Effect of Pad Groove Design on Slurry Injection Scheme during Interlayer Dielectric Chemical Mechanical Planarization

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In this study, the effect of pad groove design on slurry injection scheme during interlayer dielectric chemical mechanical planarization was investigated. A novel slurry injection system (SIS) with multiple slurry outlets was designed to allow fresh slurry to be injected through one or multiple points. At first, the SIS with one injection point scheme was compared with the standard slurry application method on a concentrically grooved pad and an xy-groove pad. On the concentrically grooved pad, the SIS with one injection point scheme generated significantly higher oxide removal rates (ranging from 3 to 9 percent), however, its removal rate enhancement was not as high as that of the concentrically grooved pad. In order to further improve slurry availability on the xy-groove pad, SIS with multi-injection point scheme was tested. Results showed that the SIS with multi-injection point scheme resulted in significantly higher removal rates (ranging from 17 to 20 percent) compared to the standard slurry application method. This work underscored the importance of optimum slurry injection scheme for accommodating particular pad groove designs.

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Figure 1. Top view of a polisher with the (a) standard slurry application method and (b) novel slurry injection system. Both pad and wafer are rotating in a counter-clockwise fashion.

shown in Fig. 2b) in the bottom of the “body” (in the trailing edge). The distance between the two adjacent inlets or outlets is 28 mm. This design allows one to inject slurry through one or multiple holes. Fresh slurry is introduced through the slurry line from the slurry tank where it flows into the inlet(s), and then flows out through the outlet(s). In addition, a channel (see Fig. 2b) which connects these five outlets is designed in the bottom of the injector “body”. It helps spread the fresh slurry onto pad surface during polishing.

Experimental

In this study, SIS was used to inject fresh slurry onto the pad surface. For comparison, the standard slurry application method was also tested. To investigate the effect of pad groove design, a Dow IC1000 concentrically grooved pad and a Dow IC1000 xy-groove pad were used. Concentric groove and xy groove were selected because (1) they represent a highly non-communicative groove and a highly communicative groove pad, respectively, and (2) both designs are used widely in high volume manufacturing worldwide. For the communicative pads, grooves are connected to one another. In comparison, for non-communicative pads, grooves are completely separated from one another and they do not “talk” to each other.16

In this study, 200-mm blanket oxide wafers were polished on an Araca APD-800 polisher and tribometer, equipped with the ability to acquire real-time shear force and down force during polishing.17,18 A 3M A2810 diamond disc was used to condition the pads for...
45 seconds between wafer polishes at a conditioning down-force of 59.2 N. Each wafer was polished for 1 minute at 22.8 kPa and 0.71 m/s. Prior to wafer polishing, the diamond disc was used to break in each pad for 15 minutes with DI water. The disc rotated at 95 RPM and swept at a frequency of 11 per minute across the radius of the pad surface. Pad break-in was followed by pad seasoning during which the shear force was monitored to ensure that stable values were achieved prior to monitor wafer polishing.

The polishing slurry consisted of 1 volume part of Cabot Microelectronics Semi-Spersion 25 slurry and 1 volume part of DI water. Three slurry flow rates (i.e. 200, 150, and 100 ml/min) were tested. For each slurry flow rate, 4 monitor oxide wafers were polished to confirm the experimental reproducibility. Before and after polishing, a reflectometer from SENTECH Instruments GmbH was used to measure the oxide film thickness to obtain the oxide removal rate.

### Results and Discussion

At first, the SIS with only one injection point is compared with the standard slurry application method on both the concentrically grooved and the xy-groove pad. For the SIS with one injection point scheme, fresh slurry is introduced through the slurry line from the slurry tank where it flows into the inlet A, and then flows out through the outlet A (see Fig. 2).

Figure 3 shows the removal rate comparison between the SIS with one injection point scheme and standard slurry application method on the concentrically grooved pad. Oxide removal rates are plotted as a function of slurry flow rate ranging from 100 to 200 ml/min. The error bars in Fig. 3 represent the standard deviation of removal rates. As evident from Fig. 3, the SIS with one injection point scheme generates a significantly higher removal rate than the standard slurry application method at all three slurry flow rates, ranging from 22 to 35 percent. This indicates that either a lower slurry flow rate or a shorter polishing time can be adopted with the SIS for removing the same amount of oxide. Therefore, slurry usage can be reduced with the SIS. Based on Fig. 3, the SIS with one injection point scheme at the slurry flow rate of 100 ml/min generates a higher removal rate than that of the standard slurry application method at 200 ml/min (i.e. 1,580 vs. 1,358 A/min). This indicates that the slurry flow rate can be reduced in half and the throughput can still be increased by the SIS with one injection point scheme compared to the standard slurry application method at 200 ml/min.

Since the slurry injector is placed on the pad surface, its “body” can effectively separate the used slurry and residual rinsing water from the fresh slurry during polishing. This has been confirmed by the thick bow wave formed at the injector leading edge during the pad rinse step and wafer polishing. As an example, Fig. 4 shows a slurry distribution image collected using the SIS via a UVIZ-100 system. UV light is projected onto the area of interest on the pad. The slurry is tagged with a special fluorescence dye. After being excited by UV light, the fluorescence light is captured by a high-resolution charged coupled device camera. The intensity of the emitted fluorescence is proportional to the slurry film thickness. As shown in Fig. 4, a bright area appears in the injector leading edge near the pad edge, indicating the formation of a thick bow wave. Containing used slurry and residual rinsing DI water, this thick bow wave is separated from the fresh slurry that is applied through the injector’s trailing edge.

