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Experimental Study on Layered Ice Bonded Abrasive Polishing of Glass-ceramics

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Layered ice bonded abrasive tools (LIBAT) is a new kind of one which not only has the ability of lapping and polishing but also has the effect of self-dressing. In this paper, two kinds of layered ice bonded abrasive tools were designed and manufactured. Experimental studies on layered ice bonded abrasive (LIBA) polishing of glass-ceramics were conducted. The results show that the surface topography of glass-ceramics polished by micro α-Al_2O_3-nano α-Al_2O_3 LIBAT is better than that of polished by micro α-Al_2O_3-nano SiO_2 LIBAT. The surface roughness S_a of glass-ceramics polished by the two kinds of LIBAT is at the nanometer scale. The reasons of this phenomenon were analyzed. The experimental results illustrate that the LIBAT shows good effect and can be used in production practice.

Keywords: layered, ice, abrasive, polishing, glass-ceramics.

1. INTRODUCTION

Glass-ceramics are composites consisting of glass and crystalline phases and have become attractive structural materials due to their good mechanical properties, chemical stability at higher temperatures, and tailored microstructures via appropriate heat treatments [1]. In disk drives, glass-ceramic is one of the major substrate materials used. However, glass-ceramic rigid substrates need to have not only very good flatness and low surface roughness but also no surface damage and scratches.

Chemical-mechanical polishing (CMP) is one of the preferred methods that are currently in use for both planarizing and smoothing surfaces [2]. Recently, it is reported that the integrity of machined surface can be improved under low temperature condition [3–5]. Polishing with an ice fixed abrasive polishing (IFAP) pad which was made of colloidal SiO_2, a super smooth surface of silicon wafer had been obtained [6]. The above IFAP pads were all manufactured with single abrasive, such as SiO_2 or α-Al_2O_3. Nevertheless, fewer research studies have been conducted on polishing hard and brittle materials with a layered ice bonded abrasive tool (LIBAT) containing two or more kinds of abrasives.

This paper aims to design and manufacture two kinds of LIBAT according to the self-dressing effect of ice bonded abrasive tool. Experiments were then conducted on LIBA polishing of glass-ceramics.

2. EXPERIMENTAL DETAILS

2.1. Design and preparation of LIBAT

Figure 1 shows the structural diagram of LIBAT. As shown in Fig. 1, the main parts of the LIBAT from top to bottom are as follows: cleaning layer, which was made of frozen deionized water, micro abrasive layer, cleaning layer (transition layer) which was also made of frozen deionized water, nano abrasive layer and thermal resistance layer, respectively.

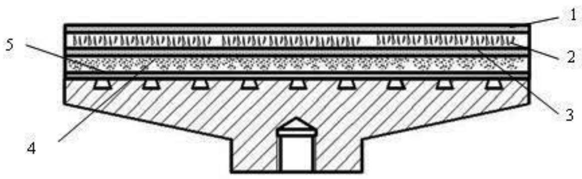

Fig. 1. Structural diagram of LIBAT: 1 – cleaning layer; 2 – micro abrasive layer; 3 – cleaning layer (transition layer); 4 – nano abrasive layer; 5 – thermal resistance layer

During LIBA polishing of glass-ceramics, firstly, the glass-ceramics contacts with the cleaning layer. This layer can clean the surface of glass-ceramics, and this is beneficial to the stability of the following polishing process. After the cleaning layer melting completely, the glass-ceramics can be polished by the micro abrasive layer. During cryogenic polishing, the quantity of heat production which produced by friction between the IFAP pad and the glass-ceramics in the polishing region can lead to the thawing of IFAP pad. With the polishing carries on unceasingly, the abrasives in the superficial coat of the polishing pad can be pulled off and the new ones can emerge continuously, this is called self-dressing process. Then, the glass-ceramics contacts with the cleaning layer(transition layer), which lies between the micro abrasive layer and the nano abrasive layer. The main function of this layer is to clean the remaining micro particles attached to the surface of glass-ceramics after being polished by micro abrasive layer. Finally, the glass-ceramics will be ultra-precision polished by nano abrasive layer until the wafer can meet the quality requirements. In addition to the above layers, at the bottom of LIBAT is the thermal resistance layer, which can decrease heat exchange

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between LIBAT and outside environment and increase service life of LIBAT.

