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The Effect of Mechanical Properties of Polishing Pads on Oxide CMP (Chemical Mechanical Planarization)

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The purpose of this study is to investigate the effects of the structure and mechanical properties of laser- processed pads on their polishing behavior such as their removal rate and WIWNU (within wafer non-uniformity) during the chemical mechanical planarization (CMP) process. The holes on the pad acted as the reservoir of slurry particles and enhanced the removal rate. Without grooves, no effective removal of wafers was possible. When the length of the circular-type grooves was increased, higher removal rates and lower wafer non-uniformity were measured. The removal rate and non-uniformity linearly increased as the elastic modulus of the top pad increased. Higher removal rates and lower non-uniformity were measured as the hardness of the pad increased.

Key words: Chemical mechanical planarization (CMP), laser process, pad, holes, groove pattern, elastic modulus, hardness

Introductions

Chemical mechanical planarization (CMP) is widely used for planarizing both metal and inter-level dielectric layers in the fabrication of integrated circuits to achieve adequate planarization necessary for the stringent photo-lithography depth of focus requirements and the formation of novel damascene interconnection structures [1]. CMP can be performed by applying the pressure to the rotating wafer against a pad with the constant flow of slurry. Planarization of the wafer results from the synergistic action of the mechanical shear forces and the chemical action of the slurry [2]. Hence, both the chemical and mechanical properties of polished films have a great impact on their chemical and wear reaction during the CMP process.

The reaction between the polishing pad and abrasive particles in the slurry is important in understanding the wear mechanism of CMP. All commercially available polishing pads are relatively complex polymeric composite materials and have micro pores in them [3]. These pores act as reservoirs for abrasive particles in the slurry and help to polish substrates effectively. They are very irregular in their sizes and distributions and can be easily deformed during the polishing and conditioning. This deformation can cause the non-uniformity in the removal rate and planarity. The pads used in the semiconductor process have groove patterns on them. The grooves facilitate the transport of the reactant slurry and the product residues across the pad surface during polishing. Even though the hardness, pore density and pattern structure of the pads are very important factors in determining their polishing performance, not much work has been reported on the pads. The purpose of this paper is to report the effects of the hardness, pore density and groove pattern structure of pads on their polishing behavior, such as their removal rate and WIWNU (within wafer non-uniformity), during CMP.

Experimental Procedures

All the polishing experiments described in this paper were carried out using an UNIPLA NS-110 (Semicontech, Korea). The carrier and platen speeds were set at 120 and 10 rpm, respectively. The down pressure and retainer ring pressure of the carrier were 7 and 9 psi, respectively. The flow rate of the slurry was set at 200 ml/min. The polishing and pad conditioning were performed for 2 mins. and 1 min., respectively. Fumed silica-based alkaline slurry (Hanhwa oxide slurry, HS-1200) was used for the polishing experiments. PECVD (Plasma Enhanced Chemical Vapor Deposition)-deposited TEOS (Tetraethylothosilicate) 6" wafers were used for the oxide polishing experiments. The PU (polyurethane) rigid blank pads were prepared without any pores in them. In order to know the effects of pores on the pads, the microholes were made on the blank pad through a laser process, which alone can easily modify the size and density of pores in conventional pads. The microhole's size and depth were determined to 200 μm and 400 μm, respectively and the density of the holes was set at 32% on the pad surface in this study. For better uniformity, a bottom pad was attached to the laser-processed PU pad. A softer PU material was used for the bottom pad. The elastic modulus and hardness of the pads were changed by changing the polymerization process of PU.

