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Effect of abrasive particle concentration on preliminary chemical mechanical polishing of glass substrate

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ABSTRACT

Effect of abrasive particle concentration on material removal rate (MRR), MRR per particle and the surface quality in the preliminary chemical mechanical polishing (CMP) of rough glass substrate was investigated. Experimental results showed that the MRR increases linearly with the increase of abrasive concentration and reaches to the maximum when the abrasive concentration is 20 wt.%, and then tends to be stable. When the abrasive concentration increases from 2 to 5 wt.%, the MRR per particle increases greatly and reaches a peak. Then the MRR per particle decreases almost linearly with the increase of the abrasive concentration. The root mean squares (RMS) roughness almost decreases with increasing particle concentration. In addition, in situ coefficient of friction (COF) was also conducted during the polishing process and the zeta potentials of abrasive particles in slurry with different solid concentration were also characterized. Results show that COF value is not related to zeta potential but be sensitive to glass surface conditions in terms of rough peaks in preliminary polishing of glass substrate.
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1. Introduction

With the rapid popularization and improvement of home electronic products such as VCD, DVD, CVD, HDVD, the demand for digital compact disc (CD) is growing at an astounding rate [1]. As the mastering substrate in the manufacturing of optical media, the roughness of glass substrate is the key factor that influences the accuracy of data transferred to the CD and the reused times of glass substrate. Chemical mechanical polishing (CMP) which combines mechanical friction and chemical corrosion, arising from the abrasives and chemical of slurries, respectively, has become an accepted planarization technology in manufacturing of CD glass substrate due to its high surface quality [2–4].

There are up to 16 variables that needed to be controlled to achieve a stable process, and one of the major variables is related to the slurry compositions [4,5]. As the basic element of slurry, i.e., the hardness, sizes, and concentration of abrasive particles are crucial for a desired CMP performance. Choi et al. have investigated the effects of particle concentration on in situ lateral friction force in sapphire CMP process [6]. According to his study, the friction force increases with solid loading. Cooper et al. studied the effects of particle concentration on removal rates in CMP of silicon dioxide and copper [7]. It was found that removal rates increases linearly with the cubic root of particle weigh percent for both dielectric and copper substrates. These results show good agreement with theory in dilute solutions, where the cubic root of weigh percent is roughly proportional to mean separation distance between abrasive particles in the slurry. Subsequently, novel interpretations of CMP removal rate dependence on slurry particle concentration were reported by Tamboli et al. [8]. He found that material removal per particle is a useful parameter in comparing performance of different abrasive concentrations. However, they did not consider the material removal induced by the polishing pad. Lee et al. [9] added the polishing pad effect modifying the equation for calculating the MRR per particle. Wang et al. [10] examined the effect of ceria concentration on CMP of optical glass. It was found that MRR sharply increased from 250 to 675 nm/min as the concentration decreased from 1 to 0.25 wt.%. There have been some studies on the effects of particle concentration on CMP performance, however, no study is involved in glass CMP using silica-based slurry with varying solid concentration.

In this work, we examined the effect of silica particle concentration on MRR and surface quality of glass in preliminary CMP using silica-based slurry with varying solid concentration. In addition,

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Table 1
Process parameters used for glass polishing using CP-4 polisher.

Pad rotation speed (rpm)	100
Wafer rotation speed (rpm)	100
Down force (psi)	5
Slurry feed rate (ml/min)	100
Polishing time (min)	30

in situ coefficient of friction (COF) during the CMP process was conducted.

2. Experimental

Silica sol with 30 wt.% solid concentration was home-made by ourselves. Then the colloid was diluted to different solid contents with de-ionized (DI) water. Two inch pristine Soda Lime glass substrates of constant surface roughness which were widely used in mastering substrates in the optical media were polished using a CMP tester (CETR, CP-4) with a polyurethane (Universal Photonics, LP66) pad. The polishing process parameters used in this study were shown in Table 1. In addition, the CP-4 polisher is designed with the online detector instruments such as acoustic, temperature and coefficient of friction (COF) sensors. The pad was conditioned prior to each polishing for 5 min using a 4 in. diamond grit conditioner. After polishing, the substrate was rinsed in an ultrasonic bath of DI water at pH 9.0.

The silica abrasives were characterized by Hitachi S-4700 field emission scanning electron microscope (FESEM). A ZetaProbe, manufactured by Agilient, was used for examining the zeta potential of silica abrasives in slurry with different concentration. This instrument utilized the electroacoustic effect to determine the zeta potential. One of the great advantages of the electroacoustic procedure is that the determination of the dynamic mobility can be accomplished at almost any particle concentration, up to almost close pack [11]. In addition, pH and conductivity were examined simultaneously using this equipment.