As the SIS effectively separates the residual rinse water from the fresh slurry, it reduces the dilution effect caused by the residual rinse water on the pad surface and therefore generates a higher oxide removal rate. In addition, Meled et al. performed slurry mean residence time (MRT) test during wafer polishing and found that the SIS generated significantly lower slurry MRTs (ranging from 27 to 50 percent depending on the slurry flow rate) than the standard slurry application method. Assuming the pad-wafer interface acts as a closed reactor, the slurry MRT refers to the average time that the slurry spends in the pad-wafer interface. As such, lower slurry MRTs with the SIS indicate the presence of a fresher slurry during wafer polishing, which leads to the higher oxide removal rates as shown in Fig. 3.

Figure 5 shows the removal rate comparison between the SIS with one injection point scheme and standard slurry application method on the xy-groove pad. The error bars in Fig. 5 represent the standard deviation of removal rates. The SIS with one injection point scheme also generates higher removal rates than the standard slurry application method at all three different slurry flow rates (on average, by 3 to 9 percent). As discussed previously, the reason for the removal increase is that the slurry injector effectively separates the used slurry and residual rinse water from the fresh slurry during polishing.

Comparing Figs. 3 and 5, the SIS with one injection point scheme generates significantly lower removal rates on the xy-groove pad than on the concentrically grooved pad. This is associated with the different slurry flow patterns on these two types of pads. Figures 6a and 6b schematically show the slurry flow patterns on the concentrically grooved pad and xy-groove pad, respectively. For the concentrically grooved pad, grooves are non-communicative and hence relatively higher flow resistance exists through the grooves. As such, most of the fresh slurry flows through the channel in the injector bottom and goes over from one pad land area to another, as shown in Fig. 6a. As the fresh slurry is retained on the pad land area, where polishing occurs, it results in relatively higher removal rates. In comparison, for the xy-groove pad, grooves are highly communicative and extend off to the edge of the pad. This results in significantly lower flow resistance through the grooves. As such, when the fresh slurry is
injected through a single point, while some of the fresh slurry still flows through the channel in the injector bottom, a large portion of the fresh slurry flows directly into the grooves without participating in polishing (see Fig. 6b). Therefore, on the xy-groove pad, the fresh slurry is not spread and retained on the pad land area as effectively as on the concentrically grooved pad, resulting in lower removal rates.

Figure 5. Removal rate comparison between the SIS with one injection point scheme and standard slurry application method on the xy-groove pad.

Figure 6. Schematic of slurry flow patterns on the (a) concentrically grooved pad and (b) xy-groove pad.

Figs. 3 and 5 also show that the removal rate enhancement by the SIS with one injection point scheme on the xy-groove pad (3 to 9 percent) is not as high as the enhancement achieved on the concentrically grooved pad (22 to 35 percent). As stated previously, the xy-groove pad has relatively lower flow resistance through grooves. As such, the used slurry and rinse water can easily flow off the pad surface through the communicating xy grooves without participating in wafer polishing, therefore reducing the dilution effect and slurry mean residence time for the xy-groove pad. With reduced dilution effect and slurry mean residence time, the SIS with one injection point scheme provides lower removal rate enhancement on the xy-groove pad than on the concentrically grooved pad.

Based on the above analysis, spreading and retaining more fresh slurry on the pad land areas will help further increase the removal rate on the xy-groove pad. The SIS, this time with multi-injection point scheme, is tested. As the pitch size of the xy-groove pad is 38 mm and the distance between the two adjacent slurry outlets is 28 mm, the multi-injection point scheme should have a higher possibility to spread fresh slurry over a larger pad land area and therefore retain more fresh slurry on the pad. In this study, the scheme with four injection points is tested. Fresh slurry is introduced through the slurry line from the slurry tank where it flows into inlets A - D evenly via a slurry distribution manifold, and then flows out through the outlets A - D (see Fig. 2).

Figure 7 shows the removal rate comparison among these three slurry injection schemes on the xy-groove pad. As evident from Fig. 7, the SIS with multi-injection point scheme enhances oxide removal rate further (ranging from 17 to 20 percent) compared to the standard slurry application method. Based on Fig. 7, the slurry flow rate can be reduced in half and the throughput can still be increased by the SIS with multi-injection point scheme compared to the standard slurry application method at 200 ml/min. It is therefore important to optimize the slurry injection scheme to accommodate particular pad groove designs.

Figure 7. Removal rate comparison among different slurry injection schemes on the xy-groove pad.

Conclusions

In this study, the effect of pad groove design on the slurry injection scheme during ILD CMP was investigated. A novel slurry injection system (SIS) was developed, which could provide optional slurry injection schemes, namely a one injection point scheme and a multi-injection point scheme. These injection schemes were tested on Dow IC1000 concentrically grooved and xy-groove pads. At first, the SIS with one injection point scheme was investigated on both pads. For the concentrically grooved pad, the SIS with one injection point scheme generated significantly higher removal rates (ranging from 22 to 35 percent) compared to the standard slurry application method. This
was due to the fact that the slurry injector could effectively separate the used slurry and rinse water from the fresh slurry during polishing. On the xy-groove pad, the SIS with one injection point scheme still resulted in higher removal rates (ranging from 3 to 9 percent), however, its removal rate enhancement was not as high as that of the concentrically grooved pad (ranging from 22 to 35 percent). This was due to the different slurry flow patterns on these two pads. On the xy-groove pad, when one injection point scheme was used, a large portion of fresh slurry flowed directly to grooves without participating in polishing. Therefore, relatively less fresh slurry was retained on the pad land area contributing to lower oxide removal rates. In order to further improve slurry availability on the xy-groove pad, the SIS with multi-injection point scheme was tested. Data showed that the SIS with multi-injection point scheme enhanced oxide removal rate further (ranging from 17 to 20 percent) compared to the standard slurry application method. As the SIS with multi-injection point scheme spread more fresh slurry on the pad land area, higher oxide removal rates were achieved.

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