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Study on high precision measurement of chemical mechanical polishing removal rate of YAG crystal

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Abstract

Chemical mechanical polishing (CMP) is the key processing method for obtaining smooth and flat surface of Yttrium aluminum garnet(YAG) crystal. The material removal rate is an important factor to evaluate the polishing efficiency of YAG crystal. Therefore, the measurement of material removal rate is of great significance for the research of CMP of YAG crystal. Aiming at the low measurement accuracy of material removal rate by traditional weighing method, a high-precision measurement method is proposed based on coherence scanning interferometry principle. By measuring changes of micro-scale scratches depths before and after CMP of YAG crystal, the material removal rate measurement of the YAG crystal is carried out. Through the surface treatment of YAG crystal and measurement tests, the experiment results demonstrate that the measurement accuracy and repeat error of removal rate are good enough. The results of the proposed material removal rate evaluation of YAG crystal are closer to the real situation. Therefore, the research in this paper provides an effective measurement method and basis for the research of YAG crystal CMP process.

Key words: YAG, chemical mechanical polishing, removal rate, measurement, scratch method

1. Introduction

With the continuous development of society, laser plays an important role in the fields of manufacturing, medical treatment and national defense[1, 2]. Yttrium aluminum garnet (YAG) crystal is the most comprehensive laser gain medium at present, and its surface and subsurface quality directly affect the performance of the laser. The process of YAG crystals mainly by chemical polishing and Chemical mechanical polishing (CMP) . Some scholars have chemically polished yttrium aluminum garnet by high concentration of phosphoric acid under high temperature conditions, but this method is prone to corrosion pits and damage to equipment and environment[3, 4]. CMP is the only ultra-precision machining method that can achieve global flattening, and is widely used in the final processing of YAG crystal manufacturing[5, 6]. CMP is a process with the removal rate of nano-scale, whose schematic is shown as figure 1. Through the relative movement of the workpiece and the polishing plate, the material is removed under the synergistic effect of the abrasive and the polishing slurry. Because of its extremely low material removal rate, the measurement becomes difficult. At present, the material removal rate of CMP is mainly measured by the weighing method. The weighing method should be subjected to multiple times of loading and cleaning, consequently the material removal rates is uneven, and the measurement is cumbersome and the accuracy of the balance must be high. What's more, the measurement is easy to fail result from the poor processing environment and YAG crystals are fragile. Through the process exploration, using the dicing saw to draw some scratches on the surface of the wafer, and then compare the depths of scratches before and after polishing to characterize material removal rate. The experiment show that measurement accuracy and repeat error of removal rate are good enough.

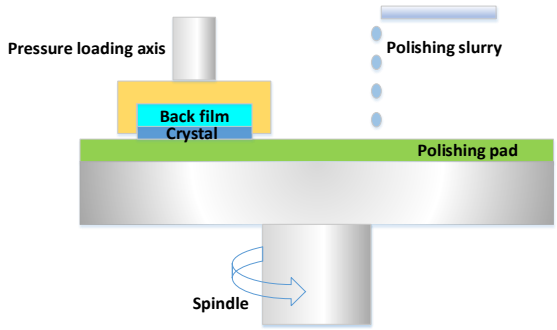


Figure 1 Schematic diagram of chemical and mechanical polishing

2. Material and methods

In this paper, some scratches are drawn on the surface of the YAG wafer by using a dicing saw, and the initial depths of the scratches are 30-50 µm. The three pieces of YAG crystals are ground until getting a globally uniform surface, then remove the upper edge damage of scratches by CMP with silica sol. The material removal rate was calculated by measuring the depth changes of scratches before and after polishing. The YAG crystals are from Shanghai Blue Crystal Technology Co., Ltd, China, with diameter of 15 mm and thickness of 2 mm. The YAG crystals are processed by Automatic polishing machine (UNIPOL-1200S, Shenyang Kejing Auto Equipment Co., Ltd.). Grinding is applied on a 3M 673LAA10 pad as a fixed abrasive pad. Then YAG crystals are grinded by 1 µm Alumina abrasives on a Polyurethane polishing pad. Finally YAG crystals are polished on a IC1000 pad by 80 nm Silica sol for 60 min. The process parameters are as table 1. The scratches depths measurement was performed using a ZYGO surface profiler(Newview5022).

Table 1 The parameter of grinding and polishing processes

Processes	Speed of plate (r/min)	slurry	Pressure (Mpa)
Grinding	30	DI water	0.02
Fine grinding	50	5% Alumina solution	0.03
polishing	60	10% Silica solution	0.03

The traditional weighing method requires separate measurement of the weight of the crystals before and after polishing, and does not allow the introduction of impurities strictly. Therefore, the workpiece needs to be unloaded and cleaned for each measurement. As shown in figure 2, when the wax is used to bond the workpiece, the distribution of the wax layer is ununiform. The height of all the crystals is different in the initial state. Consequently the pressure distribution is uneven during the polishing process. The final measurement result is the average removal rate of the crystal. Because the initial height of different crystals is hard to be controlled, the polishing removal rate obtained may vary greatly, the polishing removal rate at a short time measured by the weighing method cannot reflects the actual polishing removal rate. The scratch method enables uniform removal of all crystals because it is easy for in-situ measurement, it's beneficial to achieve even material removal rate after getting a flat surface by pre-processing. Therefore it can truly reflect the actual polishing removal rate.

