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Dishing-Free Cu Chemical Mechanical Polishing Process Based on Endpoint Detection with Laser Beam

Y. Tokuyama, H. Ogawa, M. Yanagisawa[1], J. Kikuchi[2] , H. Nakagawa[3] and Y. Horiike

Department of Materials Science, School of Engineering, The University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-8656, Japan
Phone: +81-3-5841-7164 Fax: +81-3-5841-8649 E-mail: tokuyama@micro.mm.t.u-tokyo.ac.jp
[1] Speedfam Co.,Ltd.
Hayanawa 2647, Ayase, Kanagawa, 252-1123, Japan
[2] Axiomatec Inc.
6-5-16 Ginza, Chuo-ku, Tokyo, 104-0061, Japan
[3] Semiconductor Company, Matsushita Electric Industrial Co., Ltd
19, Nishikujo-Kasugacho, Minami-ku, Kyoto, 601-8413, Japan

1. Introduction

The in-situ IR-RAS (Infra-red Reflection Absorption Spectroscopy) of the solid-liquid interface during copper (Cu) chemical mechanical polishing (CMP) process revealed that CuO of a fragile material was polished rapidly, while Cu_2O was not easy to be polished, in turn passivating the polished surface [1]. Generation of CuO or Cu_2O was controlled by addition of an oxidant like H_2O_2 to a slurry. The elucidated Cu CMP mechanism led to a concept that the dishing-free process might be achieved by replacing a CuO surface during CMP by a Cu_2O surface near the polishing endpoint. The endpoint of the Cu CMP was also detected from variation of the IR reflective light from the polished surface, while the intensity difference before and after CMP was not so large. When a laser light was irradiated accidentally to the Cu surface, we noticed notable difference of diffracted beam intensity between before and after Cu CMP. This paper reports the dishing-free Cu CMP process based on the controlled Cu surface conditions and an endpoint detection employing a laser beam.

2. Experimentals

Figure 1 shows an in-situ endpoint detection system combined with a CMP equipment. A 32mm-diameter pad (Rodel SUBA 800) was pasted on the bottom of a weight at a pressure of 63.4kPa. Its center was deviated by 16nm from a center of a patterned 4 inch Si wafer. The turn table holding the wafer was rotated at a speed of 80 rpm by a motor. The pad was also rotated with rotation of the wafer to the same rotating direction. A 670 nm wavelength laser beam with 1.5 mm diameter was irradiated at an angle of 10 degrees on the wafer surface which was distant from the pad position. The polished portion was moved to the position of the laser irradiated point approximately in 0.4 sec.. A 1.5mm diameter orifice was set between the reflection point and a sensor which detected only the zero order diffraction light.

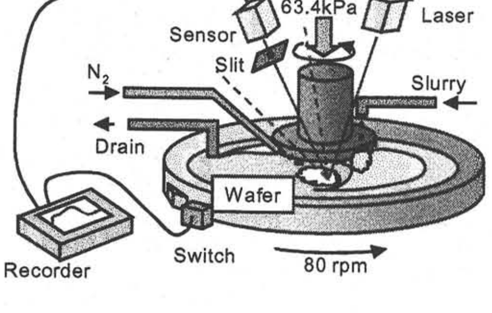

Fig. 1 In-situ endpoint detection system combined with a CMP equipment.

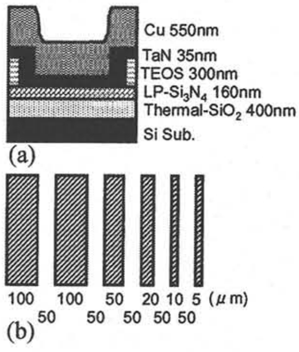

Fig. 2 Sample structures. (a) is a layer structure, and (b) is a patterned region.

Slurry was poured to the wafer surface at 50 ml/min. Simultaneously, the used slurry was drained at the same speed. The slurry was colloidal silica-based FUJIMI Planerlite-7101. N_2 gas was blown to the reflection point, allowing to remove the slurry from the irradiated surface. Thus, absorption and scattering of the laser beam in the slurry layer was reduced. The slurry included 5 wt% colloidal silica, and 1 wt% H_2O_2. Figure 2 shows the structures of the sample, (a), and the pattern, (b). Cu(550nm)/TaN(35nm)/TEOS(300nm)/LP-Si_3N_4(160nm)/Thermal-SiO_2(400nm)/LP-Si_3N_4. As shown in Fig. 2 (b), the polished surface consists of trenches with 5 to 100 μm width lined by a 50 μm gap width and no pattern regions.

3. Results and Discussions

The following two measurement methods were investigated: (1) Samplings of intensities of the beam diffracted from the polished surface were carried out 16000 times during 1.3 sec. that corresponded to rotation of 1.75 times and the average intensities were obtained from division of the sum total of intensities by the sampling times. (2) A switch was attached on a side wall of the turn table. As soon as the switch was turned on during rotation, the diffracted beam was detected by a photodiode and recorded. Thereby, the laser was irradiated to a fixed same position every rotation of the turn table.

