Study on Ultra-precise Machining of CLBO Crystal

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Abstract. Cesium Lithium Borate (CsLiB\textsubscript{6}O\textsubscript{10} or CLBO) is the most effective non-linear crystal which generates ultraviolet harmonics of the Nd:YAG fundamental laser wavelength. In order to enhance the damage threshold, low CLBO surface roughness, by ultra-precision machining, is needed. Because the CLBO crystal has easy hydroscopic reaction and micro scratches in machining, ultra-precise machining of the CLBO crystal is a difficult technical problem.

In this paper, the new lapping slurry and polishing slurry are introduced. And the deliquescence degree of CLBO is fallen to lowest. A new working technology is also adopted. After rough polishing, the concentration of ultra-precision polishing slurry is increased properly. So does the ultra-precision polishing speed, and the wiping speed is faster than the deliquescence speed. The CLBO crystal surface roughness can achieve 1nm and keep the surface quality well.

Introduction

Non-linear crystal CLBO is well suited for ultraviolet applications and generates the 4th. and 5th. harmonics of the Nd:YAG fundamental laser wavelength. CLBO is transparent down to 190 nm and can be phase matched for type-II SHG to 640 nm and type-I to 477 nm. CLBO is more readily grown than BBO (\(\beta\)-BaB\textsubscript{2}O\textsubscript{4}) in that it melts congruently and it can be grown directly from the melt, which eliminates the scatter seen in BBO due to the flux inclusions. CLBO has excellent non-linear optical properties - larger angular and spectral bandwidths than BBO. It also has high damage threshold: 26 GW/cm\textsuperscript{2}, twice that of BBO. In order to keep the crystal high damage threshold, CLBO surface needs ultra-precision machining to ensure its low roughness \cite{1}.

The traditional methods of ultra-precision machining are ultra-precision lapping and polishing. And the base agents of lapping and polishing slurry are selected as the deionized water or other water affinity liquids. Because the CLBO crystal is apt to deliquescence reaction and gets micro scratches easily in machining, these traditional lapping and polishing slurry to ultra-precision machining can’t be used \cite{2}. At present, the suitable lapping and polishing slurry and ultra-precise machining craft to obtain the super-smooth surface of CLBO is mastered in overseas. But for technical security, ultra-precise machining of the CLBO crystal is still a difficult technical problem in domestic.

Preparation of the Grinding and Polishing Slurry of CLBO

It is key to choosing suitable lapping and polishing slurry for ultra-precision machining of the CLBO crystal. For it’s easy deliquescence reaction, new base agent must be chosen to prepare lapping and polishing slurry. The new base agent should have these characteristics:

1. Does not include the water and not to absorb water easily;
2. Distribute Al\textsubscript{2}O\textsubscript{3} and SiO\textsubscript{2} powders easily;
3. Promote lapping and polishing.

Therefore the high-purity organic liquid X is selected as the base agent of lapping and polishing
slurry, which contains the extremely little water, and the liquid is hard to absorb water. It also distributes Al₂O₃ and SiO₂ powders easily. The slurry of rough and fine lapping selects #2000 and #4000 Al₂O₃ separately with the base agent and additive agent. The slurry of rough and ultra-precision polishing selects SiO₂ (60 nm) with the base agent and additive agent.

**Mechanism of Ultra-precision Machining**

In the process of lapping, the action effect of abrasives and the properties of lap work material are closely related. Abrasives in the ways of rolling and micro-cutting remove CLBO crystal. The micro-cracks are produced on the CLBO surface due to the action of abrasives. It is the main way to remove CLBO in lapping. The cracks will burst apart because of micro-cracks extension and intersection. The length distribution of micro-cracks beneath the CLBO surface is approximate equal. The higher is the load, the longer are the cracks. Sometimes, different size of abrasives is chosen in the lapping for getting the lower surface roughness. In lapping, the velocity is one of the vital factors. In general, the faster is velocity, the larger is the removal rate.

In the process of polishing, the properties of polisher material and abrasive powder are the essential conditions to ensure the super-smooth surface. A soft polisher will reduce the deterioration surface roughness, if meeting unfortunately with large abrasive or dusts in polishing. To obtain the super-smooth surface, it is extremely important both to select abrasive and to get satisfactorily a smooth surface and suitable elastic polisher. Additionally, the polishing is processed in a given environment, including dust, room temperature, and vibration which influence the quality and accuracy of work surfaces [3-4].

