Refractive beam-shaping element fabricated by silver-sodium ion-exchange in glass

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In order to implement a beam-shaping element for high power applications, glass optics is favourable to plastic optics since the absorbed power can affect the optical material. We suggest mask-assisted thermal silver-sodium ion-exchange for fabrication of gradient index phase elements in a planar glass substrate. Our first results are presented here.

1 Introduction

Laser beam-shaping is of large importance for many illumination tasks, e.g. for microscopy or optical sensors but also for high power applications like material-processing, where a certain intensity distribution of the laser beam is required.

Plastic optics is not applicable for the latter case, therefore we are looking for possible realisations in glass. We propose mask-assisted silver-sodium ion-exchange in planar glass substrates as a suitable manufacturing method for refractive beam-shaping elements.

2 Design of a refractive beam-shaping element

We start with a rotational symmetric laser beam with a gaussian intensity distribution.

$$I_1(r) = \exp\left(-p\,\frac{r^2}{s^2}\right) \qquad (1)$$

Our goal is to generate a flat-top distribution with a homogeneous intensity level over a certain circular area with radius r_2.

$$I_2(r) = \begin{cases} I_{FT} & \text{if } |r| \le r_2 \\ 0 & \text{else} \end{cases} \qquad (2)$$

We can state the following law of power conservation which describes the beam-shaping elements function:

$$P_1(r_1) = 2p\int_0^{r_1} I_1(r)\cdot r\cdot dr = 2p\int_0^{r_2} I_2(r)\cdot r\cdot dr = P_2(r_2) \qquad (3)$$

Equation (3) states that the power up to the radius r_1 is preserved and transformed to the circular area within radius r_2 of the flat-top distribution.

From this integral equation one can derive a differential equation for the phase distribution of the desired element which will perform the beam-shaping.

$$\frac{\partial^2 j}{\partial r^2} = \frac{k}{z}\left(\frac{I_1}{I_2}\cdot\frac{r}{r + \dfrac{z}{k}\dfrac{\partial j}{\partial r}}\right) \qquad (4)$$

By numerically solving this equation we obtain the phase of the element, which generates the desired intensity distribution in a certain distance z. If in addition to that, the phase is also important, e. g. if the distribution must be preserved even for larger propagation distances, a second element which corrects the phase has to be introduced at this position. The optical system is shown in Fig. 1.

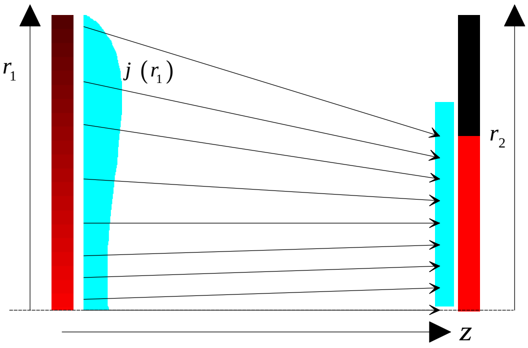

Fig. 1 *Optical system for beam-shaping*

3 Fabrication through ion-exchange in glass

The objective is to locally rise the refractive index of a glass by substituting sodium ions inside the glass matrix for silver ions from a salt melt. The result is a gradient index element inside the planar glass substrate.

In order to control this process, we apply a metal mask which is lithographically structured. Thus the ions in the melt can only reach the glass at certain positions. The pattern we used for the mask consists of circular apertures of different sizes, varied placement density and position. Fig. 2 shows the principle of mask-structured ion-exchange.

We used diffusion times of about 23 hours and an additional annealing step of approx. 48 hours without an external source of ions.

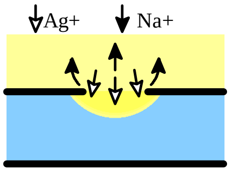

Fig. 2 *Principle of mask-structured ion-exchange*

4 Characterisation of first results

The measurement of the phase distribution is done with a Mach-Zehnder interferometer. Fig. 3 shows the measured phase in greyscale coding. A comparison between the computed profile and the fabricated element is given in Fig. 4.

