euspen's 19th International Conference & Exhibition, Bilbao, ES, June 2019
www.euspen.eu

Investigation on surface/subsurface damage mechanism in yttrium aluminum garnet crystal lapping and polishing

Qing Mu[1], Zhuji Jin[1], Renke Kang[1], Xianglong Zhu*[1], Xiaolong Han[1], Zili Zhang[1]

[1] *Key Laboratory for Precision and Non-traditional Machining Technology of Ministry of Education, Dalian University of Technology, Dalian, China*

superqing@mail.dlut.edu.cn

Abstract

The surface/subsurface damage of yttrium aluminum garnet (YAG) crystal is inevitable in lapping and polishing. The effects of fixed-abrasive lapping and polishing on the surface topography, surface/subsurface damage characteristics and material removal mechanism of YAG crystal are investigated. The experimental results show that the material is in brittle removal mode when the surface is lapped by fix abrasive and polished by 7µm and 5µm alumina, while the material is in ductile removal mode when the surface is polished by 2.5µm, 0.3µm alumina and silica sol. In the brittle removal mode, obvious pits and scratches are on the surface and the subsurface damage is serious. But in the ductile removal mode, the surface is smooth and the subsurface damage is shallow.

Key words: YAG crystal; lapping and polishing; surface/subsurface damage

1. Introduction

Yttrium aluminum garnet ($Y_3Al_5O_{12}$, YAG) crystal is one of important laser crystals, and it has been widely used in the manufacture of solid-state lasers due to its stable chemical properties, high hardness and easy doping. As the performance of solid-state lasers develops rapidly, the requirements on surface/subsurface quality of YAG crystal are increasing. However, surface/subsurface damage is inevitable in ultra-precision processing, which will seriously affect laser quality, laser threshold and so on. Thus, it is of great importance to explore the surface/subsurface damage characteristics and removal mechanism in lapping and polishing.

J.Mc Kay[1] presented a selective removal mechanism of YAG in CMP and acquired a smooth surface, whose roughness is below 0.5nm. Li et al.[2] investigated the subsurface deformation mechanism of GGG crystal by the method of varied-depth nanoscratching, which proposed that as the normal force increases, cracks generate and propagate. Ross D et al. [3] carried out experiments for polishing YAG ceramic, which found that the size of abrasive influences the material removal at the grain boundaries and the quality of the polished surface. Although many research have been carried out on lapping and polishing of hard and brittle materials, including silicon, glass-ceramics and etc., the research of YAG crystal is not enough.

Based on the considerations above, this paper mainly explores the surface/subsurface damage characteristics and removal mechanism by experiments.

2. Experimental devices and conditions

The experiment is carried out on the Automatic polishing machine(UNIPOL-1200S, Shenyang Kejing Auto Equipment Co., Ltd.). The workpiece is YAG crystal, whose size is ϕ15 × 1mm, and the machined surface is (111) plane. After lapping and polishing, the surface roughness is measured by the white light interferometer (Newview5022, ZYGO), and the topography of surface is observed by SEM (Q45, FEI).The depth of the subsurface damage (SSD) is observed by angle polishing microscopy, whose principle is shown in Fig. 1., and it can be calucated according to:

$$H_d = L \sin \beta \tag{1}$$

Where H_d is the actual depth of SSD, L is the measured depth in angle polishing microscopy, and β is the angle of the section. In this paper, the β is 5.7°, and H_d can be magnified ten times.

A 10µm-fixed-diamond-abrasive pad is used in lapping. The pad used in polishing is a polyurethane polishing pad. The slurries in mechanical polishing consist of different size alumina abrasive, with the diameters of 7µm, 5µm, 2.5µm and 0.3µm, whose concentration is 6%. In addition, the slurry in CMP is commercially available 70nm SiO_2 suspension in a NaOH solution (pH 9.9).[1] Parameters in lapping and polishing is shown in Table 1.