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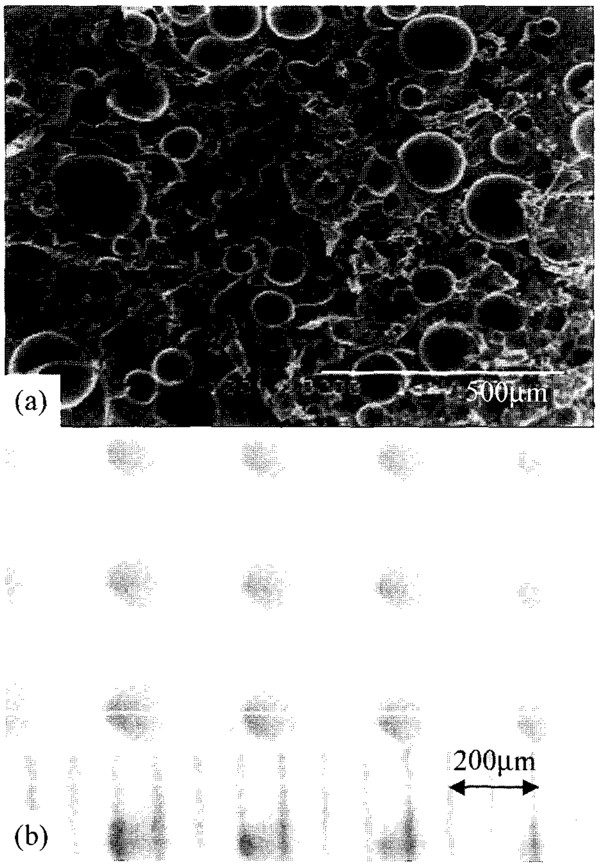

Fig. 1. SEM micrographs of (a) micro-pores on conventional pad and (b) micro holes on blank pad produced via laser processing.

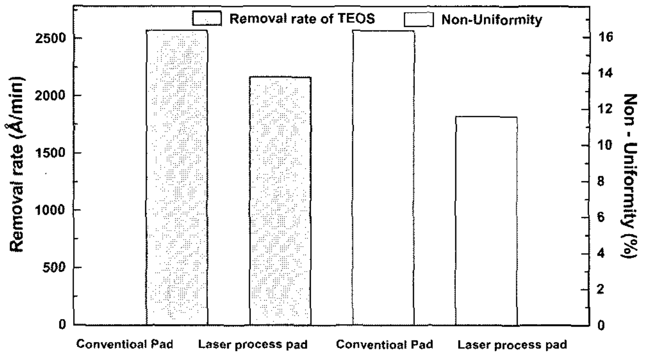

Fig. 2. Removal rate and non-uniformity of oxide wafers polished on a conventional (RODEL IC1400) pad and a laser-processed blank pad.

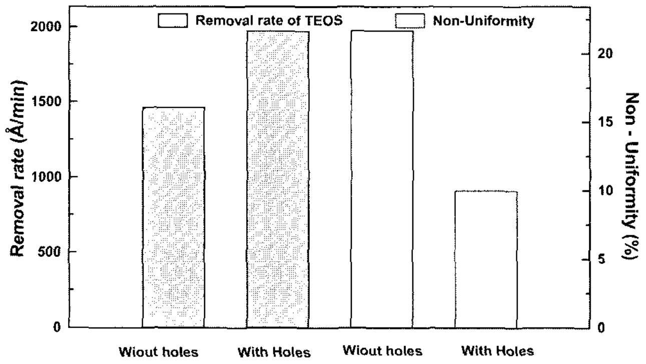

Fig. 3. Removal rate and non-uniformity of oxide wafers polished on blank pads with and without holes.

The removal rate and wafer non-uniformity were measured with the use of an optical film thickness measurement tool (Nanometrics, AFT Model 200).

Results and Discussion

The micro pores on the conventional pad are shown in Fig. 1 (a). They are very important in determining the polishing behavior of wafers during CMP. To know the effects of these pores on the pads polishing performance, microholes were made on a blank pad, as shown in Fig. 1 (b). The random distribution of pores with different sizes can be easily observed in conventional CMP pads. These irregularities of pores are the characteristics of conventional pads and are the nature of the conventional pad manufacturing process. The uniform distribution of same-sized holes was shown, however, in the laser-processed pad. The laser-processed holes had a diameter of 200 μm and a depth of 400 μm.

Figure 2 shows the removal rate and non-uniformity of oxide wafers when they were polished on conventional (Rodel, IC1400) and blank pad with holes using laser-processing. In the CMP process, the removal rate and uniformity of the wafer surface are very important factors in determining the polishing performance. A slightly higher removal rate was measured on the conventional pad. A higher non-uniformity of 16.4% was observed on the conventional pad, however, compared with 11.6 % on the blank pad with holes. Compared with the laser-processed holes on the blanket pad, the irregular pores on the conventional pad may act as better particle reservoirs and suppliers to wafer surfaces during polishing. These cause better contact between the wafer surface and the slurry particles and result in a higher removal rate on the conventional pad. It is also well known that the irregular size and distribution of pores in conventional pads cause the deformation of exposed pores during polishing and conditioning. They may be the main cause of the non-uniformity in the removal rate. The holes on the laser-processed blank pads retain their diameter during polishing and conditioning. Less deformation of holes than of pores during polishing may be the reason for the better uniformity on wafers polished on the laser-processed pads.

