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Preparation and Polishing Properties of Spherical Porous Silica Abrasive

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Abstract: Problem statement: Abrasive is one of key influencing factors on the polished surface quality in Chemical Mechanical Polishing (CMP). Solid abrasives in CMP slurries are easy to cause polishing scratches. It is well known that reducing the hardness of abrasives would improve the polished surface quality. Therefore, the change in structure or shape of the abrasives means a change in polished surface quality. The aim of this research paper is to find the differences of CMP performances on hard disk between solid silica abrasives and porous silica abrasives. **Approach:** A kind of spherical porous silica abrasive was prepared and its CMP performances on hard disk had been investigated. The influences of polishing parameters including polishing time, down force and rotation speed on Material Removal Rate (MRR) and average roughness (Ra) were studied in hard disk substrate CMP with these prepared spherical porous SBA-15 abrasives and solid silica abrasives. **Results:** After polished in slurry containing solid SiO_2, the surface became smooth and Ra decreased from 8.234-1.159 nm. However some small scratches still existed there. When polished with slurry containing spherical porous SBA-15 under the same polishing conditions, the surface became smoother, the scratches could hardly be observed and Ra decreased from 8.409-0.539 nm. **Conclusion:** Compared with solid silica abrasive, the prepared spherical porous silica abrasive has better hard disk substrates CMP performance under the same polishing conditions.

Key words: Chemical Mechanical Polishing (CMP), spherical porous, solid silica abrasives, hard disk substrate, chemical mechanical planarization, polishing properties, experiment process, solid SiO_2, channel structure, rotating speed, Material Removal Rate (MRR)

INTRODUCTION

Chemical mechanical polishing (CMP) has become a more essential surface machining technology in the manufacturing of semiconductor and computer hard disks driver (Lei and Luo, 2004; Lei *et al*., 2006; Qi and Lee, 2010; Zhang *et al*., 2010). In CMP, planarization is achieved by the chemical and mechanical function between the wafer, pad and slurry (Zantye *et al*., 2004; Lee *et al*., 2010; Aksu *et al*., 2003).

Slurries used in CMP usually consist of abrasive, oxidizer, lubricant and so on. In CMP, abrasive is one of key influencing factors on the polished surface quality. In CMP slurries, two types of abrasives are adopted usually: the traditional inorganic particles (silica particles, alumina particles, ceria particles) (Lei and Luo, 2004; Lei *et al*., 2006; 2005; Myoung-Hwan Oh *et al*., 2011) and the composite particles (Chen *et al*., 2011; Lei *et al*., 2008; 2010a; 2010b). But all kinds of abrasives mentioned above are solid particles which are easy to cause polishing scratches. It is well known that reducing the hardness of abrasives would improve the polished surface quality.

In our previous work, wheat-head porous silica abrasive was prepared and its CMP performances were studied. The result showed the wheat-head porous abrasive may have good application prospects in CMP (Liu *et al*., 2010). Compared with compact solid particle abrasive, the hardness of porous particle abrasive is reduced due to the porous structure inside. Moreover, the shape of abrasive can also impact on the CMP performances. In order to further study CMP performances of porous silica abrasives, a kind of spherical porous silica abrasive was prepared in the present paper and its CMP performances on hard disk have been investigated. In addition, we have compared the CMP performances of spherical porous silica abrasive with solid silica abrasive under the same polishing conditions.

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MATERIALS AND METHODS

Preparation of spherical porous silica abrasive and slurry: The synthesis method was based on hydrothermal synthesis method (Zhao *et al*., 1998). Based on the method of preparing wheat-head porous silica (Liu *et al*., 2010) we got spherical porous silica by adding Hexadecyl Trimethyl Ammonium Bromide (CTAB). The experiment process of preparation of spherical porous silica abrasive and Slurry is shown in Fig. 1. A more details description about the experiment process is also referred to Liu *et al*., 2010.

Polishing tests: The polishing conditions and materials of the polishing tests are shown in Table 1. The hard disk substrates were washed with ultrasonic in a detergent after polishing. Finally, they were dried by a multi-functional drying system.

Analyses of the polished surfaces: MRR and Ra have been measured to evaluate the polishing effects in different polishing conditions. The surface topography and Ra were measured by using the surface profiler (Zygo Corp., France). The MRR is determined by the hard disk's weight loss:

$$\text{MRR} = \frac{(M_1 - M_2)}{t} \qquad (1)$$

where, M_1 and M_2 are the mass of hard disk substrates before and after polishing, respectively. t is the polishing time. All mass data are mean value of six times.

