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Direct Fabrication of Micro Lens Arrays by CO_2-Lasers

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Abstract

The presented project, promoted by the Federal Ministry for Economic Affairs and Energy (MF160094), shows a new way of fabricating micro-optics, especially micro lens arrays (MLA’s) with lens heights up to several hundreds of micrometers. Existing methods of MLA fabrication will be compared to the new approach and applications will be shown. A short pulse CO_2-laser system is used for the processing, which allows pulse lengths down to 200 ns. In combination with a common galvo-scanner system, the micro lenses are preformed within a very short time, by an ablation process. Here, different lens diameters, lens radii and array sizes can be produced. In a second step, the MLA is fire-polished with the same laser source. For this process step the laser is switched to cw-mode and the scanner moves in a defocused position. The preformed lenses melt and get a defined radius as a result of the surface tension of the molten glass. Measurements of the resulting geometry are be presented. The results show, that the laser based micro lens array fabrication process has a high reproducibility, very high flexibility, short processing times and can used with different glasses like borosilicate, soda lime or fused silica.

Keywords: Micro processing; Processing of Transparent Materials; Surface functionalization; Glass; CO_2-laser; Micro lens arrays

1. Introduction

Micro lens arrays (MLA’s) are arrangements of optical lenses with a diameter smaller than 1 mm, usually on a carrier. Their optical function can vary from the collimation for diode bars or waveguide arrays, over focusing for individual detector pixels, imaging for cameras, esp. light field cameras and beam homogenizing to wavefront detection in Shack-Hartmann sensors [1]. Consequently, they are used in many fields of industry, i.e. telecommunication, sensor systems, light homogenization or laser technology. Plastic

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components are often used, because they are cheap and available in large quantities. However, MLA's made of glass have a higher thermal and chemical resistance, higher refractive indices, less stray losses and better aging properties, but their fabrication is more complex.

2. Motivation

The fabrication of MLA's made out of glass is possible by reflow or resist-melting methods, which are followed by reactive ion etching to transfer the lens-structure from the polymer to the silica-substrate [2], MEMS based methods, ultraprecision machining and molding [1]. Most of these methods have the downside of using a mask or molding tool which is usually very expensive and needs some thousand pieces produced to be cost-effective. These methods are very inflexible with regards to changing requirements and small lot sizes. With ultraprecision machining, the individual lenses are usually not identical, i.e. they all have individual fabrication deviations and the tools are very expensive. Depending on the lens depth, the beam etching-methods have very long process times and consequently very high cost.

For these reasons, a new method of direct fabrication was developed. A CO_2-Laser directly ablates the desired lens profiles directly in the glass substrate in pulsed mode and then polishes the resulting surface in cw-mode. The CO_2-Laser was chosen to make use of the linear absorption of glasses at the laser wavelength of 10.6 µm which leads to much higher ablation rates than with USP-lasers. The aim of the research project was to produce MLA's of 1 cm^2 size in under 5 minutes, with programmable freedom of lens diameter and focal length, reaching filling factors >90%.

3. Setup

The laser which was used for the experiments is a ns-CO_2-laser by FEHA LaserTec GmbH. It has an average output power of 700 W, a pulse length of about 200 ns, a pulse frequency of up to 150 kHz and a pulse energy of up to 50mJ. The laser was operated either in q-switch mode or in cw-mode by directly controlling the AOM-voltage respectively (see [3] for details). The charm of using this system is the possibility to work with short pulses for the ablation of the glass material and on the other hand to work in continuous wave mode for "fire polishing". Only one laser source is necessary. To move the laser focus on the substrate, a galvo-scanner with an f-Theta-lens (hurryscan 30; SCANLAB GmbH) were used. The scanner has a repetition-accuracy of <22 µrad. This translates to 5 µm with the focal length of 200 mm used here.

Since the production of MLA's should be carried out on borosilicate, soda-lime glass and fused silica, a preheating was implemented in the sample holder. This reduces the thermal stress on the material during the polishing. Fused silica can be processed without preheating. All other glasses (soda lime and borosilicate glass) were heated up to their transformation temperature in the range between 500° C and 600° C. For temperature regulation a self-build-controller was used. The temperature of the sample holder was measured with a thermistor and the heating power was set accordingly. Additionally, the surface temperature of the glass was measured with a pyrometer (MY51 Sensortherm GmbH).