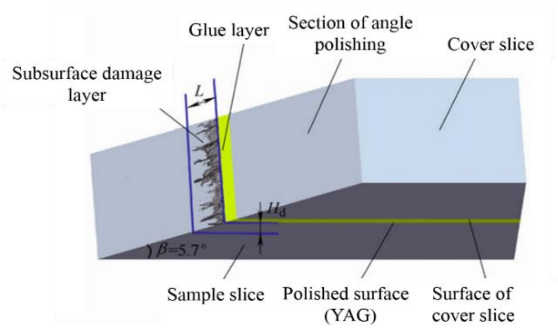

Figure 1. Principle of angle polishing microscopy

Table 1. Parameters in lapping and polishing

Parameter	Value
Pressure/ *kPa*	25
Speed / *r/min*	60
Flow rate of slurry / *ml/min*	3

3. Results and discussions

3.1. Surface damage of YAG crystal in lapping and polishing

The evolution of surface average roughness is shown in Fig.2. It shows that as the size of abrasive decreasing, the roughness decreases obviously. The roughness decreases to 67nm from 148nm when the surface is polished by 5µm alumina abrasives. The roughness greatly decreases to 0.95nm when the diameter of the abrasive is 2.5µm. The roughness changes slowly and gradually stabilizes under 0.5nm, as the size of abrasive decreases further.

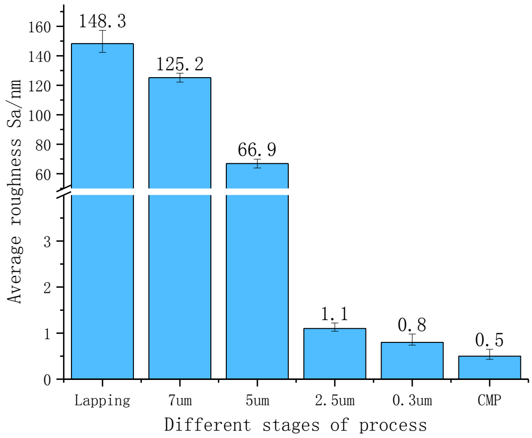

Figure 2. The evolution of roughness in different stages of process

The topographies of surface in lapping and polishing are shown in Fig.3. As shown in Fig.3(a), (b) and (c), the surface has obvious characteristics of brittle removal mode, which is damaged seriously and consists of a large number of pits and cracks. Due to the interaction between the abrasive and the surface under pressure, the surface generates transverse and radial microcracks. When the microcracks gradually expand and close, the material falls off and the surface forms pits. As shown in Fig.3 (d), (e) and (f), pits are rapidly reduced, besides, scratches and pits are hardly observed on the surface when polished by 2.5µm and 0.3µm alumina and 70nm SiO_2, which reflects typical ductile removal characteristics.

3.2. SSD of YAG crystal in lapping and polishing

As shown in Fig.4, the depth of SSD is measured by angle polishing microscopy. The depth of SSD is up to 8.82µm when lapped by fixed-abrasive and it reduces to 7.06µm when polished by 5µm alumina. However, the depth is too shallow to measure by angle polishing microscopy when the size of abrasive decreasing to 2.5µm.

Gu et al. [4] has established theoretical equation of median crack depth and assumed that the depth of SSD is equal to the depth of median crack in brittle removal mode. The equation is :

$$SSD= 0.206\,\frac{(E\cdot H_S)^{1/3}}{(K_C\cdot\beta)^{2/3}}\cdot(h_i)^{\frac{4}{3}}\cdot(\tan\frac{\alpha}{2})^{8/9} \qquad (2)$$

Where E is the elastic modulus, H_S is the hardness, K_C is the fracture toughness, h_i is the depth of penetration of abrasives in surface, β is a dimensionless constant determined by elastic recovery, and α is the sharpness angle of abrasive.

