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Reduction of Residual Stresses in Sapphire Cover Glass Induced by Mechanical Polishing and Laser Chamfering Through Etching

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Abstract

Sapphire is a hard and anti-scratch material commonly used as cover glass of mobile devices such as watches and mobile phones. A mechanical polishing using diamond slurry is usually necessary to create mirror surface. Additional chamfering at the edge is sometimes needed by mechanical grinding. These processes induce residual stresses and the mechanical strength of the sapphire work piece is impaired. In this study wet etching by phosphate acid process is applied to relief the induced stress in a 1" diameter sapphire cover glass. The sapphire is polished before the edge is chamfered by a picosecond laser. Residual stresses are measured by laser curvature method at different stages of machining. The results show that the wet etching process effectively relief the stress and the laser machining does not incur serious residual stress.

Keywords: picosecond laser, laser curvature method, residual stress, stress relief, wet etching, sapphire

1. Introduction

Sapphire is the material to cover glasses that are scratch and impact-resistant, yet flexible despite the introduction of tempered glass such as Corning® Gorilla. In addition to the use for watch glasses or as cover or filter glasses for camera lenses, now it is being tried for cell phone displays as well. Sapphire glass is made of colorless plates of synthetic corundum, i.e. minerals produced with molten aluminum oxide (Al_2O_3). In fact, sapphire glass does not have a glass-like amorphous structure, but rather a crystalline structure. With a hardness of 9 on the Mohs scale, sapphire is one of the hardest transparent materials next to diamond [1, 2].

Sapphire has very wide optical transmission band from UV to near-infrared, (0.15-5.5 μm)[2]. With its particular properties, sapphire glass offers advantages over the chemically hardened glass often used in the display industry. Traditional methods for machining sapphire glass are generally mechanical grinding and polishing. Optical fabrication processes of these operations lead to the creation of surface and sub-surface defect and residual stresses [3, 4]. Maybe in micro-size, these defects degrade the strength and the performance of functional materials. Another new development of sapphire machining is laser cutting. Laser machining is superior to conventional mechanical methods in terms of flexibility and edge quality when right laser type and proper beam processing is applied. Mechanical saw creates micro cracks at edges as the speed is high which in turn deteriorates the bending strength. However, laser thermal effect can also induce stress which is not desirable either.

A few methods can be applied to eliminate the above consequential effect from polishing process, namely, traditional loose-abrasive polishing, wet etching, and dry plasma etching [5-7].

The first method typically integrates a polishing step into the grinder itself, which offers the advantage of integrating the damage removal into the grinder tool and builds upon

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traditional chemical mechanical polishing (CMP) technology. However, it has the disadvantage of low removal rates and perpetuates the surface profile.

The second method uses familiar wet-etching processes to remove surface damage. Wet chemical etching is one of the most common thinning techniques. To etch one side of the work piece, the workpiece is immersed in etching solution e.g. dilute hydrofluoric acid (DHF). The other side is protected either by additional layers, or by applying special chucks allowing the processing of work piece. The third method uses atmospheric dry plasma etching to remove surface damage. This method has the advantage such as the surface damage is removed, the edges are improved by rounding the sharp edge, and the surface roughness can be controlled where needed for adhesion [7].

In this paper we demonstrate a production machining and compare the residual stresses after different relieving process. The sapphire is polished before the edge is chamfered by a picosecond laser. Residual stresses are measured by laser curvature method [8] at different stages of machining. The results show that the wet etching process effectively relief the stress and the laser machining does not incur serious residual stress.

2. Method

The schematic of the sapphire glass samples under process is as shown in Fig. 1. The sapphire samples are in 1” diameter. The sapphire glass samples were polished by CMP before the edge is chamfered by a picosecond laser and then they under wet etching different processes i.e., wet etching by DHF and dry plasma etching.

Residual stresses are measured by laser curvature method at different stages of machining. The schematic of the optical setup is shown in Fig. 2. The line deflection (bow) was

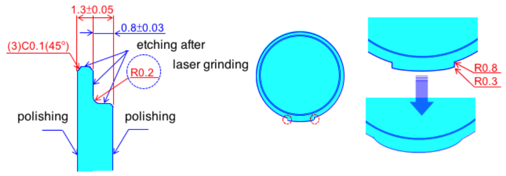


Fig. 1 Schematic of the sapphire glass samples under process

first measured across the center of the sample (initially flat before machining) as shown in Fig. 3. The stress can be then estimated by the curvature. A diagrammatic sketch is shown in Fig. 4.