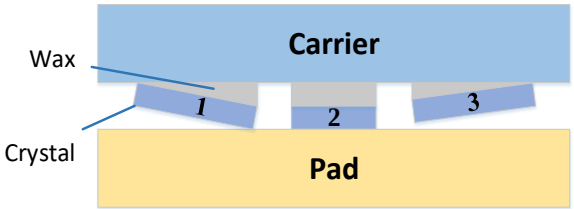
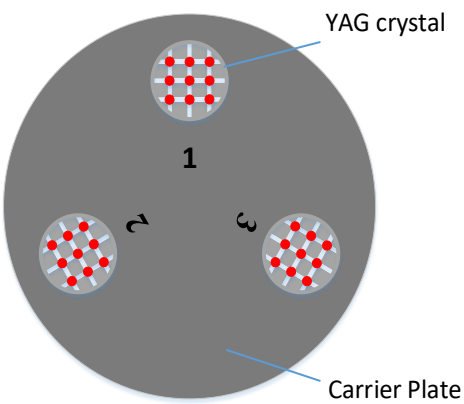


Figure 2 Actual process of uneven material removal

In this CMP processing, three pieces of YAG crystals were symmetrically bonded to the carrier, as shown in figure 3a . In order to study the accuracy of the CMP removal rate of YAG measured by scratch method, this paper calculates the local material removal rate of YAG crystal after polishing. With the purpose of avoiding the effects of uneven material removal, nine positions evenly distributed on wafers were chosen to reflect the overall material removal rate of YAG crystals. Then compare the results with weighing method using a precision balance. The scratches and measurement points distributions are shown in the figure 3b.



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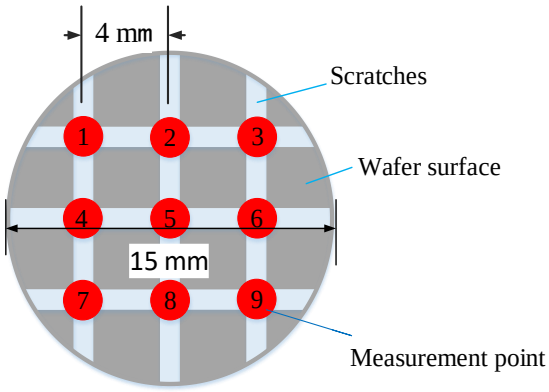


b

Figure 3 The distribution of crystals and measurement points (a) the clamping method of crystals (b) the distribution of measurement points

3. Result and discussion

In order to improve the accuracy of measurement, it's essential to guarantee a good surface quality of the bottom morphology of the scratch. As shown in the figure 4, the bottom morphology of the scratch was observed by scanning electron microscopy. The bottom of scratch has no collapse and pit, therefore scratching through the dicing saw is an ideal way.

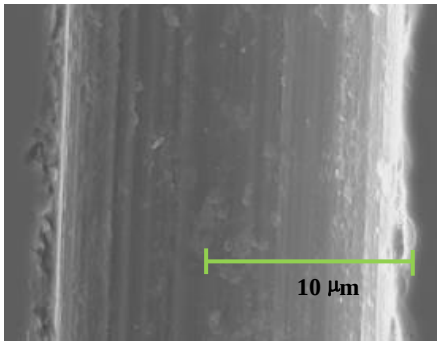
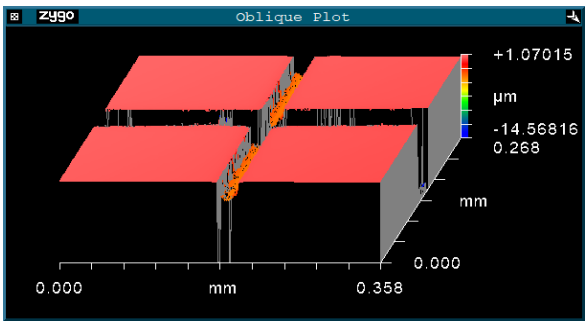


Figure 4 The bottom morphology of scratch

The polishing removal rate was measured by scratch method on nine points using ZYGO surface profiler. As shown in figure 5a, the scratch depth can be got by measuring the distance between upper surface and lower surface. In figure 5b, it can be seen that the bottom of the scratch has been relatively flat after removing damage using silica sol , which is beneficial to the measurement of the scratches depths.