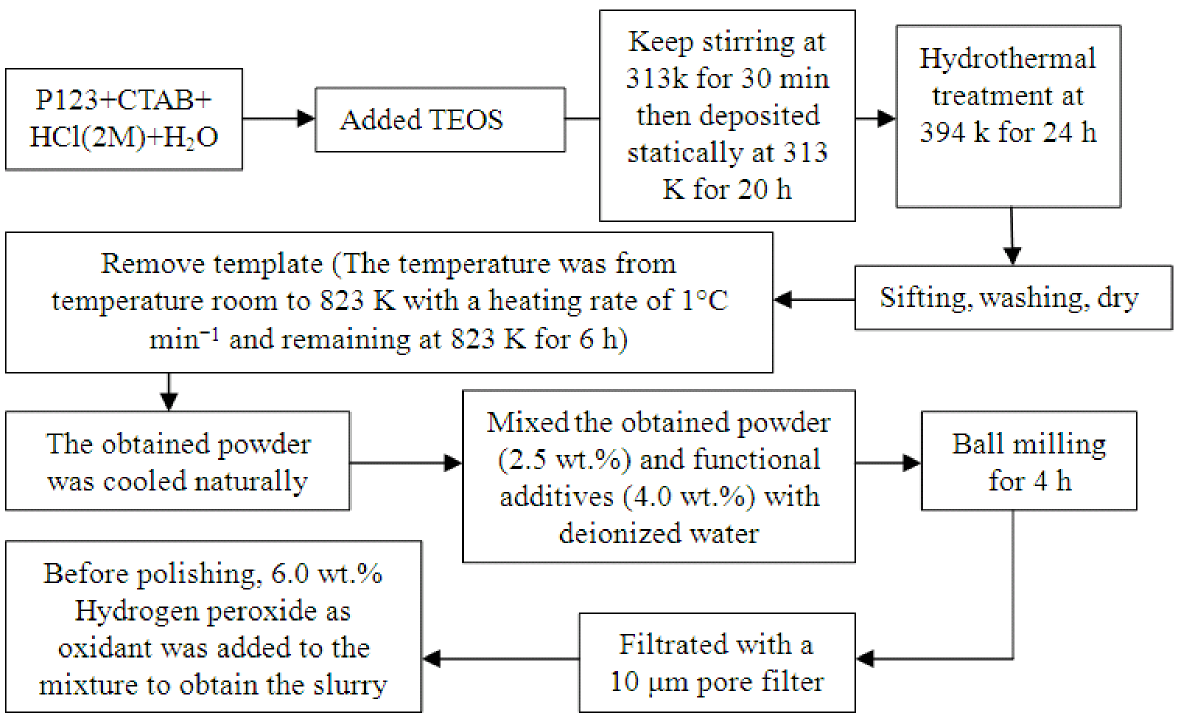


Fig. 1: Experiment process of preparation of spherical porous silica abrasive and Slurry

Table 1: Polishing conditions and materials of polishing tests

Polishing conditions	Slurry supplying rate (900 mL min^{-1})	Down force (1-5 kg)	Rotating speed (20-80 rpm)	Polishing time (5-40 min)
Polishing equipment	UNIPOL-1502 (Shenyang Kejing Instrument, Co. LTD, China)			
Work pieces	Φ 95/1.25 mm aluminum alloy disk substrates with NiP plated (85 wt.% nickel and 15 wt.% phosphorus). Ra is about 10 nm.			
Polishing pad	Rodel porous polyurethane pad			

RESULTS

Characterization of spherical porous SBA-15: In the XRD pattern of spherical porous SBA-15 (Fig. 2), the strong diffraction peak near 1° indicates that the spherical porous SBA-15 has well ordered structure. Transmission Electron Microscopy (TEM) image (Fig. 3a) shows that the spherical porous SBA-15 possesses well-ordered arrays of mesopores (1D channel). Figure 3b shows the SEM image of the spherical porous SBA-15. The diameters of the particles range from 0.5-1.2 µm.

CMP performances of slurry containing spherical porous SBA-15 abrasive: In order to further study of CMP performances of porous silica abrasives, the influences of polishing parameters including polishing time, down force and rotation speed on MRR and Ra were studied in hard disk substrate CMP with these prepared spherical porous SBA-15 abrasives.

