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Investigations into temperature measurement in a laser-based heating process of optical, machined components

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Abstract. The manufacturing of optical components is subject to constant efforts to optimise production processes in order to achieve high surface qualities under the most economical conditions possible. This includes the refinement of existing technologies or development of completely new production technologies. One possible approach is the combination of conventional machining processes for optical components like diamond turning, grinding or polishing with laser-based processes to thermally influence the surface for improved machining or surface properties. For this, knowledge of the thermal interactions of the laser on the component surface is needed, which in turn requires its metrological acquisition. In this work, measurements were carried out using various methods for the controlled heating of glass surfaces by an infrared laser (λ=1070 nm). Among other things, a clear correlation between the samples surface roughness and the laser absorption is found.

1 Introduction

Laser processes have become increasingly important in the production of optical components in recent years. There are various approaches for processing optical materials more efficiently or to a higher quality standard, either in hybrid processes, with a combination of machining processes and laser support, or in pure laser processes. One example of a direct laser process is laser polishing (CO_2 laser), in which the targeted irradiation of the component results in a thermally induced reduction in viscosity on the material surface and subsequent smoothing. This means that optical surfaces can be polished in a short processing time and surface imperfections such as scratches and micro-defects on fused silica can also be healed. [1]

A hybrid approach is used in the microlaser-assisted diamond turning process. A laser beam is focussed through the turning tool, a monocrystalline diamond, into the interaction zone of the cutting edge with the component surface. The thermal heating locally reduces the hardness of the sample material to enable a more ductile machining behaviour. [2] Laser radiation in the IR range with a wavelength of 1064 nm is used for this purpose. [3]

In order to effectively optimise the processes described and to develop new hybrid manufacturing processes based on them, a fundamental understanding of the thermal interactions between the laser radiation and the component surface is highly relevant. This approach is considered in the following for IR laser irradiation on glass samples.

2 Experimental set up

Investigations were carried out into the interaction of laser radiation from a solid-state laser (“CW-M R4 RS” from company SPI; laser output power 50-500 W) with the surface of planar fused silica (SiO_2) samples (ø 49 mm; thickness 6 mm). A collimated beam diameter of 8.7 mm was applied. The used fibre laser is characterized by a wavelength of 1070 nm which theoretically has a very low absorption on the SiO_2 material. The absorbance related heat induction into the glass surface was monitored and compared between a contact thermometer “DTM3000” and a non-contact thermographic device “Optris PI 450i” (spectral range 8-14 µm). The samples were placed with their surface horizontally orientated in a holder, enabling also a measurement of the transmitted laser power below the sample (laser power meter “1000W-Bb-34”, company Ophir). All measurement positions and angles were fixed during the investigations. Fig. 1 shows the described set up with emitted laser radiation observed by the thermography camera.

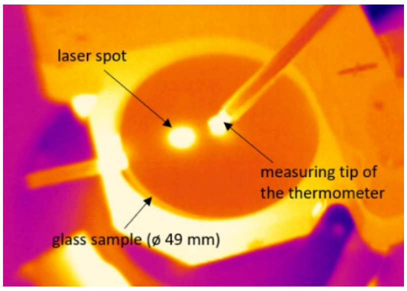

Fig. 1. Set up of the temperature investigations shown in a thermographic image with glass sample and laser spot

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A main focus was set on the influence of surface quality on laser absorption and therefore surface heating. For this, the samples were processed differently prior to the investigations by either polishing or lapping/grinding with different parameters and grain sizes to achieve defined, clearly distinguishable surface roughness values between 1 nm and 2.18 µm Rq. A constant laser radiation with a power of 500 W and an effective duration of 30 s was applied to the prepared samples and temperature variance and transmitted radiant power were then recorded.

3 Results

The obtained values of temperature increase measured by contact thermometer and transmitted laser power show a clear correlation between laser absorption and surface roughness (Tab. 1).