By calculating, the theoretical value is approximately 9.3nm in the fixed-abrasive lapping, and it is approximately 10.5nm in polishing by 5µm alumina.

In polishing by 5µm alumina, the theoretical value is much larger than the actual value because the actual *hi* is smaller than the theoretical *hi* (the diameter of abrasive) and it's uncertain. However, *hi* is a certain value in fixed-abrasive lapping, so its actual value is close to theoretical value.

4. Conclusions

In lapping and polishing, the removal mechanism of YAG crystal changes from brittle removal mode to ductile removal mode as the size of abrasive decreases, and the damage of surface/subsurface diminishs.

When lapped by fixed-abrasive, polished by slurry based on 7µm and 5µm alumina, the material is in brittle removal mode. A large number of pits and scratches on the surface, and the depth of SSD is above 7µm. When polished by slurry based on 2.5µm, 0.3µm alumina, and 70nm SiO_2, the material is in ductile removal mode. The surface is smooth without obvious damage, and the SSD is shallow. Ultra-smooth and low-damage process of YAG crystal can be acquired according to the evolution of the surface/subsurface damage.

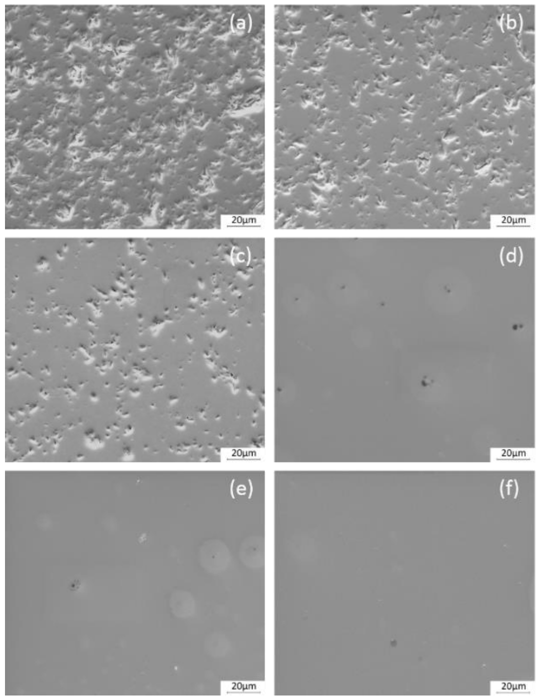

Figure 3. SEM images of the topography of surface after (a) lapped by fixed-abrasive, (b) polished by 7µm alumina, (c) polished by 5µm alumina, (d) polished by 2.5µm alumina, (e) polished by 0.3µm alumina, (f) polished by 70nm SiO2.

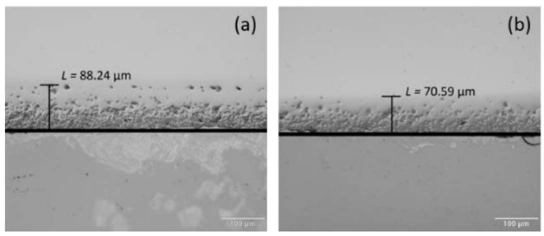

Figure 4. The micrograph of the SSD after (a) lapped by fixed-abrasive and (b) polished by slurry based on 5µm alumina.

Acknowledgements

The authors would like to appreciate the financial support from the National key Research and Development Program of China (Grant No.2016YFB1102205) and the National Science Foundation of China (Grant No. 51775084).

References

[1] J McKay 2016 Chemical mechanical and direct bonding of YAG and Y2O3D. University of California, Los Angeles

[2] Li C, Zhang F, Meng B, Rao X, and Zhou Y 2017 *Materials & Design* **125** 180-188

[3] Ross D and Yamaguchi H 2018 *CIRP Annals* **67** 349-352

[4] Gu Y, Zhu W, Lin J, Lu M and Kang M 2018 *Materials* **11** 506-524