As shown in Fig. 4, the MRR of hard disk substrate increases with the increasing of rotating speed, which is attributed to the increasing chance of friction between hard disk substrate, polishing pad and abrasives (Liu *et al*., 2010). Moreover, the Ra value decreases with the increase of the rotating speed which is attributed to the high material removal amount at the high rotating speed. The highest removal rate of 1.91 mg min^{-1} is obtained at 80 rpm but the lowest Ra is obtained at 60 rpm. Therefore, the optimum rotating speed of hard disk substrate CMP is selected about 60 rpm considering both MRR and Ra.

The effects of down force on MRR and Ra of hard disk substrate are shown in Fig. 5. The MRR increases continuously with the increasing of the down force. This may be due to a stronger mechanical grinding effect to impact and grind the substrate surface. With the down force increasing, the Ra decreases gradually and reaches the minimum when the down force is 4 Kg. Fig. 6 shows that Ra of hard disk substrate will decrease with the increasing of polishing time. But the surface average roughness value does not decrease after 20 min of polishing. In other words, polishing time of 20 min is enough for the prepared abrasive. Prolonging the polishing time cannot improve surface quality any more.

In order to compare the polishing performances between slurry containing solid SiO_2 and spherical porous SBA-15, Surface morphology and roughness of hard disk substrate polished in different slurries were analyzed by ZYGO morphology.

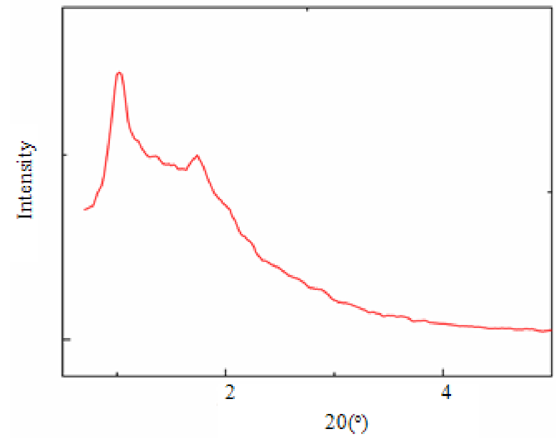
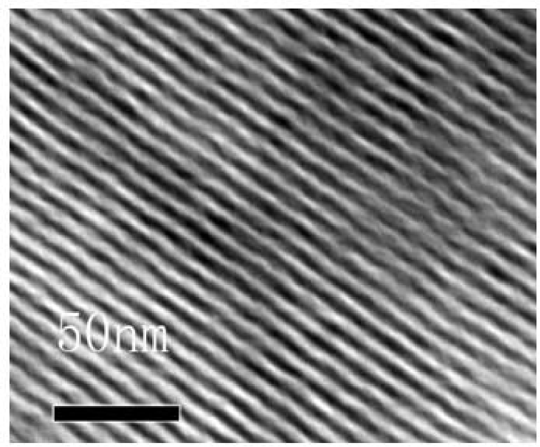
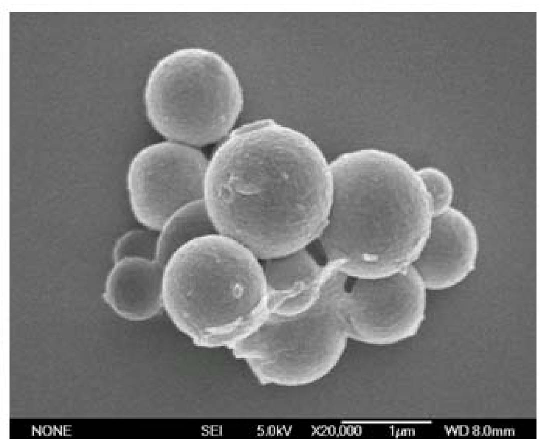


