Investigation of Non-Uniformity of Classically-Polished Fused Silica Surfaces via Laser-Induced Breakdown Spectroscopy

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Abstract. In this contribution, the surface uniformity of classically-manufactured fused silica windows was investigated via laser-induced breakdown spectroscopy. It is shown that for all investigated samples a comparatively high aluminium content was found at the edge of the surface with respect to its centre. This contamination can be attributed to residues from lapping and polishing agents and leads to a mentionable non-uniformity of the surface in terms of chemical composition and optical properties, respectively.

1 Introduction

The quality of an optics surface regarding its contour accuracy or cleanliness is extensively covered by the pertinent standards such as ISO 10110. This also applies to the homogeneity of the bulk material. However, the surface uniformity, i.e. the spatial variation of its chemical and optical properties, is not specified. This point becomes of interest for the application of high performance coatings where uniformities in final surface reflection or transmission over the surface of 0.1 to 0.5% are required. In this context, the homogeneity of the coating material and the coating thickness are strictly specified and the stability of the coating process is meticulously controlled, but less attention is usually paid to the uniformity of the substrate surface. Against this background, the homogeneity of fused silica window surfaces was investigated in the present work where the focus was on the polishing agent aluminium oxide.

2 Materials and methods

The investigated samples were classically-manufactured commercial samples made of Suprasil 2B with brightly polished surfaces (P3-polish). The chemical analysis of the surfaces was carried out via laser-induced breakdown spectroscopy (LIBS), a powerful tool for the analysis of glasses [1]. As described in detail in [2], measurements were performed at various locations on the sample surface in order to obtain a cross section of the chemical composition. In addition to such cross-sectional detection, the edge and the centre of the samples were investigated by in-depth LIBS where single laser shots were successively applied. Since no other polishing agent materials such as cerium or zirconium were detected, the distribution of aluminium on the sample surfaces was measured. Here, the LIBS analysis was performed by observing the Al I 396.15 nm resonance line.

3 Results and discussion

As shown in Figure 1, the lateral distribution of aluminium over the sample surfaces features the same qualitative behaviour for all investigated samples: A comparatively high aluminium contamination is found at the border areas or edges of the samples whereas low or even no contamination occurs at the centres.

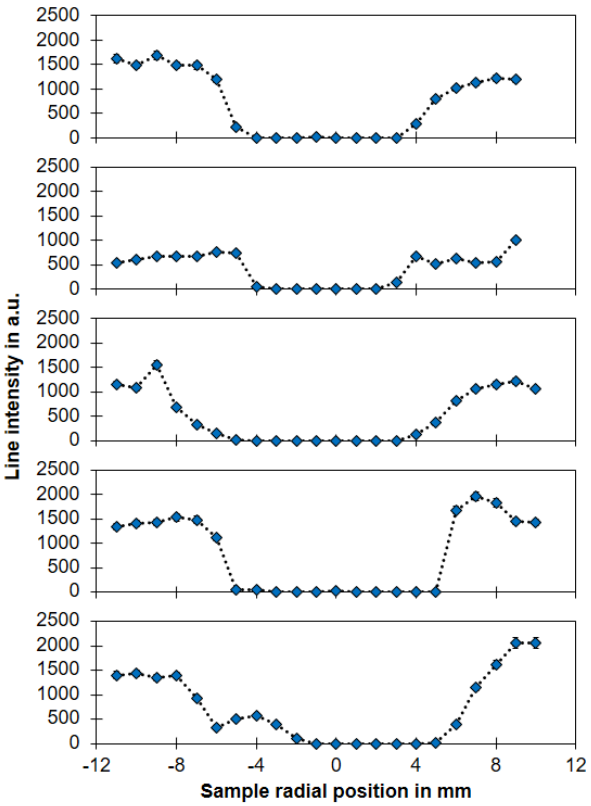

Fig. 1. Intensity of the Al I 396.15 nm transition vs. sample radial position of different commercial fused silica plates.