Table 1. Measured values for the different sample surfaces

Rq (sample roughness)	ΔT contact thermometer	ΔT thermography	transmitted laser power
1 nm	15 K	0 K	460 W
0.79 µm	77 K	62 K	281 W
2.18 µm	104 K	34 K	245 W

A high surface roughness leads to a reduction in laser transmission and a temperature increase up to over 104 K for the surface with Rq = 2.18 µm. This can be explained by multiple reflections within the peaks and valleys of the rougher surface, which significantly increases the overall absorption compared to a smooth surface. This roughness dependent temperature trend is visualized in Fig. 2. Investigations on more surface conditions with different samples are currently in preparation for a more precise quantitative evaluation of the correlation.

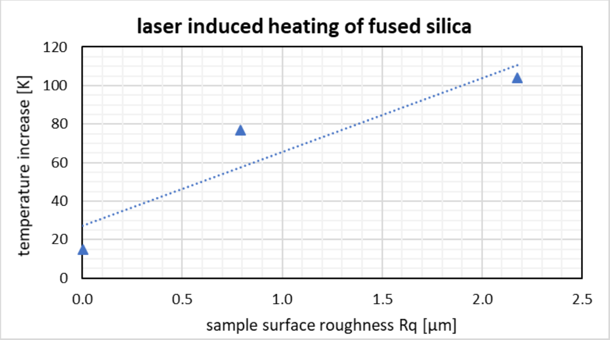

Fig. 2. Roughness dependent sample heating by solid state laser (500 W for 30 s), measured by contact thermometer

However, the comparative measurements with a thermography camera showed significantly different temperature values, as seen in Tab. 1. For the polished surface no temperature difference was measured, for the roughest surface a significantly lower temperature increase of 34 K was measured, compared to the 104 K obtained by contact thermometer. This is explainable by the influence of the so-called emission coefficient ε, which is relevant for radiation-based temperature measurement. This value must be entered in the calculation software for the evaluation of a thermographic measurement to achieve correct values. Calibration measurement with a defined heating device have shown strong differences for this value depending on the surface quality of the heated sample and also the actual, specifically set temperature of it (Fig. 3). For the presented laser investigations, the value was set constant to ε = 0.85.

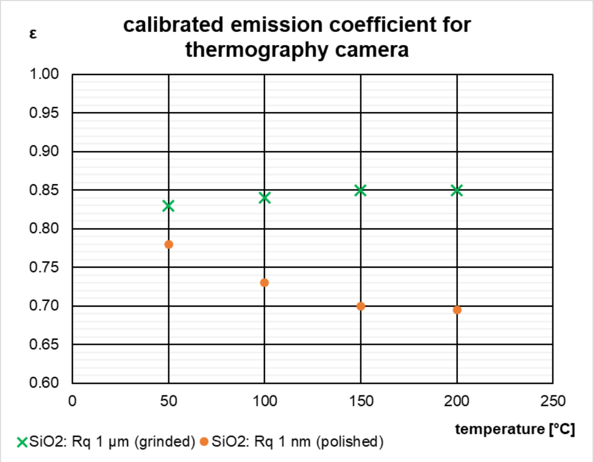

Fig. 3. Emission coefficient for thermography measurement depending on actual temperature and sample surface quality

Because of this, the contactless thermography method is rather difficult to apply for absolute measurement of temperatures, unless it is calibrated for the exact measurement approach, temperature range and sample surface properties. Also, it can be useful for qualitative evaluations of an areal temperature distribution, compared to the solely point application of a contact thermometer.

The investigations have shown an interesting relationship between surface roughness and laser-based heating with a fibre laser for fused silica. Challenges in temperature detection in such a process also became evident. The experiments on the interaction of laser radiation with glass components, also with regard to changes in surface properties in general, are currently being continued. The applied 1070 nm wavelength also has the advantage that the radiation is compatible with the use of water-based cooling lubricants. The laser power is not significantly absorbed by water, which is highly relevant for machining processes. The results should therefore contribute to the development of a new hybrid manufacturing process.

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