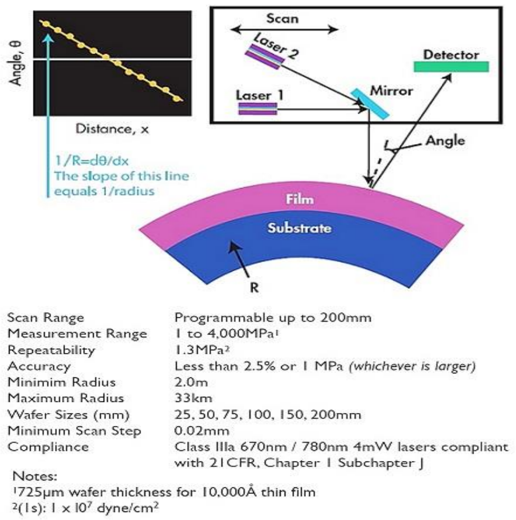


Fig. 2 Optical setup of the laser curvature method

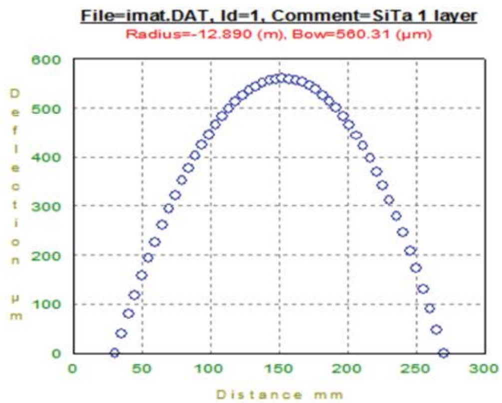
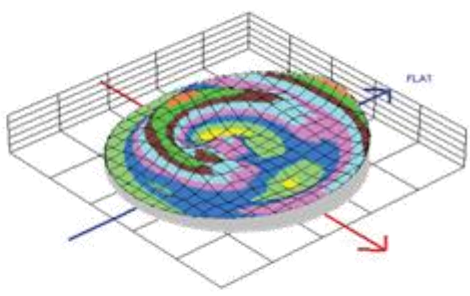


Fig. 3 Line deflection (BOW) measured across the center of the sample



3D Stress map

Fig. 4 A diagrammatic sketch of the 3D stress map by the laser curvature method

3. Results and Discussion

The average surface roughness by different methods of burnish is shown in Fig. 5. From low to high the roughness can be listed sequentially: mechanical polishing, dry etching, wet etching and thermal annealing. However, the difference within acceptable range. The line deflections of the mechanically polished sapphire glass sample (1.44mm thickness) before and after laser chamfering are as shown in Fig. 6. There is a tensile stress residing the measured surface. Interestingly, the laser machining does relief the residual stress induced. This mat be due to the instantaneous temperature rise during laser irradiation which leads an annealing effect.

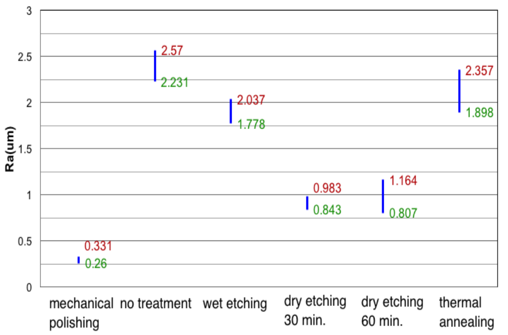


Fig. 5 Average roughness by different methods of burnish

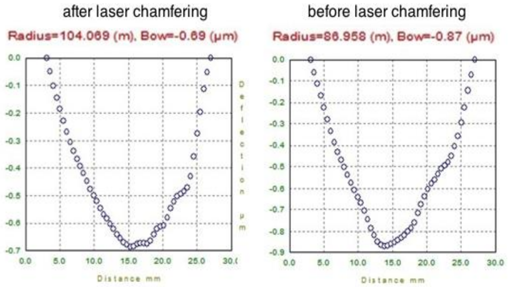


Fig. 6 Bow of the mechanically polished sapphire glass sample (1.44mm thickness) before and after laser chamfering

The bow of the mechanically polished and laser machined sapphire glass sample (0.4mm thickness) after dry plasma etching is as shown in Fig. 7. The influence of residual stress on surface deflection is more prominent in thinner sapphire glass. Before the etching the deflection is not symmetrical and irregular while it converts to a symmetrical shape and the maximal deflection at the center increases slightly from 0.7 to 0.8 μm after 300 seconds as a results of stress relaxation. The deflection at the center then starts to drop to 0.5 μm until 360 seconds has passed. At this stage the stress has been relieved to the full extent.

