Polishing of illumination optics with CO_2 laser radiation

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Polishing of optical components with CO_2 laser radiation is a current research topic at Aachen University and the Fraunhofer ILT. With this polishing technique the micro roughness can be efficiently reduced in the sub-nanometer regime [1-3]. The form deviation is below 1 µm for a 25 mm diameter lens of fused silica. This form deviation is sufficient for lightning applications. The processing time is with less than 10 s for a whole lens of 25 mm diameter very short compared to conventional techniques. This process is suitable for different glass materials e.g. BK7 and Floatglass.

1 Introduction

Polishing aspherical and freeform surfaces with conventional techniques is time consuming and cost extensive. Laser polishing represents an alternative for polishing those optical components. In this paper first polishing results are presented on spherical and aspherical fused silica and BK7 lenses with an adapted processing strategy. A great advantage of laser polishing is processing both planar surfaces and other geometries at the same speed, which is extremely fast at 1 cm²/s. The challenge is to keep the form deviation low.

2 Proceeding

For the polishing experiments a CO_2-laser with an output power of 1.5 kW is used. The laser beam is guided over the samples with a laser scanner at scanning velocities of up to 10 m/s. By scanning at high speeds a focal line is formed, and this focal line is moved over the surface with a feed speed v_{feed} of a few mm/s. The fused silica samples are preheated with a hot plate up to 550°C at the surface. The BK7 samples are treated in an oven with a preheating temperature of 660°C.

Due to the high absorption of the laser radiation in a small depth of the material of about 30 µm, the temperature rises just below evaporation temperature. That is why the viscosity is lowered down to 10^4 Pa•s and the glass can flow. Due to the surface tension the surface is smoothened. The material is only reallocated – no material is ablated. Therefore, the temperature of the material during polishing is lower than the evaporation temperature of about 2230°C. A sketch of the procedural principle is shown in Figure 1.

To achieve a low micro roughness a processing temperature just below the evaporation temperature is needed homogeneously over the whole surface. Therefore, the energy needs to be adapted to the surface geometry when non flat surfaces are polished. Three different problems

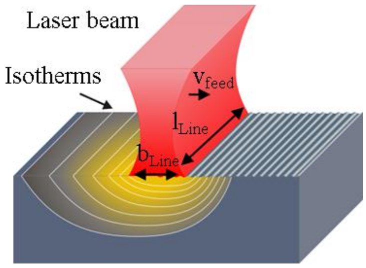

Figure 1: *Sketch of the procedural principle.*

need to be solved to achieve such a homogeneous processing temperature distribution on a lens:
1) The length of the line changes adapted to the dimensions of the lens,
2) the intensity changes due to the non-perpendicular incident with the angle β between laser beam and surface normal (Figure 2) and
3) in particular small lenses heat up during the laser treatment so that at the end of the treatment the temperature rises and material ablation can occur.

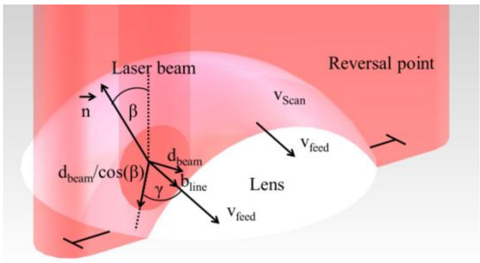

Figure 2: *Sketch of the non-perpendicular incidence of the laser beam on a lens*

The problems can be solved as follows:

1) The laser beam is guided by a laser scanner to the surface of the lens. Therefore the length of the focal line is adapted to the dimensions of the lens.
2) Due to a non-perpendicular incidence of the laser beam on the material, an ellipsoid interaction zone is formed. If the laser power remains constant for perpendicular and non-perpendicular incidence, for non-perpendicular incidence the intensity is lowered and lower processing temperatures

are reached. Additionally, the width of the line b_{line} changes depending on the orientation of the angle β (Figure 3). By varying the scanning velocity along the focal line, both effects can be compensated.