**Experimental Procedures**

The lapping machining is divided into two processes: rough lapping and fine lapping. During the preparation for lapping slurry, under the condition of additive agent and fully shaking by the ultrasonic wave, the #2000 Al₂O₃ slurry will conglomerate when the concentration is over 20wt%. Because the grain size of #4000 Al₂O₃ is too fine and more easily conglomeratic, the slurry will conglomerate when the concentration is over 10wt%. The experimental platform of lapping is carried on the ultra-precision lapping machine (Nanopoli-100). The pads of rough lapping and fine lapping adopt cast iron. The CLBO crystal is stuck on the 267g heavy stainless steel jig by paraffin wax. The ambient temperature is 17.7°C and the relative humidity is 39%. The working parameters of rough lapping and fine lapping are shown in Table 1.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>The working parameters of rough lapping and fine lapping</th>
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<tbody>
<tr>
<td>Rough lapping</td>
<td>Fine lapping</td>
</tr>
<tr>
<td>Lapping slurry</td>
<td>20wt% #2000 Al₂O₃, base agent X, additive agent</td>
</tr>
<tr>
<td>Lapping speed</td>
<td>20[rpm]</td>
</tr>
<tr>
<td>Lapping time</td>
<td>30[min]</td>
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<tr>
<td>Lapping pressure</td>
<td>0.014[MPa]</td>
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</tbody>
</table>

No scratch in CLBO surface is the borderline of rough lapping and fine lapping. CLBO is rinsed with high-purity C₂H₅OH and then wiped clean with absorbent cotton soaked with acetone.

After rough lapping and fine lapping, the fine texture(by XJZ-6 400×) and the roughness profiles(by Rerthometer S2) of CLBO are shown in Fig.1 and Fig.2. As it is shown in Fig.1, the larger highly concentrated #2000 Al₂O₃ (20wt%) powders are adopted in rough lapping. The surface of CLBO has no scratch, but it still has lots of scallops on surface, and some scallops are also large. After rough lapping, the surface for Ra is improved to 147 nm. The fine grain size powders are...
needed in fine lapping slurry to decrease the scallops of CLBO, so #4000 Al2O3 (10wt%) is adopted in fine lapping. As it is shown in Fig.2, the scallops of CLBO are decreased and diminished further. The surface for Ra is improved to 89 nm after fine lapping.

![Rough lapping process](image1.png)

**Fig.1** Rough lapping process

![Fine lapping process](image2.png)

**Fig.2** Fine lapping process

<table>
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<tr>
<th>Table 2</th>
<th>The working parameters of rough polishing and ultra-precision polishing</th>
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</thead>
<tbody>
<tr>
<td>Rough polishing</td>
<td>Ultra-precision polishing</td>
</tr>
<tr>
<td>Polishing slurry</td>
<td>4wt% SiO2 (60 nm), base agent X, additive agent</td>
</tr>
<tr>
<td>Polishing speed</td>
<td>8 [rpm]</td>
</tr>
<tr>
<td>Polishing time</td>
<td>120 [min]</td>
</tr>
<tr>
<td>Polishing pressure</td>
<td>0.006 [MPa]</td>
</tr>
</tbody>
</table>

After rinsed with high-purity C₂H₅OH, CLBO is ready to polish its surface. The polishing machining is also divided into two processes: rough polishing and ultra-precision polishing. The experimental platform of polishing is carried on under the ultra-precision polishing machine (Nanopoli-100). The polishers of rough polishing and ultra-precision polishing adopt flannelette. The dust and the larger powders may inset the soft polisher during the polishing process, but the soft polisher can bring about surface deformation. It is the best way to clamp of the CLBO by using of the same thickness organic glass as a holder. Edging effect on CLBO will transfer to the organic glass. The polishing slurry selects SiO₂ (60 nm) with the base agent and additive agent. The ambient temperature is 17.3°C and the relative humidity is 39%. The working parameters of rough polishing and ultra-precision polishing are shown in Table 2.
After rough polishing, the fine texture\((625 \times)\) and the roughness profiles of CLBO are shown in Fig.3. There still have some small and slightness scallops on CLBO surface. Deliquescence reaction results in the slightness scallops on the CLBO. Because the high-purity base agent still has a little water, during long time polishing, homeostasis of partial deliquescence and polishing process exists in the works. When the wiping speed is faster than the deliquescence speed, the surface of CLBO will be ultra-smoothness. Thus we increase the concentration of polishing slurry and the polishing speed to enhance the wiping speed. But the concentration of polishing slurry does not increase too high for the conglomeration of micro particle. And the polishing speed also should not increase too fast, which will result in centrifugal force enlarging, and the polishing slurry is thrown out the polisher easily. When the concentration of polishing slurry increases up to 6wt\%, and the polishing speed increases up to 10 rpm, after 150 minutes polishing, the surface of CLBO reaches ultra-smoothness. As is shown in Fig.4, there is no slightness scallops in CLBO surface, and 1 nm surface roughness is obtained.

![Fig.3](image1.png)  
(a) Rough Polishing: the surface for \(Ra=17\)nm\((by\ CCD, \ Microscope \ 625 \times)\)  
(b) The roughness profiles of rough lapping CLBO

![Fig.4](image2.png)  
(a) Ultra-precision Polishing: the surface for \(Ra=1\)nm\((by\ CCD, \ Microscope \ 625 \times)\)  
(b) The roughness profiles of ultra-precision polishing CLBO

**Summary**

By preparing special lapping slurry and polishing slurry, the CLBO crystal is hardly deliquescent when lapping and polishing. At the same time, a special working technology is adopted. So the wiping speed is faster than the deliquescence speed, and the ultra-smoothness surface of CLBO is obtained.
Acknowledgements

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References


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