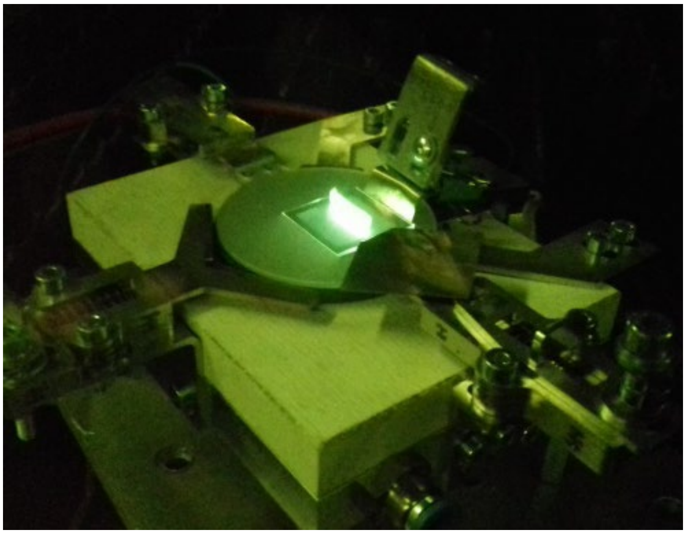

Fig. 1. Sample processing

The sample holder during the process is shown in figure 1, it is mounted on an axis-system, so the galvo-scanner is not above the heated glass substrate during heat-up and the scanner can automatically move to different horizontal position for the fire polish process.

The processed surfaces were measured with a laser scanning microscope (Keyence VK-X100). From these data the specifications of the lenses were calculated and compared with the targeted values. A polarimeter (ILIS StrainMatic M4/90 zoom) was used to measure the residual strain in the samples.

4. Experiments and Results

The strategy of fabrication is the following: In the first step the edges of the lenses are ablated with lines of 300-500 µm distance (the lens pitch). Depending on the laser parameters used, the edges of the resulting surface structures are steep or already slightly polished (see Fig. 2). The possible ablation depth ranges from several µm to several hundreds of micrometers.

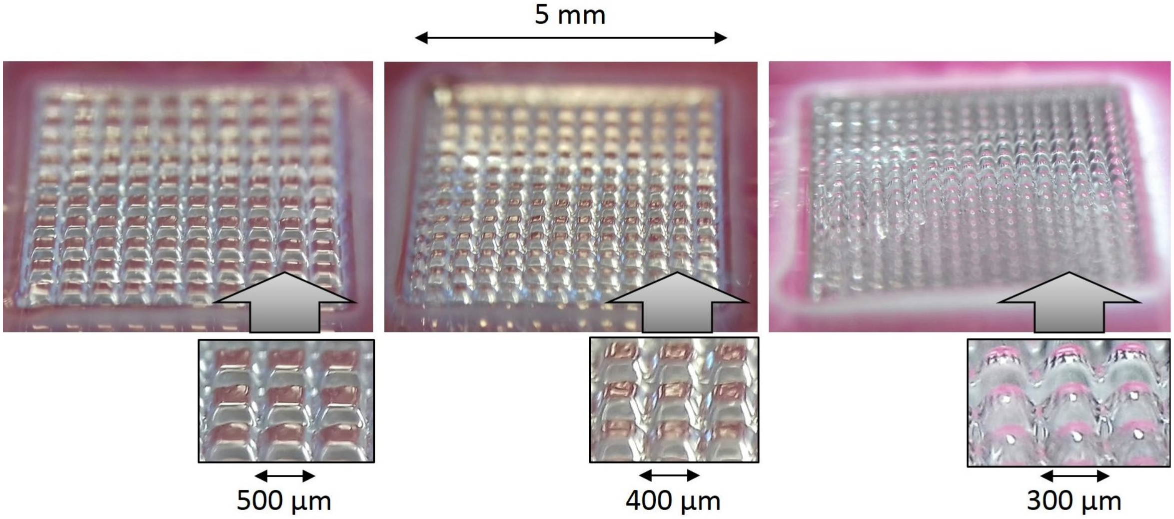

Fig. 2. result of the first ablation step

In the second step the surface structures were melted by a laser-based “fire polish” process. Therefore, the laser spot size is increased by moving the sample out of the focus of the f-Theta-lens. By this way, a high laser power can be used for a fast polishing of the whole surface, but without reaching the evaporation temperature of the material. Because of the surface tension of the molten glass, the structures form a spherical surface. During the polishing process the laser power was controlled by the pyrometer to stabilize the surface temperature in a way, so that the time was long enough for the surface tension to shape the lenses.

