Three dimensional Modification of the Refractive Index in Photosensitive Foturan Glass

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This paper presents a new approach for a nonlinear absorption based laser induced 3D patterning in Foturan glass. With this approach we have successfully integrated different functional devices such as volume Bragg gratings and volume holograms in to the bulk of the glass.

1 Introduction

Glasses are one of the essential materials for high technologies. Especially optical applications have demanding needs for technical glasses and the integration of optical elements. Usually such components are applied for example in realizing safety features or certifications, lighting effects, wave guiding, data storage and optical filters or sensors. Particularly, the possibility of realizing arbitrary structures in the bulk of the glass allows for the integration of new optical functions. Photosensitive glasses such as Foturan enable a direct writing based spatial modification of refractive index [1]. In this article, preliminary work on the fabrication of three-dimensional diffractive optical elements such as volume Bragg grating (VBG) and computer-generated volume holograms (CGVH) is presented [2].

2 Setup and process parameters

The following section describes the laser system and its specifications. A summary of the nonlinear and chemicals effects that can be induced in this glass using our system is also presented. **Figure *1*** shows the corresponding experimental setup. The Specifications of the laser and motion stages are as follows: wavelength 1550*nm*, repetition rate up to 100*kHz*, pulse energy up to 50*µJ* and pulse energy < 800*fs*

Foturan is a technical glass, which is enriched with Cerium, thereby increasing its photosensitivity. By exposing it to light in the ultraviolet spectral range, Ce^{3+} atoms switch to the Ce^{4+} state thereby emitting an electron. Silver ion Ag^+ bonds with the electron and an Ag seed occurs. Using tightly focused ultra-short pulses in the infrared range, a multi-photon absorption process can be induced. This process is only induced in the focal region, where there is a high photon density. Thus, small refractive index changes in the volume of the glass are possible. A post bake process of around 600° C per hour enhances the reaction of the Ag-crystallization [1].

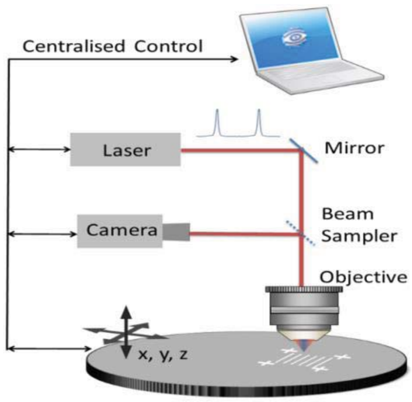

Figure 1: Experimental setup: the laser beam is focused within the bulk of the glass-wafer with a microscope objective. Motion stages are programmed to position the wafer accordingly and to move in a predefined pattern to create the desired structures.

3 Experimental results

To characterize the system and thereby assess the feasibility of fabricating 3D optical elements in the bulk of Foturan glass, a series of simulations were implemented using a beam propagation method (BPM) [3]. Initial investigations consisted in analyzing the transmission of a light through a volume Bragg grating (VBG), which is embedded in the bulk of the material. This was modelled as a weak scattering element having a sinusoidal refractive index modulation, whereby the peak index change was taken to be $\delta n = 1 \cdot 10^{-3}$. **Figure *2*** shows the results of a simulation of the transmission of a Gaussian beam which is incident on the VBG at a Bragg angle. The VBG had a thickness of $d = 120\mu m$ and a grating period of $\Lambda = 5\mu m$. It is apparent from **Figure *2*** that the VBG produces a single diffracted order at the Bragg angle θ_m at a given diffraction order m.

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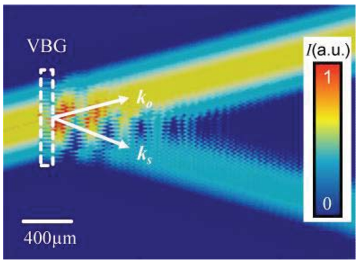

Figure 2: Simulation of the transmission of a Gaussian beam through a volume Bragg grating with a thickness of 120 µm and having a sinusoidal refractive index modulation.

In a first step, experiments were conducted to determine the Bragg angle given a VBG with these parameters. This was done by calculating the angle between the illuminating beam k_o and the scattered beam k_s and an angle of $\theta_1 = 3.6°$ was attained for the first diffraction order.

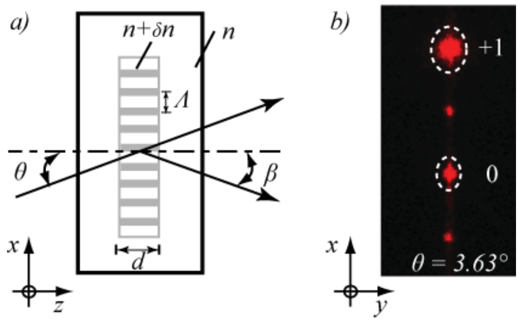

Figure 3: (a) Schematic of the VBG the setup used to measure the efficiency of the VBGs, from which the induced refractive index could be determined. (a) Diffraction pattern of a VBG illuminated with a He-Ne laser.

To investigate the optimum pulse energy for the fabrication of 3D optical elements, the VBG described above was realized and its performance was characterized. For this purpose a set of VBGs were fabricated using different pulse energies and employing the procedure described in section 2. For each of the gratings the diffraction efficiency of the first order was determined as shown in ***Figure 3***. The refractive index modulation was then calculated using the Bragg condition [4]. The results acquired showed good agreement with the BPM results. The optimum pulse energy for inducing an index change $\delta n \approx 1 \cdot 10^{-3}$ was found to be $5nJ$.

This preliminary studies paved way to the fabrication of computer generated volume holograms (CGVH) in the bulk of Foturan glass. A CGVH of voxel Volume 64^3 (c.f. **Figure *4***) with voxel sizes of 1x1x1.5μm was realized. Investigation on the performance of the CGVHs described here was recently reported [2]. These CGVHs can be applied to realize a hybrid system that facilitates dynamic synthesis of wave fields with a large space-bandwidth-product as compared to conventional DOEs. Such a system has been described in depth elsewhere [3]. Using a DIC microscope [5], the distribution of the induced refractive-index change was characterized and a good agreement between designed and fabricated structures could be observed as it can be seen in ***Fig. 3*** (a) and (b).

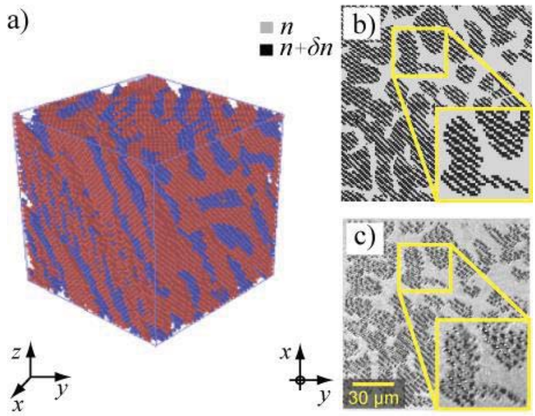

Figure 4: (a) CAD of the CGVH generated during the design process. (b) Top layer of the CGVH and (b) its DIC micrograph after fabrication [2].

4 Conclusion

In this work we demonstrated an approach that allows for the fabrication of functional devices in the bulk of photosensitive Foturan Glass by means of a nonlinear laser induced 3D modification of refractive index.

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