometer scale smoothing in the micro area and nanometer scale planarization in the macro area for the substrate surface. Cu is suitable for the substrate material due to the good thermal and electrical properties. CMP method with abrasives is conventionally adopted for finishing Cu surface.

Then we applied the CMP method to finishing Cu substrate which was used for the above-mentioned bonding, and clarified the problem about the obtained surface quality. And to solve the problem, the previously developed AFP method utilizing VUV light irradiation [2] was adopted for finishing Cu substrate after the Cu-CMP. VUV light irradiation generates and decomposes ozone gas, which is expected to bring the surface planarization.

2 Problems of CMP with abrasives

In Cu-CMP, the surface planarization of workpiece progresses on the basis of a synergistic combination of chemical reactions with mechanical planarization using abrasives. With the increase of mechanical removal effect, a planarization in the macro area was achieved, namely, the surface roughness obtained was less than 1 nm Ra, as shown in Figure 1. But a lot of scratches and the defects caused by abrasives, such as particles (Figure 2(a)), scratch (Figure 2(b)) and projections (Figures 2(c) (d)) were observed in the micro area. Especially, the projections (even it's less than 10 nm in height), which cannot be removed by conventional cleaning methods, become a killer defect for the bonding process. It is expected that these projections can be removed by the developed AFP method. The polishing experiments with in-situ VUV light irradiation and electrolyzed water were carried out.

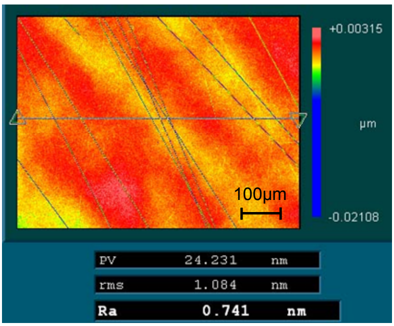

Fig.1 Optical interferometer image of after Cu-CMP with abrasives

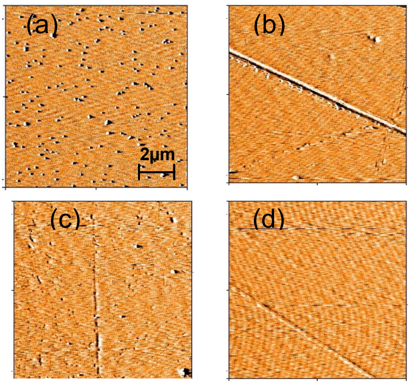

Fig.2 AFM images of after Cu-CMP with abrasives

3 Experimental and measurement method

Figure 3 shows the experimental setup of the developed AFP method under the polishing conditions of Table 1. The Xe excimer lamp (λ 172 nm and power density 50 mW/cm^2) was adopted as VUV light source and set under the polishing plate. The polished synthetic quartz plate was used as the polishing plate so that the light was irradiated the polishing point directly. The felt type polishing pad having a lot of holes was attached on it, and the light was irradiated through the holes. The workpiece was pre-finished by Cu-CMP. The polishing plate was rotated at 20 rpm, and the workpiece was rotated at 80 rpm by a constrained rotation of ceramic ring.

Electrolyzed oxidized water (EOW) and electrolyzed reduced water (ERW) were adopted as the polishing fluid, and the supply rate was set to be 2 mL/min.

As the measurement method of polished surface roughness, optical interferometer (Zygo, New View 7200, Z-resolution 0.1 nm) and AFM (Nanosurf, Nanite, Z-resolution 0.027 nm) were used in the macro area 500 µm square and in the micro area 10µm square, respectively.

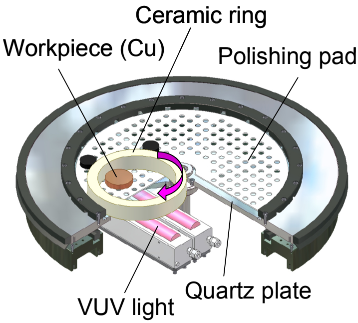

Fig.3 Experimental set-up of AFP

Table1: Polishing conditions

Workpiece	Oxygen-free Copper
Polishing pad	Felt type
Diameter of pad	400 mm
Polishing pressure	4.0 kPa
Rotation of pad	20 rpm
Rotation of workpieces	80 rpm
Polishing fluid	-EOW (pH5 – 6) -ERW (pH 10 – 11)
Supply rate	2 mL/min

4 AFP method utilizing VUV light irradiation

Figure 4 represents the changes in the surface roughness Ra (10 point measuring) and optical interferometer images in the macro area 500 µm square. The surface roughness in the macro area got worse with polishing time, because an object of this AFP method was finishing, and chemical reactions was stronger than mechanical planarization. In the case of that polishing fluid was EOW, after the polishing time of 60 minutes, the surface roughness Ra got over 1 nm. A deep etching was occurred by the photoelectric effect from VUV light irradiation. After the polishing time of 10 minutes (in that case, the surface roughness in the macro area was less than 1 nm Ra), surface observation in the micro area was carried out, consequently, the projections were still observed, a smoothing in the micro area was not achieved.

On the other hand in the case of ERW, after the polishing time of 60 minutes, the surface roughness maintained less than 1 nm Ra. Most of scratches were disappeared and there were not projections from the micro area observation at 8 points. The smoothing in the micro area was achieved, namely, the surface roughness obtained was less than 5 nm Ry.

As explained above, it was clarified that the control of the dissolution reaction by the photoelectric effect was important in this study. It made a decision that EOW was unsuited for use in obtaining the super smooth surface, because polishing progressed in etching zone. In the case of that ERW was adopted as polishing fluid, it was possible that the achievement of the super-smooth surface in the macro and the micro area.

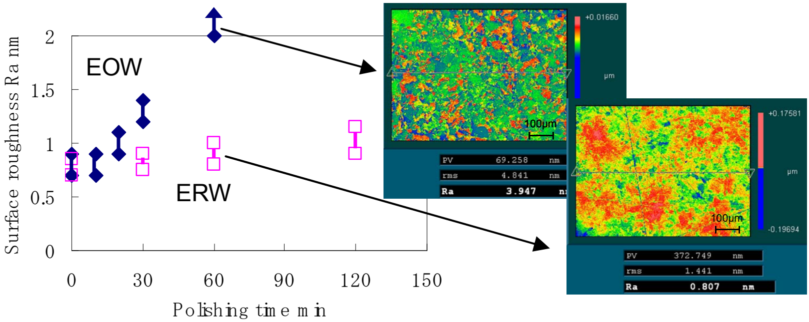

Fig.4 Changes in polishing surface roughness with finishing time and optical interferometer images of after AFP

5 Conclusion

To solve the problems of Cu-CMP with abrasives, the developed AFP method was applied to finishing process after the Cu-CMP. The experimental results revealed that the developed method was effective for obtaining the super-smooth surface less than 1 nm Ra in the macro area and 5 nm Ry in the micro area.

Acknowledgments

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