Polishing Glass-ceramic Based Rigid Disk

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Abstract. In this study, experiments were conducted to reveal effects of polishing parameters on surface characteristics and removal rate when polishing glass-ceramic based rigid disk. The parameters studied including rotational speed, applied pressure, and abrasive concentration. Experimental results show that surface roughness, waviness and removal rate could be improved by adjusting the levels of polishing parameters.

Introduction

In disk drive, electroless NiP plated Al-Mg alloys (NiP/Al) and glass-ceramic are two major substrate materials used today. With a higher strength and hardness, glass-ceramic substrate is superior to NiP/Al substrate in high rotational speed. In order to increase the capacity of disk drive, it is required to improve surface characteristics including surface roughness and waviness. The most popular planarization process of substrates is chemical mechanical polishing (CMP). Also CMP is used as an important processing technique for achieving a high degree of planarization for VLSI application \cite{1, 2}. Generally, CMP process could be considered as the process of smoothing and planning aided by the chemical and mechanical forces \cite{3}. With CMP process, a global planarization and an ultra-smooth surface to meet the more strictly requirements can be achieved.

In this study, effects of polishing parameters on surface characteristics as well as material removal rate are experimentally studied when polishing glass-ceramic substrates. The polishing parameters include rotational speed of upper/lower wheel and inner pin ring, applied pressure, and the abrasive concentration. The surface characteristics studied include surface roughness and surface waviness.

Experimental Design and Experimental Set-up

In order to study effects of polishing parameters on surface properties of glass-ceramic substrate in CMP process, a series of experiments were conducted. All the experiments were conducted on the Peter-Wolters Micro Line AC 319 double sides polishing machine. Experiments were conducted with three levels of applied pressure, two levels of upper and lower wheel rotational speed, two levels of inner pin ring rotational speed, and two levels of abrasive concentration. All the two-level parameters were designed with the one-half fraction of the $2^k$ design \cite{4}. Therefore, a $3 \times 2^{3-1}$ fractional factorial experiment was carried out. And all these polishing parameter levels were listed in Table 1. The surface characteristics studied in this study including surface roughness and surface waviness. The effects of polishing parameters on material removal rate were also studied. The surface roughness of specimens was measured using the Tencor P-12 probe profilometer. The scanning length was $200 \, \mu m$, and the scanning directions were all along the radial direction. Surface waviness were estimated by Fast Fourier Transfer from surface data measured using the Optiflat interferometer.
Table 1 Polishing parameters and levels used in experiments

<table>
<thead>
<tr>
<th>Workpiece</th>
<th>Glass-Ceramic substrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polishing machine</td>
<td>Peter-Wolters Micro Line AC 319</td>
</tr>
<tr>
<td>Abrasive</td>
<td>Mitsui MIREK E30</td>
</tr>
<tr>
<td>Applied force (kgw)</td>
<td>60 120 180</td>
</tr>
<tr>
<td>Rotational speed of upper/lower wheel (rpm)</td>
<td>15 30</td>
</tr>
<tr>
<td>Rotational speed of inner pin ring (rpm)</td>
<td>3 6</td>
</tr>
<tr>
<td>Abrasive concentration (g/L)</td>
<td>50 100</td>
</tr>
<tr>
<td>Flow rate of slurry (L/min)</td>
<td>3</td>
</tr>
</tbody>
</table>

The thickness of workpiece was measured by using the Mitutoyo digimatic micrometer with a precision of 1 µm. The difference of the thickness before and after the polishing process was used to estimate the amount of material removed and the removal rate. The vibrations during polishing process were measured by using PCB 339B11 piezoelectric accelerometer. The accelerometer signals were analyzed using FFT to identify the dominant vibration frequency and corresponding amplitude. The glass-ceramic substrate used in this study was P95105-RTP provided by Advanced Disk Technology. The abrasive particles, CeO₂ powders, used in this study were Mirek E30 provided by Mitsui, and the polishing pads were MH-C series provided by Rodel.

Results and Discussion

Material Removal Rate. Figure 1 shows interaction effects of applied load and rotational speed on material removal rate. As shown in the figure, the material removal rate increase as applied load or rotational speed increased. However, the removal rate was not simply proportional to the pressure as it was claim in Preston’s equation [5]. This is also found by others [6-9]. The increase in abrasive concentration also increase material removal rate. In the polishing mechanism of glass-ceramic substrate, effects of abrasive particles on removal rate are not only on the mechanical but also the chemical aspect since the abrasive not only could scrape the surface material of workpiece but also could absorb the ions from the workpiece surface. More abrasive particles in the slurry would increase the efficiency of slurry in removing workpiece surface material, and hence the material removal rate is increased.

![Fig. 1 Interaction effects of applied load and rotation speed on removal rate](image)

Surface Roughness. Figure 2 shows the change in surface roughness as polishing process proceeds. The average surface roughness for each test condition before polishing is ranging from 220 nm to 280
nm. A one to two orders reduction in surface roughness was observed after first 8 minutes. The average surface roughness is now ranging from 1 nm to 38 nm. After 30 minutes, all combinations of test conditions can effectively reduce the average surface roughness to around 1 nm. The average surface roughness for is now ranging from 0.76 nm to 1.13 nm.