The weight of glass substrate before and after polishing was measured by electron balance to calculate the material removal rate (MRR) according to Eq. (1).

$$MRR = \frac{10^7 \times \Delta m}{\rho \times 2.54^2 \times \pi \times t} \quad (1)$$

Here, $\triangle m$ (g) is weight change after polishing, t (min) is polishing time, ρ is the density of glass substrate, and MRR (nm/min) is the corresponding removal rate.

The polished surface topography and root mean square (RMS) were measured by a Quesant Q-Scope 250 atomic force microscopy (AFM). The AFM operating mode was contacting mode, and scan area was 10 μm × 10 μm.

3. Results and discussion

3.1. Characterization of abrasive particles

Fig. 1 is the SEM images of dried colloidal silica abrasives used in this study which were produced from alkaline silicate precursor through ion-exchange and nuclear growth. It can be seen that the amorphous silica particles are spherical and monodisperse with relatively narrow size distribution of 50 ± 10 nm.

Zeta potential is an important parameter for understanding electrostatic colloidal dispersion stability; it profoundly influences the extent of the electrostatic interactions between the abrasives and the polished substrates. Zeta potential is the charge a particle acquires in a particular medium. It is dependant on the pH, ionic strength and/or concentration of a particular component. Fig. 2 shows the change of zeta potential as a function of abrasive concentration. The original abrasive concentration of slurry is 30 wt.%, the addition of DI water to the slurry decreases the abrasive concentration of the slurry system. As seen in Fig. 2, the magnitude of zeta potential increases sharply with the increasing abrasive concentration.

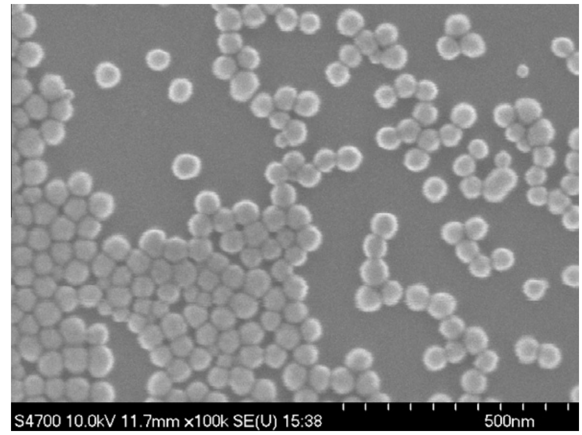

Fig. 1. SEM image of silica particles used in this study.

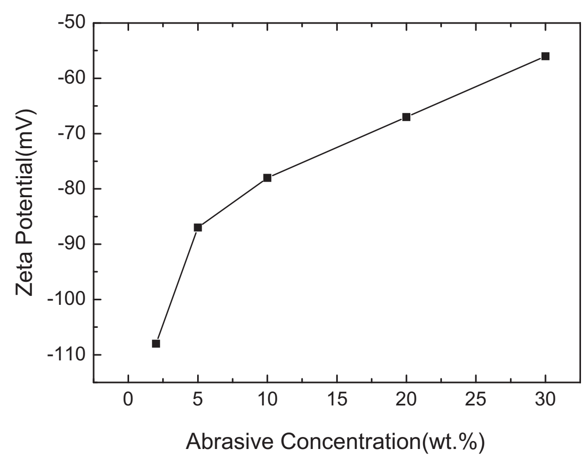

Fig. 2. Zeta potential as a function of abrasive concentration.

In order to investigate the reason for zeta potential changes with particle concentration, the changes of pH value and conductivity during the diluted process were also analyzed. Figs. 3 and 4 show the pH value and conductivity as a function of abrasive concentration, respectively. The pH value decreases slightly during the diluted process, whereas the conductivity declines proportionally. If the abrasive concentration was fixed, decreasing of pH value from 9.5 to 9.1 would reduce the absolute value of zeta potential. Therefore, the increasing absolute value of zeta potential with the decreasing abrasive concentration was resulted in the decrease of conductivity followed by decrease of ionic strength which leads to the expandedness of the electric double layer around the silica particles. Electric double layer expandedness and increase of the particle surface charge make silica particles more stable.

3.2. Effect of abrasive concentration on material removal rates

Fig. 5 depicts the MRR as a function of abrasive concentration. Polish rates for glass substrates appear nearly as a liner function of abrasive concentration up to 20 wt.%. However, there is almost

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