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Removing microdefects on glass surfaces using laser radiation

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Abstract. Scratches and microdefects on glass surfaces significantly impair the optical and mechanical properties of optical components. They already occur during mechanical processing (shaping) and have to be removed in several specific processing steps. A process is presented with which scratches and microdefects can be removed by means of CO_2 laser radiation.

1 State of the art

Conventional mechanical processing of optical surfaces incurs considerable costs and is time-consuming. In many grinding, lapping and polishing steps, the geometry is created and the surface roughness is reduced bit by bit. This leads to significant material removal and high tool wear, because deep cracks in the surface (sub-surface damage) have to be removed at great expense. [1]
If the surface is sufficiently well mech. polished, scratches can quickly reappear, which negatively affect the function of the optical component and are also the starting point for the mechanical failure of glass under load. To remove them, mech. polishing would have to be performed again or other expensive polishing processes such as ion beam polishing or magnetorheological finishing (MRF) would have to be resorted to. One way to remove microdefects quickly and without additional tools and polishing agents is laser beam polishing (LBP). It has been researched for several years in numerous scientific studies for various materials. In the polishing of metallic surfaces, it has been transferred to industrial production through the development of a special machine technology [2]. In addition, there are numerous publications on studies of surface treatment - especially polishing - of glass (e.g. [3], [4]). In [5] and [6], the method was used to remove scratches on surfaces. In the first example pulsed laser radiation was applied; the scratches could not be completely removed and there was material displacement. The 2nd example is a combination of mechanical and laser processing (partial surface damage removed by LBP, surface then conventionally mech. polished to remove structures from LBP).

2 Proceeding

In the present study, it is shown how microdefects can be smoothed by targeted irradiation of the surface with laser radiation of wavelength 10.6µm. This wavelength is almost completely absorbed by quartz glass surfaces, leads to heating of the surface up to softening. In a flow process, the scratches/micro defects are filled and smoothed. LBP is suitable for polishing glass surfaces in a short time with little effort, without additional tools/polishing agents. On conventionally mech. polished fused silica samples (25 x 25 x 3 mm³), diagonally running scratches and micro defects were selectively introduced and the samples were subsequently smoothed with laser radiation. To demonstrate the effectiveness of LBP, the samples were analyzed before the defects were applied and after smoothing (with confocal sensor (FRT), white light interferometer (WLI), transmission measurement). The first two methods to assess surface quality, transmission measurement to determine how micro defects change the optical properties of the material and that this change is eliminated by LBP.

3 Experiments and Results

A 2 kW CO_2 laser and a 2D scanning system in a polishing chamber are used. The parallel beam diameter is 7.1 mm. To achieve a uniform energy input, the beam is linearly deflected at high speed (1400 mm/s). The resulting polishing line is guided over the sample surface in an additional y-motion (v = 34 mm/min). The overlap of the lines is >90%, so that a homogeneous energy input can be assumed, which prevents the formation of a "polishing structure". It is known from previous studies that some energy input is required to heat the surface of amorphous SiO_2 to the point where flow occurs. The calculated energy input resulting from the processing parameters is 500 J/mm², which leads to an average sample heating of about 2100°C (measured with thermal imaging camera for process monitoring). In order not to introduce new defects on the glass surface during LBP, it must be cleaned very well before polishing and the environment must contain only few particles (dust). Residues on the surface and dust from the environment cause defects on laser treated surfaces [9]. Therefore, LBP takes place in the polishing chamber (with filters to reduce particles). During LBP, due to the high thermal shock resistance of fused silica (compared to other glasses), no additional heating of the samples is required. After irradiation, the samples are treated in a heating furnace to remove introduced stresses that negatively affect the mechanical durability of the fused silica elements and their optical properties (optical path length difference). The mech. polished samples have a surface roughness of Sq = 18nm. After removal of the microdefects, Sq is reduced to 10 nm. The scratches (detail in Fig. 1) have an average depth of about 5.1 µm, are about 100 µm wide and material upheavals in the range of 1 µm occur in some cases. The roughness along the scratch is Rq = 3.1 µm. This is in the range defined as suitable for LBP in previous studies [7].

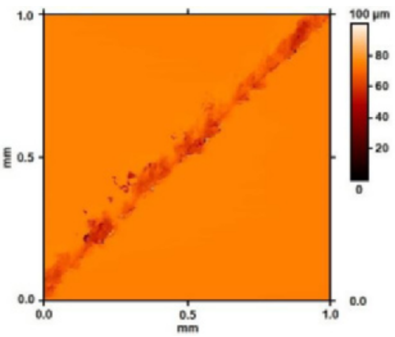

Fig. 1. Detail of a scratch on a mechanically polished surface.

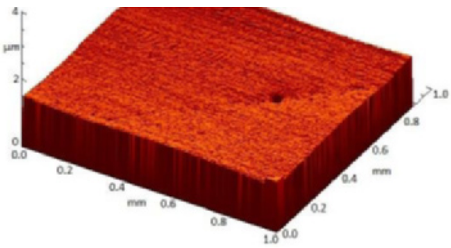

Fig. 2. Scratch, not completely removed (detail).

LBP reduces scratches/microdefects and finally remove them after parameter optimization. Fig. 2 shows the part of a scratch that was not completely removed. The flow of the material has not been sufficient to completely eliminate the defect (tiny pits remain). It could also be observed that if the scratches are not completely leveled, a uniform depression (depth approx. 0.7 µm) remains. In other words: the surface has no clearly defined defects, the roughness remains the same (in relation to the surrounding area), but the shape of the surface is changed.

Table 1. Surface parameters before and after laser polishing.

Sample…	WLI [nm]		FRT [nm]	
	Sq	Rq	Sq	Rq
mechanically polished	13		18	14
LBP incl./on scratch residue	27	15	16	27
residue-free LBP	12		10	12

Table 1 shows some of the surface characteristics (measurements at WLI, FRT) of the fused silica samples during the tests. Although the measurement conditions (measurement field size, filter settings, etc.) were chosen to be the same, the measured values differ due to the different measurement methods.

Another way to check the quality of optical elements is transmission measurement. A glass component with perfect, defect-free surfaces allows a certain amount of light to pass. If the surfaces have defects, there is a loss of transmission due to absorption or diffusion. This can be used to evaluate the effectiveness of LBP. A Goniospectrophotometer is used to determine the effect of scratches/microdefects on the transmitting light. Since the introduced surface defects account for only about 0.6% of the total surface area, the change in the detected light is also only a few percent. The scratches/microdefects reduce the measured value by 2.1%. After LBP the difference is 1.4% (to the untreated, mechan. polished sample). Even if scratches and micro defects can no longer be detected with FRT or WLI, there are losses whose origin must be further investigated.

4 Conclusion

The results show that it is possible to completely remove scratches and microdefects on quartz glass surfaces by LBP. In future investigations, suitable methods will be examined to check the results better and faster (measurements on FRT: 30 min/mm^2; WLI reaches its limits due to the measuring principle for polished surfaces; transmission measurement not significant enough so far). In the future, it will also be necessary to determine how scratches/microdefects can be categorized on basis of their lateral/vertical extent before machining in order to eliminate them in a targeted manner, since the investigations showed that too much introduced energy leads to deformation of the entire sample.

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