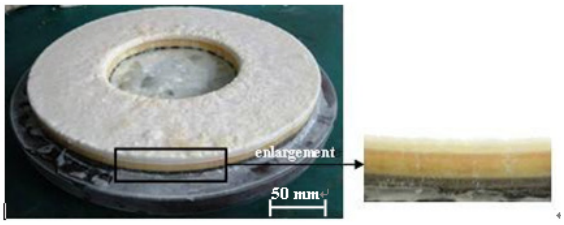


Fig. 2. Photograph of LIBAT

In this paper, two kinds of LIBAT were manufactured, which are micro α-Al_2O_3-nano SiO_2 LIBAT and micro α-Al_2O_3-nano α-Al_2O_3 LIBAT, respectively. The average particle size of micro α-Al_2O_3 of both LIBAT is 2 μm, and that of nano SiO_2 and nano α-Al_2O_3 are all 20 nm. The photograph of LIBAT is shown in Fig. 2.

2.2. LIBA polishing setup

Figure 3 shows the schematic diagram of LIBA polishing apparatus. The LIBA polishing experiments were conducted at the ambient temperature of 0 ºC. Glass-ceramics wafers of 2 inches in diameter were chosen in the experiments. For the sake of ensuring uniform contact between the wafer and LIBAT during LIBA polishing, the polishing pressure was provided by a cylinder. Eccentricity is the distance between the center of the spindle and that of the object carrier. In this article, the eccentricity was measured by using a vernier caliper.

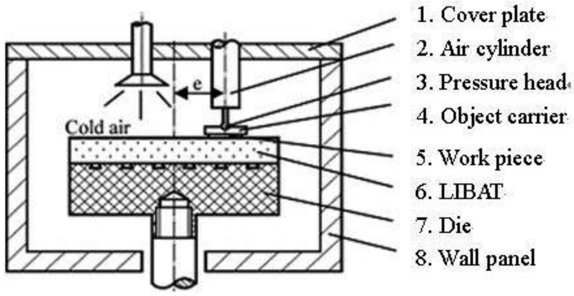


Fig. 3. Schematic diagram of IBA polishing apparatus

2.3. LIBA polishing process

LIBA polishing parameters used in this study can be seen in Table 1. The parameters polished with micro layer are different from that polished with nano layer for both LIBAT. Each set of experiments was repeated 3 times and taken its mean as experimental results. S_a was measured by non-tactile MicroXAM surface profiler (ADE). Here, the average parameter S_a is defined as the arithmetic mean of the absolute value of the height within a sampling area.

Table 1. LIBA polishing parameters used in this study

Polishing parameters		Type of LIBAT	
		micro α-Al_2O_3-nano SiO_2 (1#)	micro α-Al_2O_3-nano α-Al_2O_3 (2#)
Eccentricity (mm)		75	
Micro layer	Polishing pressure (MPa)	0.025	
	Speed of mainshaft ($r \cdot min^{-1}$)	100	
	Polishing time (min)	90	
Nano layer	Polishing pressure (MPa)	0.05	
	Speed of mainshaft ($r \cdot min^{-1}$)	200	
	Polishing time (min)	30	