Fig. 2: Powder XRD pattern of spherical porous SBA-15

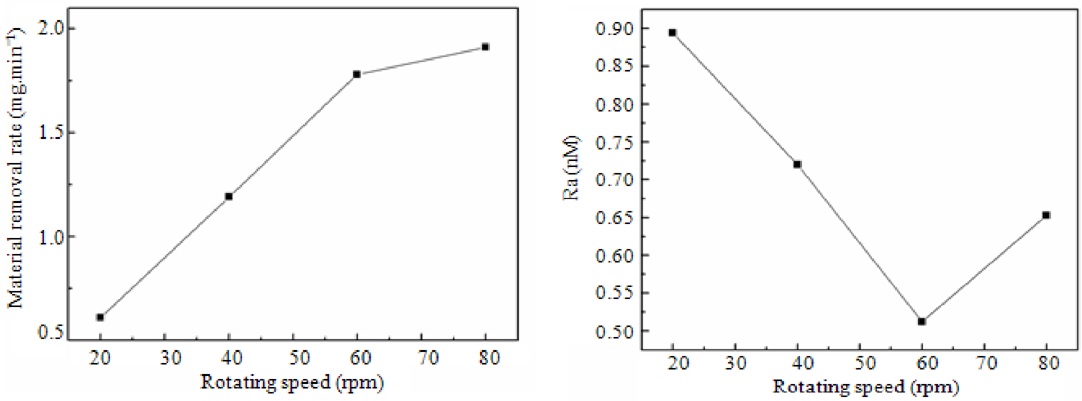


(a)



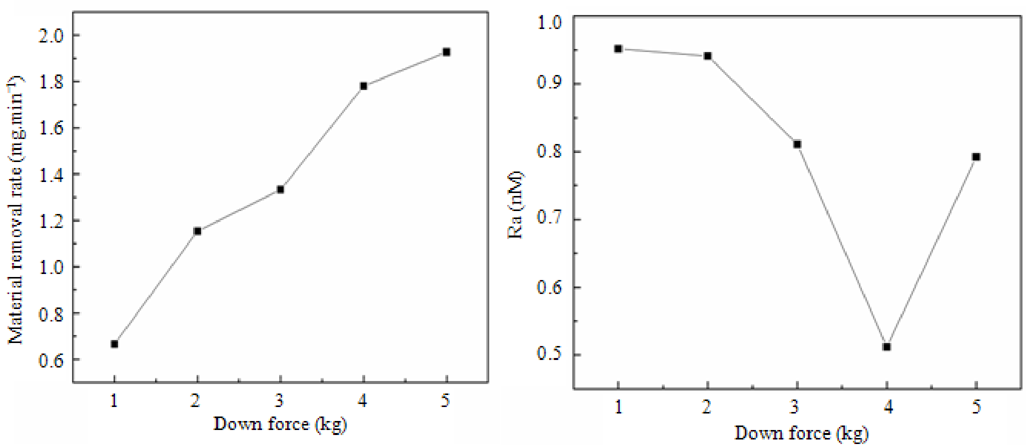
(b)

Fig. 3: TEM image (a) and SEM image (b) of spherical porous SBA-15



(a) (b)

Fig. 4: Effect of rotating speed on (a) MRR and (b) Ra (down force = 4Kg; polishing time =15 min)



(a) (b)

Fig. 5: Effect of down force on (a) MRR and (b) Ra (rotating speed = 60 rpm; polishing time = 15 min)