Figure 3 shows variations of reflectance as a function of the polishing time, where the curve of (a) was given from average reflectance values in the case of (1), and both (b) and (c) curves indicate reflectance from the fixed points at a patterned (see Fig. 2 (b)) and a non-patterned flat region in

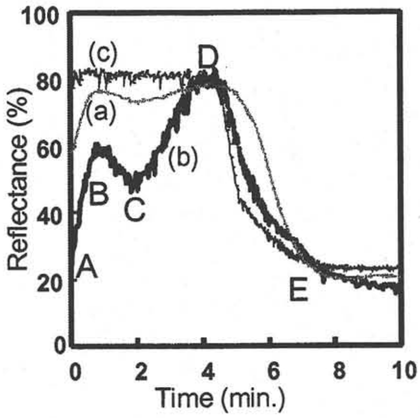

Fig. 3 Variations of reflectance vs. polishing time, where the curve (a) was given from average reflectance values and both (b) and (c) curves indicate reflectance from the fixed points at a patterned and a non-patterned flat region, respectively.

the case of (2), respectively. In the case of (a) and (b), an initial reflectance value of A increased to the first maximum of B after 1 min. due to decrease in the surface topology. Then, the reflectance dropped to the first minimum of C after 2 min. and increased again to the second maximum of D after 5 min. Finally, all the curves converged to the second minimum after about 7 min. The decrease in the reflectance from D to E resulted from the appearance of the underling opaque material of TEOS after polishing of the Cu layer. One notices that the first minimum value at C in the patterned case of (c) was smaller than that in the average value case of (a), and in the flat surface case of (b), and no change in reflectance was observed at a. period of B to D. These results imply that such topological variations relate with the polished features. Hence this origin was considered as follows based on cross sections of polished patterns measured in A to D points in the curve (b) using the surface roughness measurement (Tenkor P-10) as shown in Fig. 4. At A to B, upper surfaces were polished as keeping sharp gap edges, thus increasing the reflectance. However, edge features which was going to be round around B reduced the reflection due to diffused reflections of the laser beam at edges and this effect was maximized at C. Afterward the gap depth diminished and the surface texture changed smoothly. Hence the reflectance was improved, thus becoming maximum at D. Consequently, the detection method of the diffracted beam from the fixed point of the patterned surface was found to be sensitive in CMP of the actual LSI patterns.

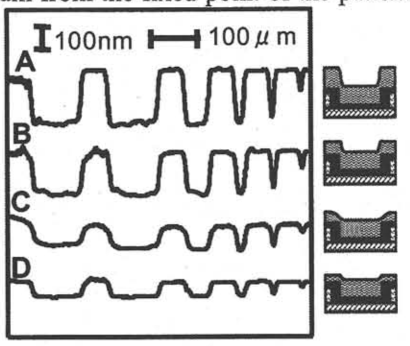

Fig. 4 Variations of cross sections of polished patterns measured in A to D points in the curve (b) using the surface roughness measurement.

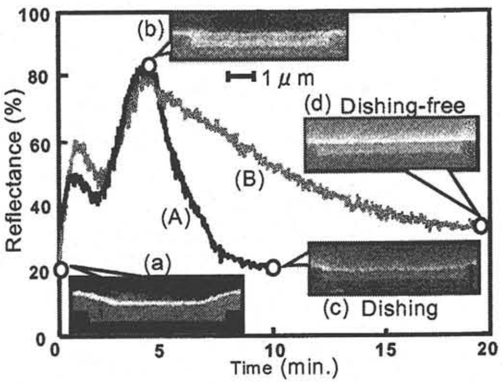

Fig. 5 Polishing time dependence of the reflectance for two types for Cu CMP. One(curve A) is the case using one kind of the slurry with addition of H_2O_2 through the CMP process. The other (curve B) is the case using the H_2O_2 additive slurry at first and changing H_2O_2 removed slurry at the second maximum point.

Figure 5 shows the polishing time dependence of the reflectance for two types Cu CMP. One (curve A) is the case using one kind of the slurry with addition of H_2O_2 as an oxidant through the CMP process. The other (curve B) is the case using two type slurries, where the H_2O_2 additive slurry was used from the start to the second maximum and then the slurry without H_2O_2 was changed quickly from this maximum to the end. The inset four pictures show SEM cross sectional pictures of a 5 μm width gap patterns before CMP, (a), the Cu layer at the maximum point, (b), at each converging point after CMP, (c) and (d). The (b) picture made it clear that the maximum point originated from the fairly flattened Cu layer with 220nm thickness covering TEOS. Since the H_2O_2 additive slurry led to high polishing rates, a heavy dishing feature was caused as shown in the (c) picture of the curve A. To the contrary, the oxidant-removed slurry which provided low polishing rates realized a dishing-free Cu CMP as shown in the (d) picture of the curve B.

4. Conclusion

The end point detection which was necessary to achieve dishing-free CMP was studied by detecting the zero order laser beam diffracted from a fixed point on the pattered Cu surface during polishing. The detection method enabled us to measure sharp topological variations of the polished surface. Based on the reflectance measurement, at first the Cu surface was polished at high speed with the H_2O_2 additive slurry and H_2O_2 was removed quickly from the slurry at the maximum reflectance point in which the flat Cu surface was obtained. The H_2O_2-removed slurry changed the Cu_2O from CuO surfaces, thereby realizing the dishing-free Cu CMP surface. However, the prolonged polishing time should be reduced by some acceleration means.

Reference

[1] H.Ogawa, Y.Tokuyama, M.Yanagisawa, J.Kikuchi and Y.Horiike, Extended Abstracts of the 2000 International Conference on Solid State Devices and Materials, pp.20-21