3. RESULTS AND DISCUSSION

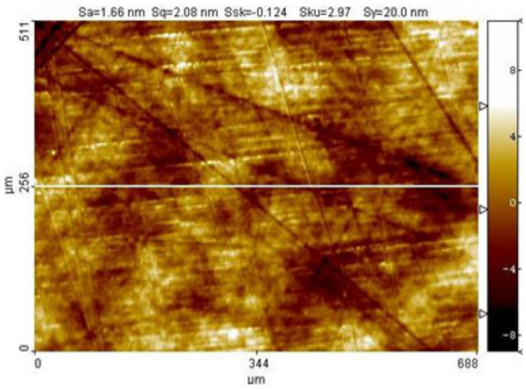
Table 2 shows the surface roughness S_a of glass-ceramics polished by two different LIBAT. As shown in Table 2, the average surface roughness of glass-ceramics polished by micro α-Al_2O_3-nano α-SiO_2 LIBAT is 1.70 nm, while that polished by micro α-Al_2O_3-nano α-Al_2O_3 LIBAT is 1.005 nm.

Table 2. Test results comparison of different LIBAT

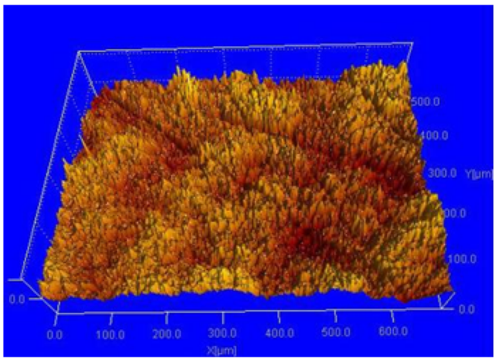
Group number	S_{a1} (nm)	S_{a2} (nm)	S_{a3} (nm)	$\overline{S_a}$ (nm)	Sum of squares of deviations
1#	1.66	1.69	1.76	1.70	0.0117
2#	0.982	0.942	1.09	1.005	0.0053

The surface topography of glass-ceramics polished by micro α-Al_2O_3-nano SiO_2 LIBAT and micro α-Al_2O_3-nano α-Al_2O_3 LIBAT is shown in Fig. 4 and Fig. 5 respectively. As can be seen from Fig. 4 and Fig. 5, the surface topography of glass-ceramics polished by two LIBAT is different. There are some obvious scratches on the surface of glass-ceramics polished by micro α-Al_2O_3-nano SiO_2 LIBAT(see Fig.4) while that polished by micro α-Al_2O_3-nano α-Al_2O_3 LIBAT has a bit of surface undulation without scratches(see Fig. 5). As for the surface roughness, the value (S_a = 1.66 nm) of glass-ceramics polished by micro α-Al_2O_3-nano α-SiO_2 LIBAT is greater than that (S_a = 1.09 nm) of polished by micro α-Al_2O_3-nano α-Al_2O_3 LIBAT, and both of them are all at the nanometer scale.

From the above analysis, we can conclude that the surface topography of glass-ceramics polished by micro α-Al_2O_3-nano α-Al_2O_3 LIBAT is better than that of polished by micro α-Al_2O_3-nano SiO_2 LIBAT. The reasons are as follows: Because the nano SiO_2 slurry is colloidal solution, the dispersion degree of particles becomes worse with the decreasing of temperature. During the preparation of LIBAT, the colloidal nano SiO_2 could flocculate and agglomerate. In the end, some bulky grains appeared, and this can lead up to the amount of effective abrasives in LIBAT decreasing and the hardness of colloidal nano SiO_2 increasing. Sun et al [7] found that with the increasing of the amount of the active abrasives, the motion tracks of multiple abrasives became more and more uniform, so it is more beneficial to IFA uniform polishing, and the more the

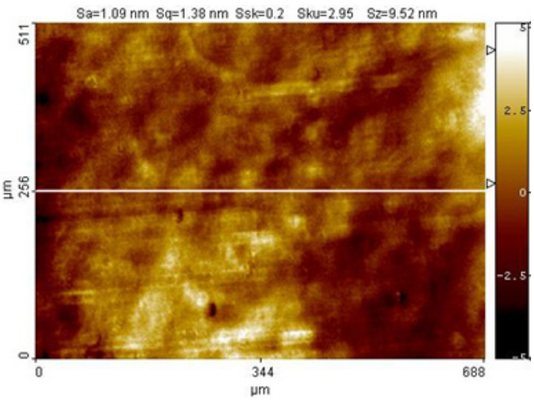


a



b

Fig. 4. Surface topography polished by micro α-Al_2O_3-nano SiO_2 LIBAT: a – two-dimensional morphology; b – three-dimensional morphology



