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Twyman effect in laser polishing of fused silica wafers

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Abstract: This paper investigates the challenges of minimizing wafer deformation during laser polishing of fused silica. The focus is on the Twyman effect, which causes unwanted curvature in thin plates. Strategies to reduce stress-induced deformation are proposed to enhance the reproducibility of the laser polishing process.

1 Introduction

Laser polishing is a cutting-edge technique for finishing optical components [1], offering significant advantages over traditional methods. These include enhanced precision, the ability to achieve exceptionally smooth surfaces, and the capability to polish complex shapes. Despite these benefits, one significant challenge persists: wafer deformation during the polishing process. This deformation, primarily driven by the Twyman effect, can compromise the surface quality and reproducibility of the polished wafers.

The Twyman effect refers to the bending or warping of thin plates, such as fused silica wafers, due to stress induced by surface treatments like laser polishing. In the field of precision optics, even slight deformations can degrade the optical performance of components, making it essential to understand and control the factors that contribute to this effect.

This study focuses on identifying the key parameters influencing wafer deformation and exploring methods to mitigate these effects. By optimizing the laser polishing process, we aim to minimize deformation and improve the overall quality and consistency of fused silica wafers.

2 Understanding the Twyman Formula

The Twyman effect is mathematically described by the Twyman formula, which relates the deflection height (Δh) of a thin polished surface to the induced stress (σ). The formula highlights the importance of various factors, such as wafer thickness, diameter, and material properties, in determining the extent of deformation.

The formula is expressed as [2]:

$$\sigma = \frac{4 * E * \Delta h * t^2}{3 * D^2 * (1 - \nu)}$$

where σ is the surface stress, E is the Young's modulus of the material, Δh is the deflection height induced by the stress, t is the thickness of the wafer, D is the diameter of the wafer, and ν is the Poisson's ratio of the material.

Understanding this relationship allows for targeted adjustments to the laser polishing parameters, helping to reduce stress-induced deflection and minimize deformation.

The wafer deforms during laser polishing of quartz glass. The aim is to reduce the deformation to achieve better reproducibility of the laser polishing process. An example shows the following wafer, which was polished using the one-shot strategy - all one-shots were shot with the same laser parameters.

Fig. 1. Illustration of the unreproducible polishing spots on a fused silica wafer caused by the Twyman effect

As can be seen in Fig. 1 the laser polishing spots are not identical (compare sizes of the polishing spots), although they were all written with the same process parameters. The reason for this lies in the deformation of the wafer. The wafer lifts off the edges of the heating plate. This

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forms an insulating air layer between the heating plate and the wafer. The insulating air layer leads to a poorer heat flow and thus to larger polishing spots and ablation at the edges, as the heat accumulates or cannot flow away. This behaviour can be described with the Twyman effect.

3 Experimental Methods

The experiments were conducted using fused silica wafers with a diameter of 100 mm and a thickness of 0.65 mm. These wafers were polished on one side to ensure uniformity across the samples.

A CO2 laser system, with a wavelength of 10.6 µm and a power output of 100 W, was used for the polishing process. The laser beam was intentionally defocused to create a broader area of impact on the wafer surface. The wafers were placed on a heating plate that could reach temperatures of up to 600 °C, aiding in the polishing process.

Key experimental parameters included:

Laser Power and Exposure Time: We tested two power settings (50% and 100%) and two exposure times (3 seconds and 0.35 seconds).

One-Shot Spacing: The distance between successive laser spots was varied between 6 mm and 9 mm.

Heating Conditions: Experiments were conducted with and without the use of an oven to assess the impact of heat distribution on wafer deformation.

Polishing Sequence: The impact of different scanning strategies, such as monodirectional versus spiral, was evaluated to determine their effect on deformation and surface roughness.

4 Results

Initial Wafer Condition: The unpolished wafers showed minimal mechanical stress, with a deflection of approximately 6 µm, serving as a baseline for comparison.

Impact of One-Shot Spacing: Increasing the spacing from 6 mm to 9 mm resulted in a significant 50% reduction in wafer deflection. By increasing the distance from 6 mm up to 9 mm, only 76 one shots are now placed on the wafer instead of 172. This means that less surface is polished and therefore less mechanical stress is induced in the wafer. Therefore, the ratio of polished to unpolished wafer surface is an important parameter.

The following profilometer measurement in Figure 2. shows the bending of the polished wafer from this experiment. The measurement is identical in X and Y directions. The measurements are made on the back side of the wafer.

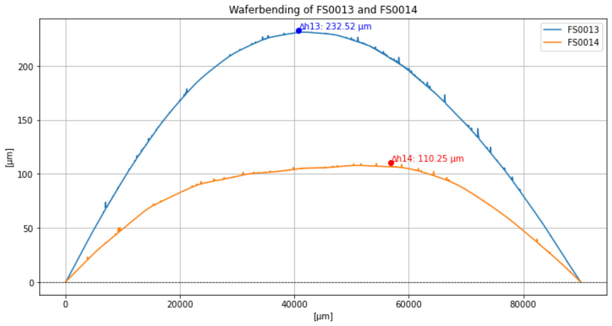

Fig. 2. Profilometer measurement of samples FS0013 and FS0014. FS0013 was polished with a spacing of 6 mm and FS0014 with a spacing of 9 mm.

Exposure Time and Laser Power: The combination of shorter exposure times with higher laser power led to a 33% decrease in deflection, highlighting the effectiveness of optimizing these parameters to reduce stress.

Cut-Out Structures: Introducing cut-out structures in the wafer design helped alleviate mechanical stress, reducing deformation by about 28%. This approach also enhanced the reproducibility of the polishing process.

Heating Plate and Oven Use: Utilizing an oven in conjunction with the heating plate reduced heat convection, leading to a further 12% improvement in deflection height, demonstrating the benefit of controlled thermal conditions.

Polishing Sequence: While the choice between monodirectional and spiral polishing sequences did not significantly affect deflection, the spiral sequence offered better repeatability in surface roughness, making it a preferable option for consistent quality.

5 Conclusions

The study confirms that the Twyman effect plays a critical role in the deformation of fused silica wafers during laser polishing. By carefully adjusting key parameters such as laser power, exposure time, shot spacing, and using thermal management strategies like cut-out structures and oven use, it is possible to minimize deformation and improve the reproducibility of the process. These findings provide valuable insights for optimizing laser polishing techniques, ensuring the production of high-quality optical components with minimal surface deformation.

References

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