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For the edges, a mean aluminium mass fraction of about 1,000 ppm (0.1%) can be estimated based on the measurements [2]. This high aluminium content cannot be attributed to the glass bulk material since the investigated type of fused silica contains a negligible aluminium content of <10 ppb according to the glass manufacturer's data sheet. It can rather be explained by the contamination of the surface by aluminiferous lapping and polishing agents such as corundum in the course of the manufacturing process.

The observed lateral distribution is another point of great interest. It could be explained by the fact that in classical optics manufacturing, the surface is usually shaped slightly concave with respect to the final radius of curvature by each single previous process step. As a result, the subsequently applied tool rests on the border of the component [3]. Such edge support leads to an extremely stable self-guidance of any following grinding, lapping or polishing step. However, it also increases the strength and time of interaction of the tool and the border area of the work piece. In comparison to the centre, the tool's impact is thus much higher at the edge, leading to a larger density of micro cracks where contaminants from working materials such as – in the present case – aluminium oxide can accumulate.

This assumption is also supported by the performed in-depth measurements where a high contamination and penetration depth of aluminium at the edge with respect to centre was verified as shown in Figure 2.

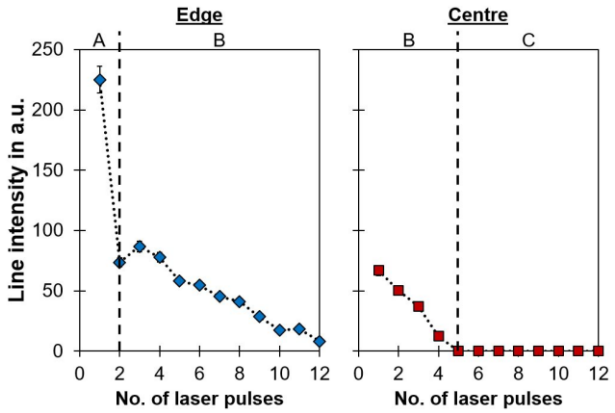

Fig. 2. Comparison of the intensity of the Al I 396.15 nm transition vs. number of successive laser pulses at different positions on the surface of commercial fused silica plates (left: edge, right: centre).

Here, three different depths or areas can be identified (see Figure 3): Area A features severe surface-adherent aluminium contamination, which is indicated by a comparatively high line intensity for the first laser shot at the edge of the sample. Such contamination of classically-manufactured optics surfaces by residues from the polishing agent aluminium oxide was also reported in [4] and usually occurs in the form of agglomerated flakes on the surface as shown in Figure 3. The second depth range, Area B, represents the near-surface contamination layer where the aluminium content decreases linearly with increasing number of laser pulses or depth, respectively. Area C finally shows the bulk material without any aluminium contamination. This is found after five laser pulses at the centre and not reached even after twelve laser pulses at the edge where the contamination layer is thus much thicker.

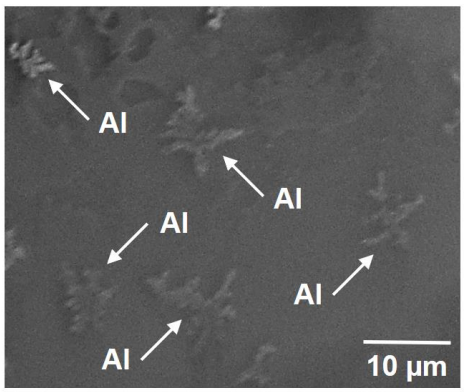

Fig. 3. Scanning-electron microscopy image of a classically-manufactured fused silica surface, taken at the edge of the component. The whitish flakes are aluminium-containing compounds as verified by energy-dispersive X-ray spectroscopy.

4 Conclusions

The detected local contaminations and the accompanying non-uniformity in chemical composition of fused silica windows has a notable impact on the uniformity of the optical properties. As verified via ellipsometry, the index of refraction features an inhomogeneity of about 1.15% over the surface. This effect has severe consequences on the performance of subsequently applied optical coatings. The presented results are thus of notable interest for the manufacture of coated optical components.

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