Development of laser-based processes for the production of miniaturised optical structures made of glass

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Abstract

Within the scope of two projects, processes for the laser-based production of micro lens arrays from different glass materials were developed. On the one hand, a 2.5D machining process had to be worked out for the generation of lenticular surface profiles. On the other hand, a polishing process had to be devised to restore the high optical transparency of the lens array surface after laser ablation of the material.
Micro lens arrays are miniaturised optical structures used in a variety of light homogenisation applications, such as lighting and camera systems. Due to their small size, their use allows for lighter and smaller optical assemblies. The production of micro lens arrays by laser radiation has the advantage of easily adaptable lens geometries, making it particularly suitable for small quantities and prototypes. In addition, unlike established processes (photolithography, injection moulding), no mask or individual mould is required.

Because of their high optical transparency and good mechanical, chemical and thermal resistance, silicate materials (optical glasses) for demanding operating conditions were used as substrate materials in the projects, in particular Borofloat® 33 and fused silica.

The manufacturing process consists of several steps. First, a suitable lens geometry and arrangement is determined by simulation. After data processing, the resulting model can be used for the defined laser ablation by means of the respective laser system's processing software. In this process, the lens interstices are ablated layer by layer. After modelling with ultra-short pulse lasers (USP) or short pulse (SP) CO2 lasers, the material surface is laser polished with a continuous wave (cw) CO2 laser beam. The workpieces are then evaluated using a laser scanning microscope and polarimetry. In addition, the manufactured micro lens arrays are integrated into an optical test bench to verify their functionality.

When using the USP laser beam, athermal removal of the material is achieved due to the very short laser pulses (ps), allowing very small amounts of glass to be evaporated without melting. A parameter study was carried out on Borofloat® 33 to determine processing parameters that could be used to ablate approximately 1 μm thin layers of the glass materials. This resulted in micro lens arrays with a mean roughness value of Ra $\approx$ 0.4 μm.

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Significantly higher ablation rates were achieved on fused silica using the SP-CO_2 laser. In contrast to the USP laser system, this laser system emits pulses in the nanosecond range. Again, the short pulse duration resulted in a reduced heat-affected zone in the material. The layer thickness achieved was approximately 10 μm and the arithmetic roughness value was Ra $\approx$ 1 μm.

Suitable polishing parameters were also determined. Important factors were shape accuracy and achieving the lowest possible surface roughness. A defocused laser beam was used to create a quasi-line through a fast scanning motion. This line was slowly guided over the workpiece. In this way, the glass material was heated to just below the evaporation temperature by the high and spatially limited heat input. Due to the reduced viscosity of the surface layer, the roughness was reduced by surface tension. A heating plate was used to preheat the substrates to the appropriate glass transition temperature (Tg) in order to minimize stress in the workpiece and to reduce the temperature gradients induced by the laser radiation in the material surface. A pyrometer was used to monitor and control the polishing process. Laser polishing reduced the mean roughness of the micro lens arrays to 0.08 μm while the lens radius was maintained.

The projects demonstrated that micro lens profiles with high shape and dimensional accuracy can be produced by selective laser ablation of thin glass layers. The low roughness of the resulting surfaces allows subsequent laser polishing. The developed laser polishing process smooths profiled, rough glass surfaces and improves their transparency for optical applications. By adjusting the temperature of the glass substrates to suit the material, the stress during laser polishing was kept to a minimum.
The developed processes allow glass surfaces to be shaped and polished with high precision and good reproducibility of the target parameters. Compared to conventional manufacturing processes, lens geometry and arrangement can be varied over a wide range at relatively low cost. This makes it economically feasible to produce small quantities with customized parameters. The fabricated micro lens arrays can be used for beam shaping and lighting applications.

Keywords: laser material ablation, laser polishing, micro lens array, Borofloat® 33, fused silica, USP laser, CO2 laser