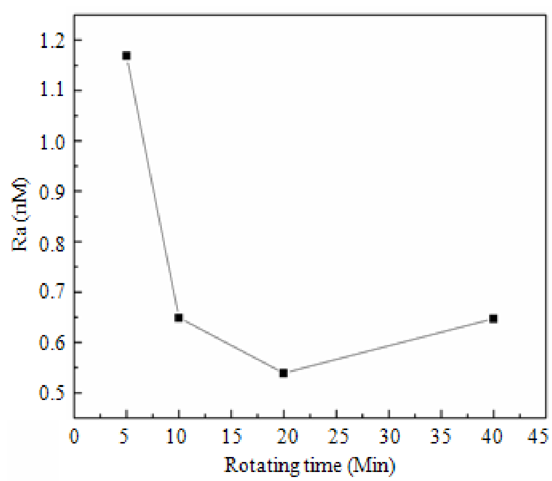
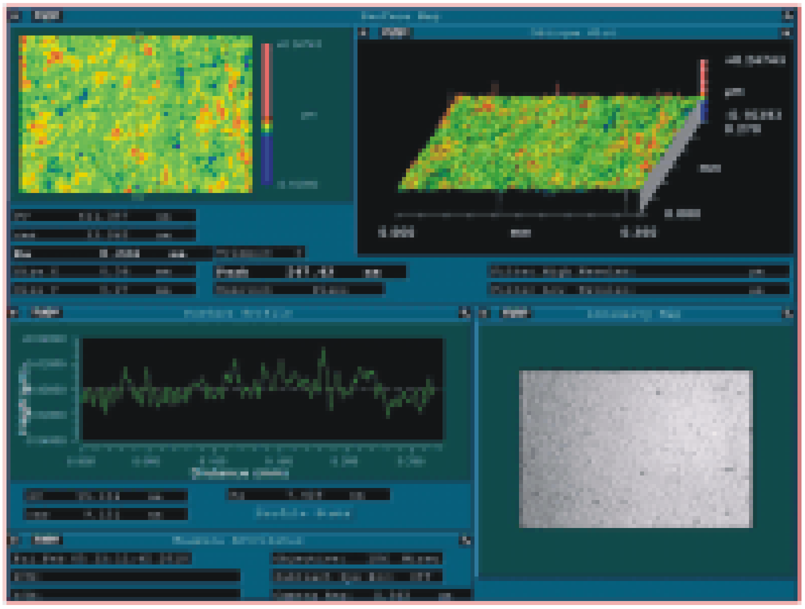
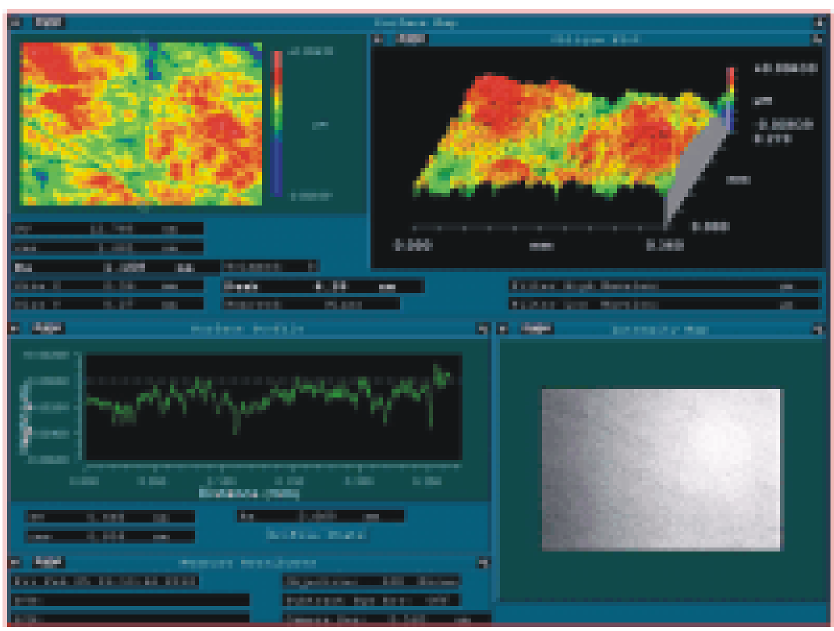


Fig. 6: Effect of Rotating time on Ra (rotating speed = 60 rpm; down force = 4 kg)

As shown in Fig. 7-8, the surface before polishing is very rough with many scratches. After polishing in slurry containing solid SiO_2, the surface became smooth and Ra decreased from 8.234-1.159 nm, but some small scratches still exist there. However, when polished with slurry containing spherical porous SBA-15 under the same polishing conditions, the surface became smoother, the scratches could hardly be observed and Ra decreased from 8.409-0.539 nm.

