Research on Chemo-Mechanical-Grinding (CMG) of large size silica glass substrate

Takeshi SHIINA¹, Libo ZHOU², Zhongjun QIU³, Takeyuki YAMAMOTO⁴, Jun SHIMIZU⁵, Hiroshi EDA⁶

¹Graduate School of Science and Engineering, Ibaraki University, 06nm922a@hcs.ibaraki.ac.jp

²Department of Intelligent Systems Engineering, Ibaraki University, lbzhou@mx.ibaraki.ac.jp

³VBL, Ibaraki University

⁴Department of Intelligent Systems Engineering, Ibaraki University, ytake@mx.ibaraki.ac.jp

⁵Department of Intelligent Systems Engineering, Ibaraki University, jshimizu@mx.ibaraki.ac.jp

⁶Department of Intelligent Systems Engineering, Ibaraki University, eda@ipc.ibaraki.ac.jp

Abstract:

As finishing techniques for silica glass substrate, the free abrasive processes are able to offer a better surface roughness, but sacrifice profile accuracy. On the other hand, the fixed abrasive process or grinding is known as a promising solution to improve accuracy of profile geometry, but always introduces damaged layer. In order to simultaneously achieve both surface quality and profile accuracy, this research has proposed a novel chemo-mechanical-grinding (CMG) process by effective use of chemical reaction in the grinding process.

Keywords: Chemo-Mechanical-Grinding (CMG), Silica glass, Fixed abrasive process, Finishing technique

1. Introduction

As demand in highly accurate photomask goes up every year, demand for machining accuracy of silica glass substrate increases. It is because surface quality and profile accuracy of photomask influence optical characteristic as transmittance and aberration.

As finishing techniques for silica glass substrate, the free abrasive processes like lapping and polishing are able to offer a better surface roughness when finer abrasive are applied, but sacrifice profile accuracy. On the other hand, the fixed abrasive processes like grinding is known as a promising solution to improve accuracy of profile geometry, but always introduces damaged layer on the surface. In order to simultaneously achieve both surfaces quality and geometry accuracy, authors has developed CMG (Chemo-Mechanical-Grinding) process by effective use of chemical reaction in the grinding process.

This research aims to applying CMG to machining of silica glass substrate, and optimizing the machining conditions that simultaneously achieve surface quality, profile geometry and removal rate.

2. Experimental methodology

Figure 1 shows the grinding machine (NAGASE INTEGREG Co., LTD. KTC-1) used in this research for CMG processing of 6 inch silica glass substrate. The grinding machine incorporates two hydrostatic pressure spindles. The work spindle moves along Z-direction, and the wheel table oscillate along X-direction about 10 mm.

Figure 2 shows two kinds of CMG wheels. Table 1 shows specification of CMG wheel. Type (a) uses the epoxy for bonding material, and wheel geometry is a ring shape. On the other hand, Type (b) uses the phenol for bonding material, and wheel geometry is radial shape.

In experiment on CMG, 6 inch polished silica glass shown in Fig. 3 was ground until the pre-machined surface was completely removed. After grinding, surface roughness, permeability and removal rate were evaluated.

Figure 1: Grinding machine

(a) Epoxy

(b) Phenol

Figure 2: CMG wheels

Figure 3: 6 inch silica glass wafer

Moreover, these results are compared with commercial polished silica glass, and diamond ground silica glass as well.

3. Result of the experiment

3.1 Evaluation of surface quality and aberration

Both sides of 6 inch silica glass are machined by CMG, and surface roughness and permeability were evaluated. Experimental conditions are shown in Table 2. Machining time of one side varied from 20 to 50min. All surfaces of ground silica glasses are mirror finished.

In Fig. 4, (a), (b), and (c) shows the AFM image of machined surface by polishing, CMG and grinding by SD800 diamond wheel respectively. (b) shows a smooth surface almost similar to (a). On the other hand, a clear asperity can be confirmed on the surface of (c). Moreover, surface roughness of CMG is 0.46nm Ra, which is better than that of (a). From these results, it is understood that surface quality of silica glass with CMG is obtained equally or better than that with polishing.

Results of the transmittance and reflectance of machined silica glass is shown in Fig. 5. Lines of CMG and polishing are almost overlapped, and the transmittance of CMG and polishing exceed 92% at visible range (wave length from 400 nm to 700 nm).

From above results, it is able to conclude that both surface quality and transmittance of silica glass machined with CMG are equally or better than those with polishing.

3.2 Optimization of machining conditions

At the beginning of experiment, the removal rate was low though good results had been obtained for surface quality and permeability. Therefore, in order to improve removal rate, the experiment for optimization of machining conditions is performed by using quality engineering.

Table 3 shows the orthogonal array of L_4 used in this experiment. The orthogonal array of L_4 has three two-level factors, and correspondence with machining conditions is shown in Table 4.

According to four kinds of machining conditions shown in this orthogonal table, machining experiments are carried out in 30 minutes respectively, and removal rate and Ra are measured every 10 minutes. Dressing had been done only before machining in each conditions. Mist-coolant is used at C1 (0.1ℓ/min), and normal coolant is supplied at C2 (1.0ℓ/min).