To know the role of pores on pad during polishing, two blank pads were prepared with and without the holes on the pad surfaces. Figure 3 shows the removal rate and non-uniformity of oxide wafers when they were polished on blank pads with and without holes. Circular K-groove patterns were made on both blank pads with and without holes to facilitate the slurry flow on the pads. The pads with holes showed a higher removal rate and better uniformity on polished oxide than the ones without holes. This indicates that the holes on pads act as the reservoir of slurry particles and enhance the

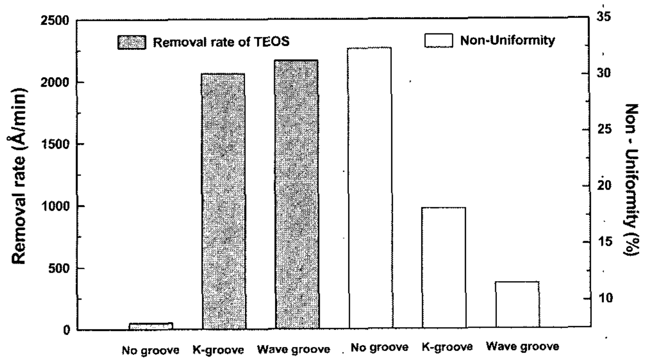

Fig. 4. Removal rate and non-uniformity of wafers polished on pads without grooves, with K-grooves and with wavy K-grooves.

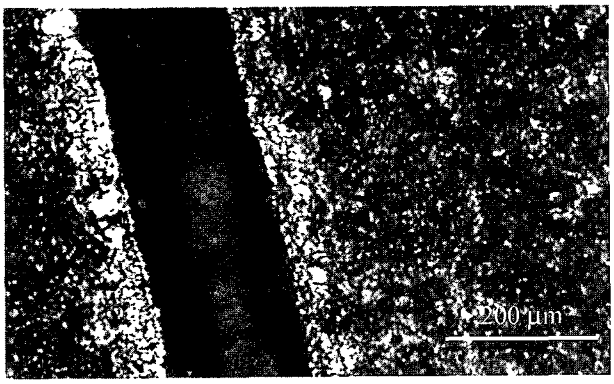

Fig. 5. Optical micrograph of a laser-processed groove.

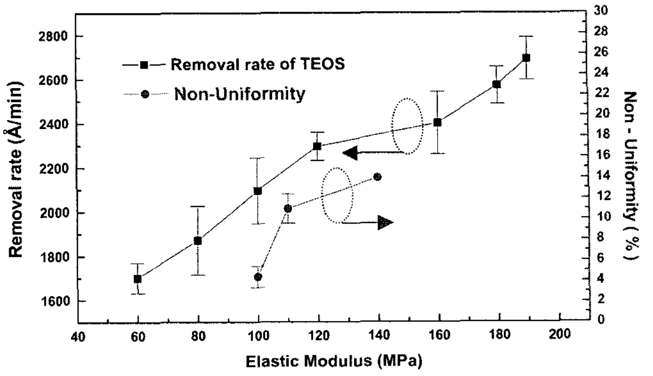

Fig. 6. Removal rate and non-uniformity of wafers as functions of the elastic modulus of pads.

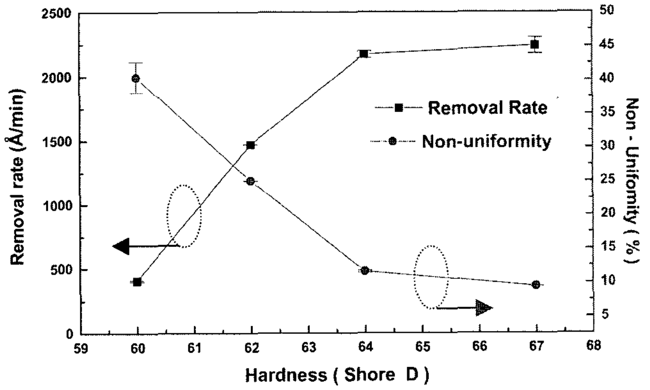

Fig. 7. Removal rate and non-uniformity of wafers as functions of the hardness of pads.

contact time and area between the slurry and the wafers. Holes are also believed to act as a distributor of intruded slurry and help promote better uniformity after polishing. As shown in Figure 3, the pads with holes showed much better uniformity compared to the ones without holes. This explains why pores play an important role in pads during polishing.

