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Optics manufacturing by laser radiation

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ABSTRACT

Current results of the development of a process chain for optics manufacturing with laser radiation are presented. The process chain consists of three process steps: *High Speed Laser Ablation* creates the surface geometry by material ablation, *Laser Polishing* reduces the surface roughness by material remelting and *High Precision Laser Ablation* applies a form correction by removing redundant material. Compared to conventional optics manufacturing methods, this process chain benefits from its high flexibility concerning the optics geometry and its processing speed, which is independent from the processed geometry.

1. Introduction

Optics with aspherical or even freeform surfaces enable high degrees of freedom as well as lightweight design since they can take the place of several spherical lenses. Therefore, the demand for non-spherical components is increasing in the fast-growing market of optical components at a very high rate [1].

Conventional methods for manufacturing aspherical and freeform glass optics enable the fabrication of optics either with slight aspherical shape in small production lots with grinding and polishing, or optics with complex surface geometry in very large production lots with glass (precision) molding. However, the production of single pieces or small series of non-spherical optics is very expensive and seldom economically feasible.

In order to improve the manufacturing process of glass optics with complex surface geometry, laser radiation can be used instead of conventional tools due to its flexibility and its decoupling of tool and work piece geometry. Several research institutes have been investigating glass treatment by laser radiation. This research covers the production of micro-optics [2,3] as well as single process steps like polishing [4] or form creation [5] with laser radiation. At the Fraunhofer Institute for Laser Technology ILT, a completely laser-based process chain for manufacturing aspherical and freeform optics is in development [6]. The aim of this process chain is to create an economical production method for manufacturing single pieces or small series of optical components with variable and complex geometries by using laser radiation for the whole manufacturing process. This paper presents current results of the development of laser-based process chain and its single process steps.

2. Description of the process chain and its single process steps

The process chain is shown in Fig. 1. Three laser-based process steps are used to manufacture the desired optics, which generally begin by starting a simple process step to manufacture glass preforms such as a spherical lens or an ingot with a ground surface. Within the first process step, *High Speed Laser Ablation*, the optics geometry is created by locally removing glass material from the surface.

The roughness of resulting surface after the first process step is too high for optical applications. For reducing this surface roughness, *Laser Polishing* as second step of the process chain is applied. Here, the surface is remelted and the surface roughness is reduced due to surface tension. During this step, no material is removed from the glass surface and its geometry is preserved.

The third step, *High Precision Laser Ablation*, is used to apply a final form correction. Prior to this process step, the surface has to be measured so that deviations from the desired shape can be

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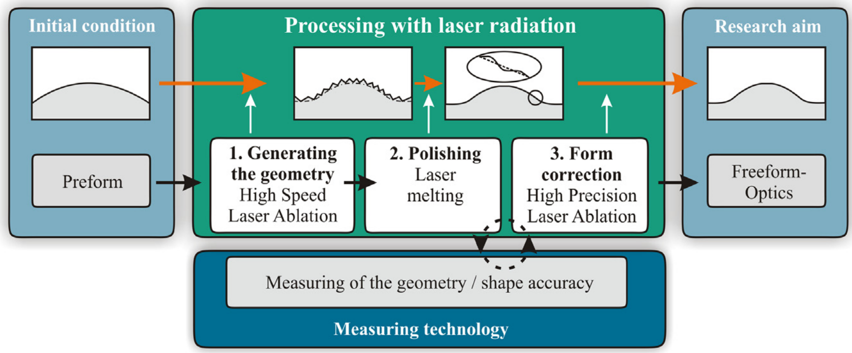

Fig. 1. Laser-based process chain for optics manufacturing.

localized. Based on these measurement results, *High Precision Laser Ablation* removes smallest amounts of redundant material locally at a high spatial resolution. If needed, another *Laser Polishing* step can be added afterwards.

Compared to conventional manufacturing methods of optical components, this process chain enables a shorter processing time for complex non-spherical geometries [6]. Due to the decoupling of tool and work piece geometry and the possibility to control the laser radiation very rapidly, the processing time remains nearly constant regardless of the geometry to be processed, so that every geometry can be processed in the same time and with the same tool. In particular, producing smaller lot sizes down to single optics is economically possible.