Removal rate is calculated by Eq. (1) from mass reduction before and after CMG which is measured by an electronic balance.

$$\text{Removal Rate } \Delta h = \frac{4 \times \Delta M \times 10^6}{t \times \pi \times d^2 \times \rho} \text{ (nm/min)}$$

$$\begin{cases} \Delta M & : \text{Mass difference (g)} \\ t & : \text{Processing time (min)} \\ d & : \text{Diameter of workpiece (mm)} \\ \rho & : \text{Density of workpiece (g/cm}^3\text{)} \end{cases} \quad (1)$$

Table 1: Wheel specifications

	(a)	(b)
Abrasive	CeO ₂	CeO ₂
Bonding agent	Epoxy	Phenol
Additive	none	Na ₂ CO ₃
Concentration of CeO ₂	56 vol%	40 vol%
Concentration of bonding agent	11 vol%	45 vol%
Concentration of additive	-	15 vol%
Concentration of porousness	33 vol%	-

Table 2: Experimental conditions

Processing pressure	12 kPa
Wheel revolution	300 rpm
Work revolution	50 rpm
Grinding fluid	aqueous sodium hydroxide (pH: 8.5), 0.6 ℓ/min

(a) Polishing
(Ra=0.56 nm)

(b) CMG
(Ra=0.46 nm)

(c) Grinding by SD800
(Ra=72.9 nm)

Figure 4: AFM images

Surface roughness and three dimensional topography were measured with NewView200 interferometer made by Zygo Company. Fig. 6 shows removal rate measured at each machining interval. Condition No.1 shows remarkably high removal rate about 190nm/min, compared with others. Fig. 7 shows Ra measured at each machining interval. In each condition, Ra are around 0.8nm, and varied very little. Condition No.2 shows the minimum value of Ra =0.6nm.

SN ratio at each condition is derived from these responded results y_i and calculated by Eq. (2)

$$\text{SN ratio } \eta = -10 \log \left(\frac{1}{n} \times \sum_{i=1}^n \left(\frac{1}{y_i} \right)^2 \right) \text{ (db)} \quad (2)$$

Higher SN ratio means better condition (higher removal rate) in this case. Table 5 shows calculation result of SN ratio for each condition. No.1 stands out as the optimum condition in among four tested conditions because it shows the maximum SN ratio. Table 6 shows result of effect of each factor from SN ratio. In this table, the level with a large numerical value shows optimum conditions for each factor. Therefore, optimum conditions of removal rate is combination of A:1, B:1, and C:1, and it is corresponding to condition of No.1. Which means that condition of lower rotational speed, higher pressure, and lower flowing quantity is preferable to obtain a high removal rate.

Similarly, SN ratio and effect of factor about Ra show Table 7 and Table 8. In this case, SN ratio is derived by Eq. (3) because lower Ra is better.

$$\text{SN ratio } \eta = -10 \log \left(\frac{1}{n} \times \sum_{i=1}^n y_i^2 \right) \text{ (db)} \quad (3)$$

Higher SN ratio means better condition, or lower Ra in this case. No.2 stands out as the optimum condition among four tested conditions because it shows the maximum SN ratio. The optimum conditions of Ra derived from effect of factor is combination of A:1, B:2, and C:2, and it is corresponding to condition of No.2. Therefore, it is shown that condition of higher pressure, higher rotational speed, and higher flowing quantity is preferable to have a small Ra.

In Fig. 8, (a) and (b) show three dimensional topography of machined surface with polishing and CMG respectively. This is the result after 30 min machining at the condition of No.2

4. Conclusion

This research aims at a highly accurate machining of silica glass by CMG process in order to ensure both high quality and high accuracy. CMG was applied to 6 inch silica glass in this study. The obtained surface quality, profile geometry and removal rate were evaluated. The obtained results are summarized below.

- (1) The grinding experiment by use of CMG processing for 6 inch silica glass is conducted, and machined surface is mirror finished.
- (2) Surface roughness of silica glass machined with

Figure 5: Transmittance and reflectance

Table 3: Orthogonal Table (L_4)

No.	1	2	3
	A	B	C
1	1	1	1
2	1	2	2
3	2	1	2
4	2	2	1

Table 4 Factor and level

Factor	Level	1	2
A Pressure [kPa]		25	5
B Wheel speed [rpm]		100	500
C Coolant flow rate [ℓ /min]		0.1	1.0

Table 5: SN ratio of removal rate

No.	y_1	y_2	y_3	S/N[dB]
1	191	121	83	41
2	30	29	19	28
3	10	9	5	17
4	14	4	7	16

Table 6: Effect of factor on removal rate

Level	A	B	C
1	9	4	3
2	-9	-4	-3

Table 7: SN ratio of Ra

No.	y ₁	y ₂	y ₃	S/N[dB]
1	1.20	0.79	0.78	0
2	0.87	0.63	0.60	3
3	0.79	0.83	0.78	2
4	0.86	0.80	1.01	1

Table 8: Effect of factor on Ra

Level	A	B	C
1	0.1	-0.4	-0.9
2	-0.1	0.4	0.9

CMG is 0.46 nm. It is equal or better than that with polishing.

- (3) The transmittance of silica glass machined with CMG is 92% or more, and it is almost equal to that with polishing.
- (4) Removal rate has been improved to about 0.2 μ m/min by optimizing machining conditions, using the quality engineering. Moreover, it has been understood that machining pressure and flow rate of grinding fluid greatly influence removal rate.

References

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Figure 6: Removal rate

Figure 7: Surface roughness Ra

(a) Polishing (Ra=0.92 nm)

(b) CMG (No.2, 30min) (Ra=0.60 nm)

Figure 8: 3D topography of silica glass