2) Due to a non-perpendicular incidence of the laser beam on the material, an ellipsoid interaction zone is formed. If the laser power remains constant for perpendicular and non-perpendicular incidence, for non-perpendicular incidence the intensity is lowered and lower processing temperatures are reached. Additionally, the width of the line b_{line} changes depending on the orientation of the angle β (Figure 3). By varying the scanning velocity along the focal line, both effects can be compensated.

3) To prevent the lens from heating up the laser power is lowered at the end of the processing.

The laser power can be adapted by using a pyrometer. The pyrometer measures the temperature in the center of the focal line and due to the desired temperature the laser power is controlled to achieve a processing temperature just below evaporation temperature. The homogeneous temperature distribution along the focal line is achieved by the scanning velocity.

The adaption of the processing parameters depends on the glass material and has been investigated for fused silica and BK7.

3 Results

The initial roughness before laser polishing is Ra = 100 nm (ground) for all laser-polished samples. The lens has a diameter of 25 mm and a radius of curvature of 13.8 mm. The feed speed v_{feed} of the focal line is 2.5 mm/s. The micro roughness on different positions on the lens is measured for spatial wavelengths < 50 µm with white light interferometry. The micro roughness can be lowered to the roughness of a laser polished plane sample of Rq = 0.4 nm (measuring field 50 x 70 µm²) homogeneously over the whole lens which is equal to a conventionally polished plane sample with a surface quality of λ/10. The lens is laser polished on both sides. These lenses were the first laser-polished lenses which exhibit a surface quality allowing for laser interferometer measurements.

In Figure 3 a measurement is shown of the curved and the plane side of a laser-polished fused silica lens. After polishing the plane side of the lens a form deviation of 0.7 µm on the curved side is achieved. This form deviation mostly results from non-sufficient preheating of the samples. During the laser treatment, thermal tensions induce bending of the sample. This has already been discovered on plane samples. The back side also exhibits, equal to the front side, a form deviation of 0.7 µm.

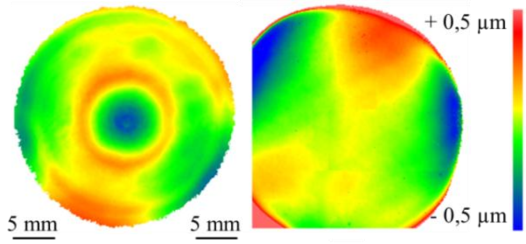

Figure 3: *Measurement of the curved and the planar side of the laser polished lens of fused silica.*

Nevertheless, the form deviation achieved is already suitable for illumination optics. The scanning velocity for polishing fused silica lenses is varied between 10.0 m/s and 6.4 m/s and the laser power between 250 W and 400 W. The glass can be annealed afterwards to reduce thermal tensions but this is not always necessary. The micro roughness of all laser polished optics is very low so that e.g. the transmission of the optics can be increased. Also spherical and aspherical lenses of BK7 have been laser polished. The form deviation with PV = 22.4 µm very high. The current work therefore involves repeating the fundamental investigation for BK7 to reduce the form deviation.

4 Summary and Outlook

By adapting the processing parameters to the geometry and using a pyrometer for a temperature control in the center of the focal line, spherical and aspherical lenses can be homogeneously laser polished. The micro roughness can be reduced homogeneously over the whole lens. On fused silica a form deviation of below 1 µm can be achieved. The process is also adaptable to different glass types. Spherical and aspherical lenses of BK7 are laser polished with a form deviation of 22.4 µm. Fundamental investigations are currently repeated for BK7 so that the reason for the high form deviation can be investigated in more detail. Due to the high processing rates of 1 cm²/s, laser polishing is very likely to become an alternative to conventional polishing techniques for polishing difficult geometries like freeform optics, in particular because the achieved results achieved are already suitable for illumination optics.

References

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