Since CO_2-laser radiation is absorbed at the glass surface at a rate of about 80% in a few tenths of a micron, it is used for the *Laser Polishing* step. For economic reasons, this laser source is favored for two ablation processes as well, although they can also be carried out with ultra-short pulsed laser radiation. Within this paper, the results shown have been achieved with CO_2-laser radiation. The experimental setup is described in Section 3. In the following, the single process steps are described in more detail.

2.1. High Speed Laser Ablation

The aim of *High Speed Laser Ablation* is to create the optics geometry in a short time with moderate surface roughness. During this process step, CO_2-laser radiation is used to heat up the glass material to evaporation temperature and, therefore, ablate it from the preform. With laser powers of up to $P_L = 1.2$ kW, short processing times are realized. Based on the achieved ablation depth z, the ablation rate which describes the amount of ablated material per time is calculated according to the following equation:

$$\dot{V} = \frac{z d_y v_s}{n} \quad (1)$$

A scan strategy, which describes the pattern in which the laser beam moves across the glass surface, is of great importance because it determines the form accuracy as well as the resulting surface roughness. An example of the scan strategy in combination with the relevant process parameters is shown in Fig. 2. Here, the focused laser radiation with the laser power P_L and the focus diameter d_s is moved across the glass surface at the scan speed v_s in a meandering scan strategy. The track pitch d_y is set to values smaller than d_s so that contiguous areas are ablated. If necessary, the number of exposure layers n can be increased for a higher ablation depth. In addition to the scan strategy shown in Fig. 2, a unidirectional scan strategy is possible and will also be discussed in this paper.

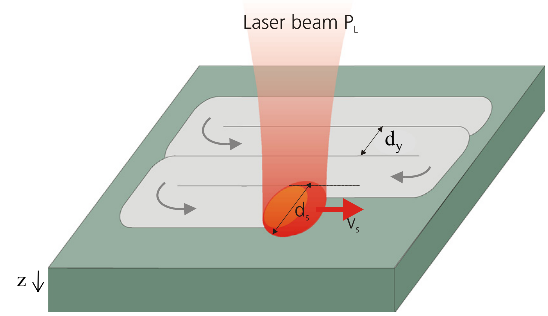

Fig. 2. Procedural principle of *High Speed Laser Ablation*.

2.2. Laser Polishing

The aim of *Laser Polishing* is to reduce the roughness of glass surface. As for *High Speed Laser Ablation*, CO_2-laser radiation is used to heat up the glass material, but only to values below its vaporization temperature. In order to prevent the glass material from being destroyed due to thermal tensions occurring during *Laser Polishing*, it is preheated to a temperature T_V which is usually as high as the glass transition temperature.

The procedural principle for flat surfaces is shown in Fig. 3 (left). The defocused laser spot is moved at a high scan speed v_s in the y-direction to create a quasi-line with length l_{Line} and width b_{Line}. This line is then moved in the x-direction at the feed speed v_{feed}. If a non-perpendicular incidence with the angle β of laser beam and the normal of surface takes place, an elliptical laser spot is formed on the surface of sample, as shown in Fig. 3 (right). The angle γ is the angle between the feed speed v_{feed} and the longest principal axis of the ellipsoid. In this case the width of the focal line b_{Line} is given as $b_{Line} \cos(\beta)/\cos(\gamma)$.

The resulting temperature on the glass surface depends on the process parameters and can be measured and controlled with a pyrometer. The pyrometer measures the process temperature in the middle of the focal line and controls the laser power in order to achieve constant temperatures on the surface. With this closed loop control, the process temperature can be controlled within ± 15 K during *Laser Polishing* [8]. On the one hand, the process temperature has to be kept below evaporation temperature to avoid material ablation, which would result in dents in the surface. On the other hand, the viscosity of glass material decreases with increasing process temperature, which leads to a lower surface roughness. For best results, the process temperature has to be set to values just below the evaporation temperature of the glass material.

The biggest influence on the surface roughness achievable with *Laser Polishing* is the interaction time between laser radiation and glass material. As interaction time increases, the surface