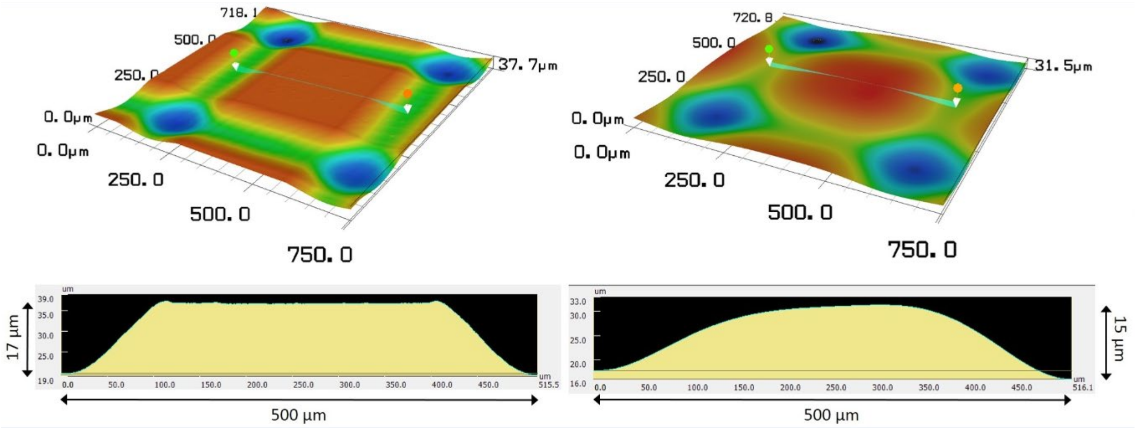

Fig. 3. LSM-measurement of an early processed surface before (left) and after (right) the polish

The profile of an early structured surface before and after the polish is shown in fig. 3. Two important aspects can be deducted from these measurements: First, the crosspoints of the ablation lines are to deep and disturb the profiles and second the resulting lenses were partially not symmetric. The first problem could be solved by changing the ablation pattern to a series of short lines, see fig 4. The asymmetry of the lenses could be removed by further increasing the spot size of the polish-beam to make sure, that each lens is irradiated homogeneously during the process.

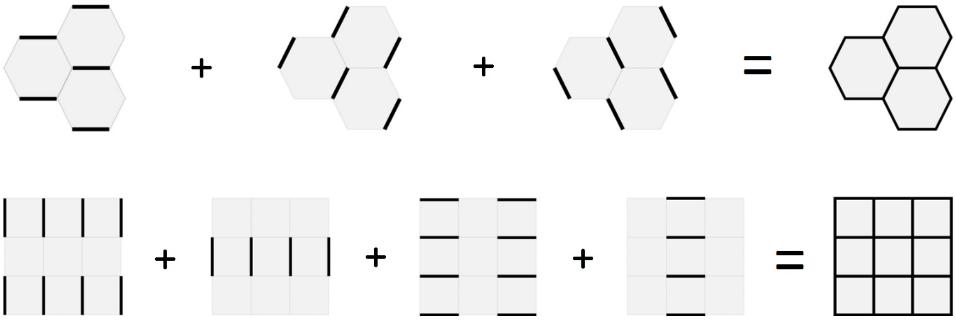

Fig. 4. optimized line ablation strategies without crosspoints

Figure 5 shows the result of this optimization process. The lenses are symmetric and perfectly spherical over a diameter of more than 350 µm, at a pitch of 500 µm.