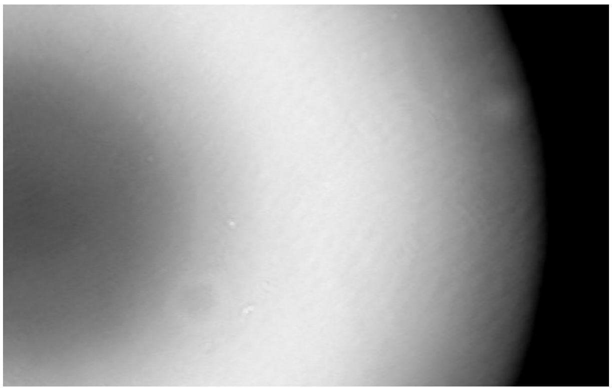

Fig. 3 *Measured phase distribution, range: Fig. 4*

In order to validate the beam shaping characteristics of the manufactured element, we introduced it into an expanded gaussian laser beam and measured the intensity distribution at the distance where the flat-top should be observable. In Fig. 5 one can see the original gaussian beam profile and the intensity distribution after inserting the manufactured element.

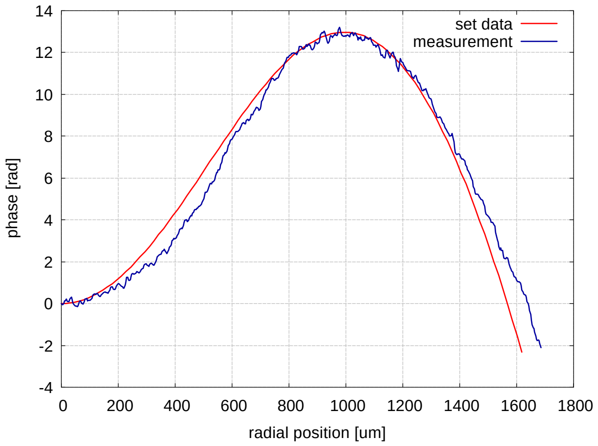

Fig. 4 *Comparison between measured phase profile and computed values*

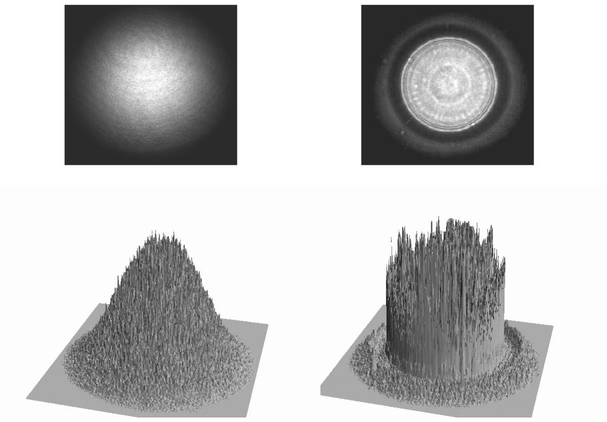

Fig. 5 *Gaussian beam and beam profile after introducing the fabricated element.*

5 Outlook

We have shown that it is possible to realise a rotational symmetric beam-shaping element by MSI. Asymmetric geometries, which are needed for special needs such as diode-lasers or specific illumination tasks should be possible, as well as the second element for phase correction.

By fabricating both elements through MSI we obtain two planar glass substrates with an index distribution inside, which we can easily assemble to an integrated beam-shaping system.

References

[1] J. Bähr, K.-H. Brenner, “Realization of refractive continuous phase elements with high design freedom by mask structured ion exchange", Proceedings of SPIE, Vol. 4437, 50 – 60, ISSN 0277-786X/01, San Diego (2001)