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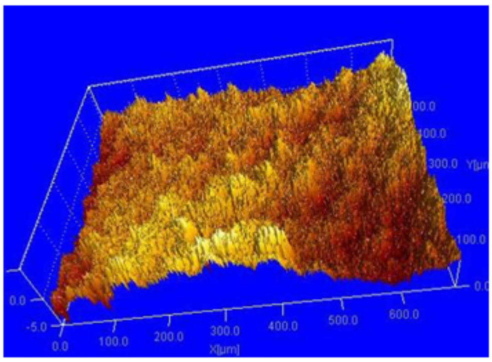

b

Fig. 5. Surface topography polished by micro α-Al_2O_3-nano α-Al_2O_3 LIBAT: a – two-dimensional morphology; b – three-dimensional morphology

active abrasives, the higher the polishing efficiency. Therefore, though the hardness of α-Al_2O_3 is higher than that of SiO_2, the polishing quality of glass-ceramics polished by micro α-Al_2O_3-nano α-Al_2O_3 LIBAT is better than that polished by micro α-Al_2O_3-nano SiO_2 LIBAT.

4. CONCLUSIONS

Within the limitations of the present study, the following conclusions can be drawn.

(1) According to the self-dressing effect of ice bonded abrasive tool, two kinds of LIBAT were designed and manufactured. This can integrate different polishing processes into one production line, decrease manufacturing cost, improve machining efficiency, and reduce polishing time.

(2) The surface topography of glass-ceramics polished by micro α-Al_2O_3-nano α-Al_2O_3 LIBAT is better than that of polished by micro α-Al_2O_3-nano SiO_2 LIBAT. The surface roughness S_a of glass-ceramics polished by the two kinds of LIBAT is all at the nanometer scale.

Acknowledgments

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REFERENCES

1. **Lambropoulos, J. C., Jacobs, S. D., Gillman, B. E.** Deterministic Microgrinding, Lapping, and Polishing of Glass-ceramics *Journal of the American Ceramic Society* 88 (5) 2005: pp. 1127 – 1132.
2. **Wang, C. C., Lin, S. C., Hochen, H.** A Material Removal Model for Polishing Glass-ceramic and Aluminum Magnesium Storage Disks *International Journal of Machine Tools & Manufacture* 42 2002: pp. 979 – 984.
3. **Liu, X. Y., Wang, L. J., Gao, C. F., Wu, X. S., Liu, W. N.** Experimental Study on Cryogenic Polishing Optical Material without Abrasive *Chinese Journal of Mechanical Engineering* 38 (6) 2002: pp. 47 – 50.
4. **Sun, Y. L., Zuo, D. W., Zhu, Y. W.** Surface Formation of Single Silicon Wafer Polished with Nano-sized Al_2O_3 Powders *Chinese Journal of Chemical Physics* 20 (6) 2007: pp. 634 – 648.
5. **Sun, Y. L., Zuo, D. W., Zhu, Y. W., Li, J.** Using Taguchi Method to Optimize Polishing Parameters in Ice Fixed Abrasive Polishing *Materials and Manufacturing Processes* 28 2013: pp. 923 – 927.
6. **Han, R. J., Sun, H. D., Xu, D. Q.** Cryogenic Polishing Technology of Monocrystalline Silicon Wafer *Optics and Precision Engineering* 6 (5) 1998: pp. 104 – 109.
7. **Sun, Y. L., Zuo, D. W., Li, J., Lu, W. Z., Yu, Z. Z.** Computer Simulation on the Motion Tracks of Ice Fixed Abrasives Polishing *Key Engineering Materials* 426 – 427 2010: pp. 376 – 380.