![Graph](image1)

**Fig. 2** The variation of surface roughness as polishing process proceed

Figure 3 shows effects of applied load on surface roughness. As shown in the figure the surface roughness with an applied load of 60 kgw is much worse than those with higher applied load after 4 or 8 minutes. For an applied load of 80 or 120 kgw, the surface roughness had reached 1 nm level after an 8 minutes polishing.

![Graph](image2)

**Fig.3** Effects of applied load on surface roughness

Figure 4 shows interaction effects of applied load and abrasive concentration on surface roughness after a 30 min. polishing. As shown in the figure, when applying a higher pressure, surface roughness would become better. According to the studies of Flaitz [10] and Hsu [11], it was found that an increase in applied pressure would result in a better surface roughness when polishing glass or NiP/Al substrate. Shi et. al. states that with a harder workpiece material, the effect of pressure might be similar to that with a softer pad. With a softer polishing pad, an increase in the polishing force applied to the workpiece surface would cause the abrasive particles to embed into the asperities of the pad surface, which may act like an elastically soft spring. With the increase in the applied force, the asperities of softer pad surface would go further into the pad, and the contact area between workpiece and pad was also increased. Therefore, the pressure distribution on workpiece surface would become more uniform. Consequently, polishing with a higher pressure might be helpful for the reduction of surface roughness when a softer polishing pad was used. It is also shown that with a higher abrasive
(CeO$_2$) concentration, a better surface finish can be achieved. The effects of rotational speed are relatively less significant in this case.

![Graph showing interaction effects of applied load and abrasive concentration on surface roughness (after 30 min.)](image)

**Fig. 4** Interaction effects of applied load and abrasive concentration on surface roughness (after 30 min.)

**Surface Waviness.** In this study, surface waviness was estimated by filtering the data of surface form with spatial wavelength range of 0.4 mm ~5.0 mm and making an average of those data within the wavelength range. Fig. 5 shows the change in surface waviness as polishing process proceeds. The average surface waviness for each test condition after 4 minutes polishing is ranging from 1.72 nm to 5.0 nm. A two time reduction in surface waviness was observed in the first 8 minutes. The average surface waviness is now ranging from 1.05 nm to 2.14 nm. A 22 minutes more processing had little improvement in surface waviness. The average surface waviness is now ranging from 1.25 nm to 1.99 nm.

![Graph showing the variation of surface waviness as polishing process proceed](image)

**Fig. 5** The variation of surface waviness as polishing process proceed

Figure 6 shows effects of applied load on surface waviness. As shown in the figure the surface roughness with an applied load of 60 kgw is slightly worse than those with higher applied load after 4 or 8 minutes. The surface waviness is improved gradually when a small load was applied. However, it is of interest to find that when a heavier load is applied, the waviness is improved in the beginning but is degraded slightly at the end.
Figure 7 shows interaction effects of applied load and rotational speed on surface waviness after a 30 min. polishing. As shown in the figure, the surface waviness slightly improved with lower applied load. According to Nakamura’s study [12], surface flatness of the polished surface became more precise as the floating gap between workpiece and pad increased and the instantaneous elastic deformation of the pad decreased. It was assumed that effects on surface waviness were similar to those on flatness. And the increase in applied pressure would result in the decrease in floating gap and the increase in the instantaneous elastic deformation, and hence an increase in waviness. In addition, the increase in applied pressure would decrease the fluidity of the slurry and hence the uniformity of slurry distribution might degrade. The non-uniformity in slurry distribution might be another reason for degrading surface waviness. Therefore, surface waviness increased as the applied pressure increased.

Surface waviness increased as the rotational speed of upper/lower wheel increased. The increase in rotational speed might result in the increase in floating gap and the decrease in the instantaneous elastic deformation, and hence a decrease in waviness. However, the vibrations in polishing process increased drastically as the rotational speed of upper/lower wheel increased. The vibration signals were measured using accelerometer and analyzed using FFT. And the amplitude of the signal around 360 Hz in z-direction were used as an index of vibrations. Vibrations could be another reason that degraded the surface waviness. Besides, the abrasive particles in slurry might be driven rapidly to the outer of the pad due to the high centrifugal force with a high rotational speed. The uniformity in
abrasive particles distribution on the pad might degrade. Therefore, surface waviness increased as the rotational speed increased.

Conclusions
In this study, a series of experiments over a range of polishing parameters have been conducted to study the effect of polishing parameters on surface characteristics as well as material removal rate when polishing glass-ceramic substrate based rigid disk. Some conclusions could be made based on the studies. Surface roughness is mainly affected by the applied pressure. Applying a higher pressure improve surface roughness. An increase in abrasive concentration also improves surface roughness. Surface waviness was mainly affected by the applied pressure and rotational speeds of upper/lower wheel. Besides, the vibrations in polishing process might be another reason that degraded the surface waviness. The applied pressure is a significant parameter that had significant effect on most of surface characteristics and removal rate when considering both of them. However, their levels should be comprised to achieve both the better surface characteristics and higher removal rate.

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