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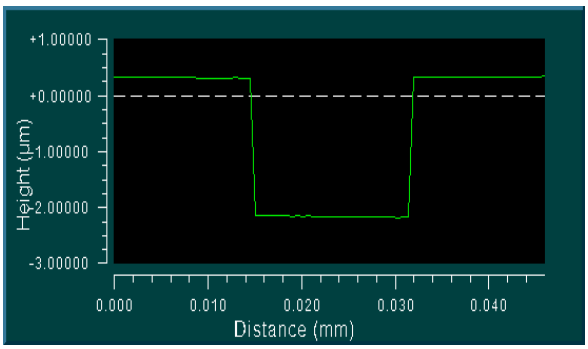

b

Figure 5 The measurement of material removal rate (a) the stereogram of scrstches (b) the measurement of the scratch depth

The material removal height is shown in table 2. In order to reduce error, the material removal of nine points were measured at 60 min on the same wafer. The material removal on the position of nine points are fitted by matlab in figure 6. Because the wax layer is unevenly distributed after the loading, the surface of the sample is inclined, and the higher part is in contact with the polishing pad first, therefore the polishing removal is ununiform.

Table 2 The removal height in different position (nm)

Point	1	2	3	4	5
Removal height	440	586	735	423	577
Point	6	7	8	9	
Removal height	700	435	591	727	

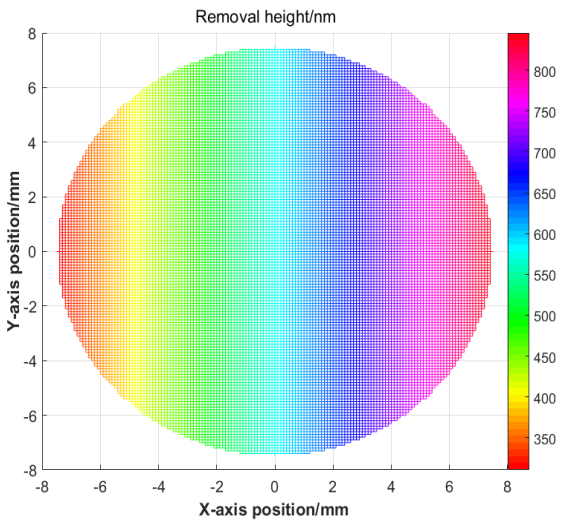

Figure 6 Distribution of material removal height

In order to test the accuracy of the scratch method, the removal volume is fitted by Matlab, and the removal weight of a YAG crystal was 0.46 mg/h. The fitting calculation process is as formula (1), (2) and (3). After integral of the removal height, we can obtain a removal volume is $1.022 \times 10^{-4}\ cm^3$.

$$V = \int h\, dxdy \quad (1)$$

$$v = 1000\rho V/t \quad (2)$$

ρ is the density of YAG crystals, $\rho = 4.55\ g/cm^3$, and t is polishing time, t = 60 min, V is the total removal volume, h is removal height during polishing processing, v is the material removal rate per time unit.

$$v = 0.46\ mg/h \quad (3)$$

The precision removal rate of the crystal after the same polishing was measured by a precision electronic balance with an accuracy of 0.01 mg, and the average polishing removal rate was 0.49 mg/h, which is close to the removal rate measured by the above scratch method. It demonstrates that the scratch method has a high measurement accuracy.

In order to get the repeat error of scratch method measurement, YAG crystals were polished to a global flattening surface, then polished by Silica Solution for one hour to measure the material removal rate. The material removal rate of polishing was measured twenty four times at the same crystal, which was calculated by taken the total material removal rate by fitting. The removal rate frequency distribution was as figure 7.

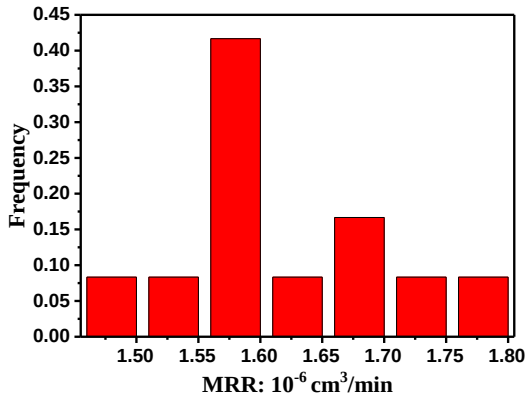

Figure 7 Frequency distribution of removal rate

It can be seen that after one hour polishing, the repeat error of removal rate measured by scratch method is about 3×10^{-7} cm^3/min, and most material removal rate is concentrated at 1.55-1.60 $\times10^{-6}$ cm^3/min, and satisfies most requirements about measurement accuracy of YAG crystals. This results demonstrate that using scratch method to measure polishing material removal rate of YAG is accessible and convenient.

4. Conclusion

In this paper, aiming at the large error and cumbersome work in weighing method measurement, through the process exploration and experimental data analysis, a high-precision measurement method for the CMP removal rate of YAG crystals is proposed. The analysis of accuracy and repeat error measured by scratch method were carried out, which shows the accuracy is high enough, and repeat error is about 3×10^{-7} cm^3/min. It provides guidance on the optimization of polishing slurry and polishing process of YAG crystals.

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