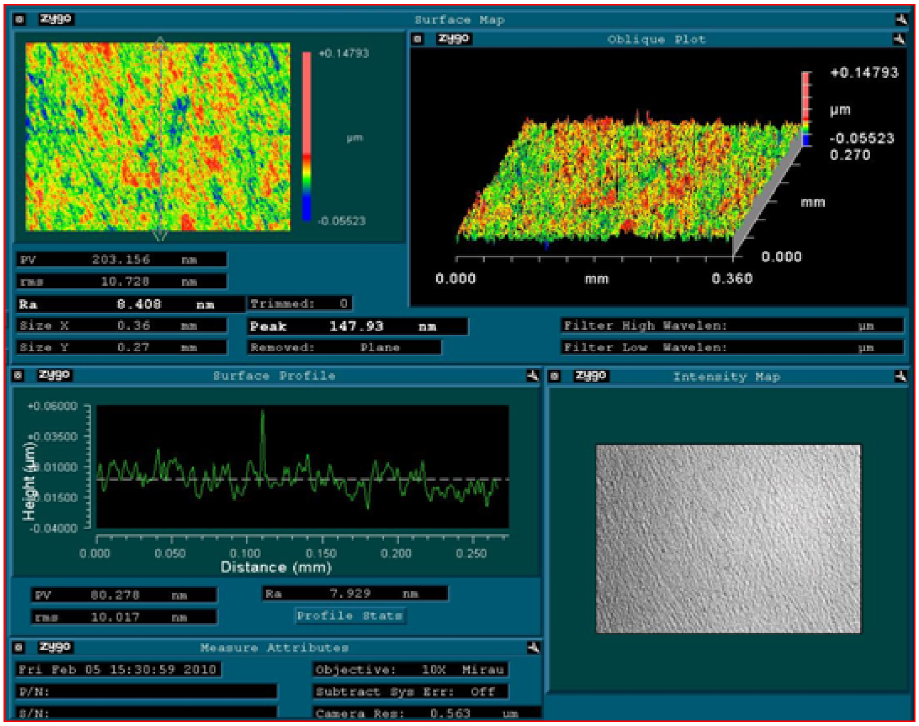


(a)

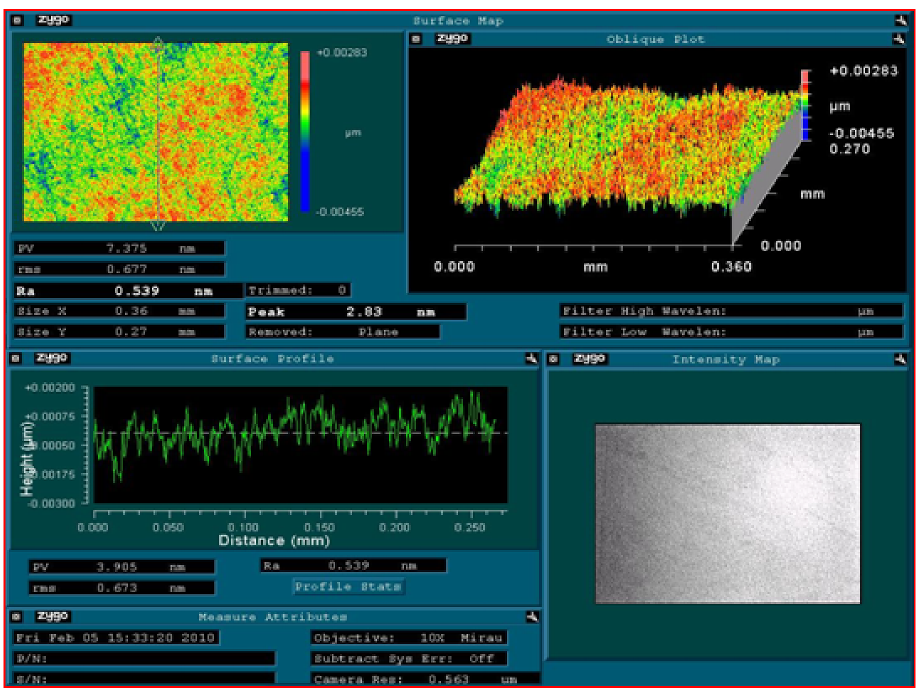


(b)

Fig. 7: Surface morphology and roughness of hard disk substrate (a) before polishing, (b) after polishing in the slurry containing solid SiO_2. (The polishing conditions are the rotating speed of 60 rpm, the down force of 4 kg and the polishing time of 20 min)



(a)



(b)

Fig. 8: Surface morphology and roughness of hard disk substrate (a) before polishing, (b) after polishing in slurry containing spherical porous SBA-15. (The polishing conditions are the rotating speed of 60 rpm, the down force of 4 kg and the polishing time of 20 min)

DISCUSSION

The improvement in CMP performance of spherical porous SBA-15 abrasive comparing with solid silica abrasive may be attributed to their channel structure. With channel structure, the porous SBA-15 abrasives can absorb water and H_2O_2 during CMP polishing, which may improve the chemical performances of slurry. On the other hand, the pore channel structure makes the spherical porous particles susceptible to small deformation. Thus the channel structure can decrease excessive mechanical damage. Therefore the scratching was prevented and surface roughness was reduced.

CONCLUSION

The spherical porous silica abrasive was synthesized based on the hydrothermal synthesis method. Compared with solid silica abrasive, the prepared spherical porous silica abrasive had better aluminum alloy disk substrates CMP performance under the same polishing conditions. Moreover, when enhancing the polishing down force and rotating speed in CMP with porous silica abrasives, Ra of hard disk substrate decreases and MRR increases. And Ra will decrease with the increasing of polishing time and get minimum value after about 20 min. In addition, understanding the differences of CMP performances between spherical porous silica abrasive and wheat-head porous silica abrasive needs more work to be done in the future.

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