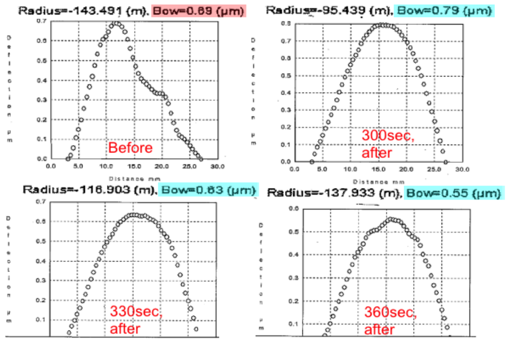


Fig. 7 Bow of the mechanically polished and laser machined sapphire glass sample (0.4mm thickness) after plasma dry etching

Bow of the mechanically polished and laser machined sapphire glass sample (0.4mm thickness) after wet etching by DHF is as shown in Fig. 8. The deflection is irregular before the wet etching similar to dry etching. After the wet etching starts the bow turns to the other direction i.e., from concave to convex. As the etching process progresses the deflection drops until after 180 seconds the maximal deflection remains the same at 0.57 μm. It is believed the residual stress is relieved to the full extent. The reason for the change of concavity is that before the polishing process the sapphire glass is not evenly cut or ground and the work piece retains its original shape after stress is relieved.

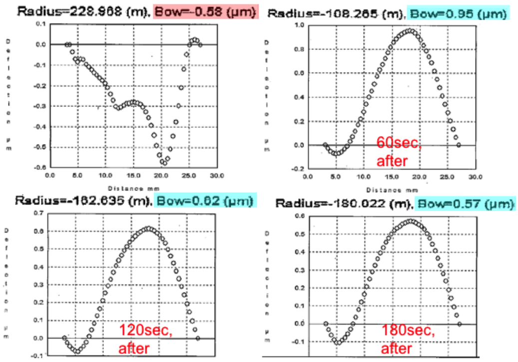


Fig. 8 Bow of the mechanically polished and laser machined sapphire glass sample (0.4mm thickness) after wet etching by DHF

The optical transmission and reflection ratio before and after wet etching are as shown in Fig. 9. There is not much difference in reflection, however, the transmission is improved.

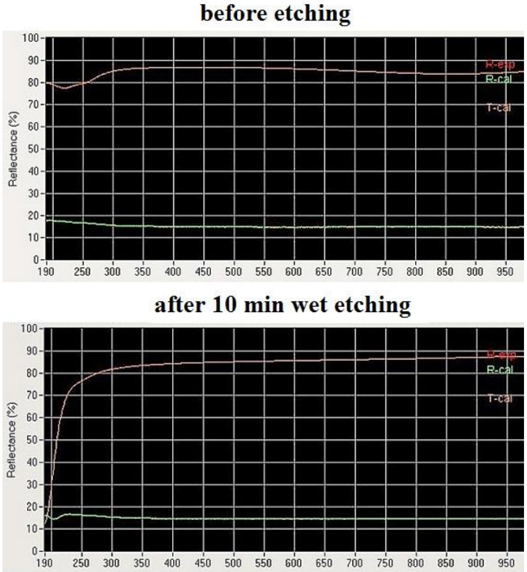


Fig. 9 The optical transmission and reflection ratio before and after wet etching

4. Conclusions

In this paper, we demonstrate a production machining and compare the residual stresses after different relieving process. The laser chamfering does not incur further stress, on the contrary, it somehow reduces the stress. Both dry and wet etchings are effective in relief of residual stress induced by mechanical polishing. Also the etching process did not impair the transparency of the sapphire glass. Ball-on-ring test is proposed to confirm the effect of residual stresses on the strength of the sapphire work pieces before and after wet etching.

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