It is necessary to have grooves to facilitate the flow of slurry during polishing. The most commonly adapted groove patterns are circular-type K-grooves and x- and y-type grooves. Two types of grooves were generated on pad's and used in the polishing processing, to observe the effects of grooves on pads on pads polishing behavior. The pad without grooves was also used for the comparison. Two different regular K-grooves and modified wavy K-grooves were formed on the blank pads. The density of the K-grooves was the same as that on the conventional Rodel IC1400 pad's. The density of the modified wavy K-grooves was two times higher than that of the K-grooves. Figure 4 shows the dependency of groove patterns on the pads on the removal rate and non-uniformity. A higher removal rate and lower non-uniformity were observed when the wavy groove pads were used in polishing. These may be attributed to a longer slurry residence time on the wavy-grooved pad than on the K-grooved pad during polishing, due to the formers longer groove paths. Longer slurry residence may increase the contact time of slurry particles on wafer and enhance the distribution of slurry particles over wafer surfaces on contact. It is also interesting to note that no removal of oxide was measured when the wafers were polished on pads without grooves. A very high non-uniformity was observed on these pads. It indicates that the presence of the groove patterns is very necessary to achieve a higher removal rate and lower non-uniformity. Figure 5 shows the optical micrograph of a groove channel made by laser processing.

The mechanical properties of pads affect the polishing behavior of wafers. The top pads were fabricated to each have a different elastic modulus and hardness, in order to know the effects of these parameters on polishing. The same bottom pad was used for all pads used in the experiments. Generally, a hard top pad provides a higher removal rate and better planarity while a more compressible bottom pad provides better long-range uniformity with the conventional pads. In these experiments, all pads had laser-processed holes and K-grooves on them. Figure 6 shows the removal rate and non-uniformity of oxide wafers as a function of the elastic modulus of top pad's. The removal rate linearly increased as the top pads elastic modulus increased. The removal rates changed from 1700 to 2700Å/min when the modulus was changed from 40 to 190 MPa. The pad was observed to deform itself according to its modulus values and to exert different pressure on the TEOS films. These different pressures on the wafers result in the different removal rates. The elastic modulus directly relates to the elastic deformation of pad during polishing process. A higher elastic modulus can exert a higher pressure on the wafer surface and result in a higher removal rate. The non-uniformity increased as the elastic modulus increased. Higher pressure on wafers might cause the non-uniform supply of slurry and the uneven distribution of pressure on the surface. They might be the main reason for the higher non-uniformity when pads with a high elastic modulus were used in polishing.

Figure 7 shows the removal rate and non-uniformity of wafers as a function of pad hardness. Hardness was measured using a shore D-type method. Hardness was measured in relative units based on the D-type and mode of indentation, and it was generally a measure of the ability of the pad to maintain its shape. The removal rate increased and the non-uniformity decreased as the hardness of the pads increased. It was noted that the harder pad provides better planarity and less deformation of pads. When the hardness was increased from 60 to 67, the removal rates increased from 400 to 2200Å/min. The non-uniformity decreased from 40% to 10%, however. The optimization of mechanical properties such as the elastic modulus and the hardness of pads are very important in controlling the removal rates and non-uniformity of polished wafers.

Summary and Conclusions

In this study, laser-processed CMP pads were evaluated in terms of their removal rate and non-uniformity. The effects of parameters such as microholes, groove pattern structures, elastic modulus and hardness of the top pad on polishing were investigated. The formation of uniform arrays of holes on the blank pad enhanced the uniformity and the removal rate. These holes sufficiently acted as the abrasive particle's reservoir and distributors during polishing. The grooves on the pad were also very important in determining the CMP performance. Without the grooves, no removal of wafers was observed with very poor wafer uniformity. Modified wavy-type grooved pads had a higher removal efficiency than K-grooved pads due to their longer groove paths. The higher removal rate and lower non-uniformity might have been due to the better contact of slurry with wafers in the wavy-grooved pads. The removal rate and non-uniformity linearly increased as the top pads elastic modulus increased. The elastic modulus might determine the contact area of slurry on wafers, i.e., the pressure of the pad. The removal rate increased and non-uniformity decreased as the hardness of the pads increased due to less pad deformation.

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