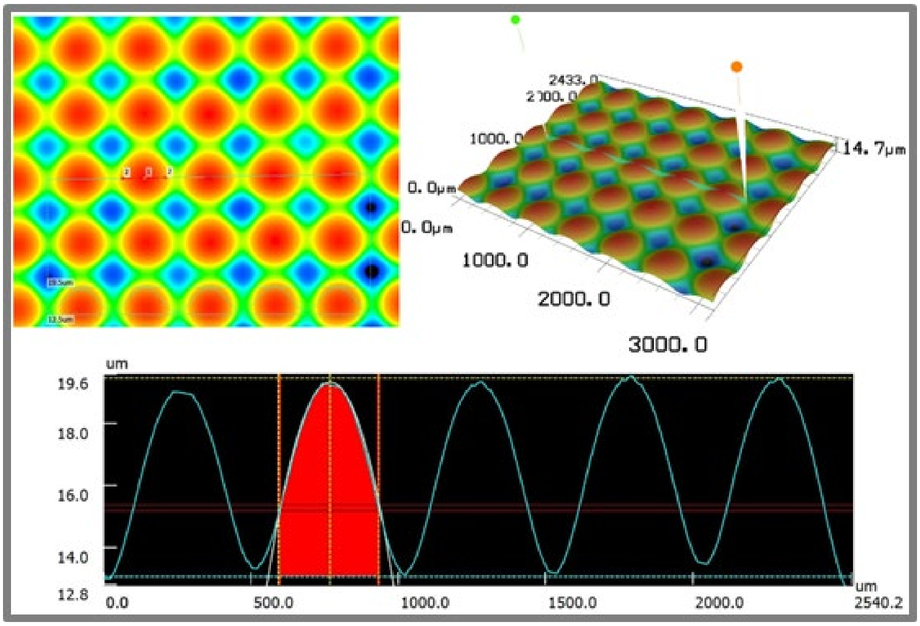

Fig. 5. surface profile after first optimization steps

For a first test of optical properties of the MLA, the samples were irradiated with a point source and the foci were measured with a camera. The results, depicted in fig. 6, show a very homogenous pattern of foci. This shows that adjacent microlenses have very similar shapes and focal lengths. Over the full 1 cm-length of the sample, a deviation of the focus depth can be seen. This was attributed to a slight inhomogeneity of the preheating-plate and will be improved in future experiments.

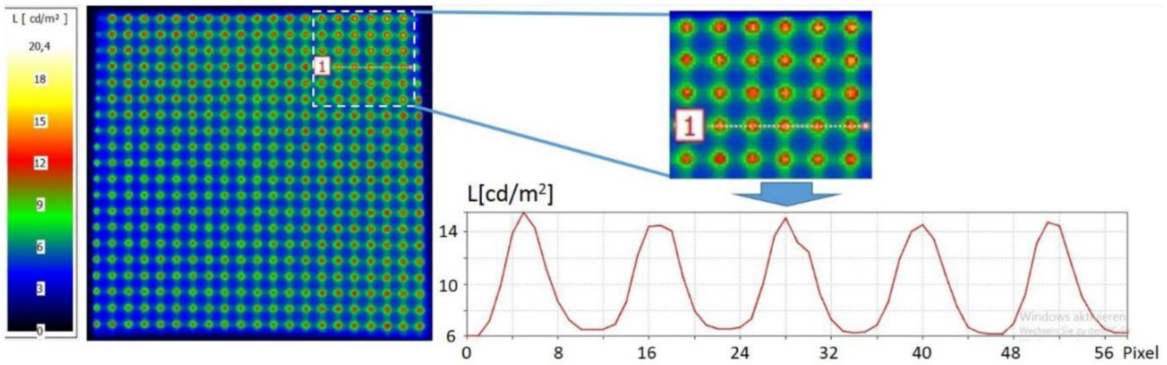

Fig. 6. focus-profile of the produces MLA under irradiation from a point source

5. Conclusions

A new method for fabrication MLA's was developed. The process is very fast flexible with regards to the geometrical specifications of the MLA. An array in the size of 2 x 2 cm² needs approx. 3 minutes of processing time. Different lens sizes down to 200µm are programmable. Also, the size of MLA's can be varied without the need for toolmaking. Microlens heights from some micrometers to several hundred micrometers are producible. Further research will address the characterization and optimization of the optical quality and the processing of non-planar surfaces, like compound eyes.

Funding

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