Maskless lithography and its applications in holography, diffractive optics and integrated photonics

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We present a maskless lithography setup to fabricate microstructures with optical functionality in polymers. The lithography setup is utilized to create a micro-structured hot embossing stamp. Subsequently, the stamp is employed to generate diffractive optical elements and holographic structures in polymethylmethacrylate (PMMA). Waveguides are fabricated by applying a core material onto hot embossed trenches through a doctor blading process. In future applications, our method will enable the fabrication of integrated devices such as Mach-Zehnder interferometers and micro-spectrometers.

1 Introduction

Modern trends in optics and photonics are heading towards smaller feature sizes and complex structures of optical elements to be fabricated by lithographic processes. The rapid development of consumer optics and also various research applications are, in addition, leading to an urge for flexible and fast processes to generate micro-patterns with optical functionality. Prominent examples of such micro-structures are integrated photonic devices where optical waveguides form the building blocks. To achieve a desired optical functionality not only an accurate optical design is required but also its realization in suitable optical material is crucial. While in the past semiconductor materials such as silicon were mostly used for the realization of optical devices, modern research focuses on polymers. Especially plastic materials offer several advantages compared to their semiconductor counterparts, among which low asset cost and the capability for high-throughput fabrication are important aspects. Also, flexible process technologies for polymers are available which meet modern demands with regard to industry 4.0. To create micro-optics or even waveguide structures, printing techniques such as inkjet-printing have drawn great attention [1]. The spectrum of applications of such highly integrated optical photonics is broad and ranges from displacement sensors [2] to micro-opto-fluidic chips for biomedical sensing [3].

In this work, we present a maskless lithography setup based on a simple microscope setup and a digital-mirror-device (DMD) projection system to generate arbitrary microstructures in photosensitive resist or optical materials such as hybrid polymers directly [4,5]. The former material class requires a soft stamp hot embossing process to create transparent optical structures and is especially suited for diffractive optics and holographic structures [4,6]. However, the latter material class offers the possibility to instantaneously fabricate fully polymer based integrated photonic devices and components such as optical waveguides. We present our latest results utilizing both materials classes with an emphasis on polymer optics including diffractive optical elements and directly patterned optical waveguides and sensing structures.

2 Fabrication Process

The initial fabrication step relies on maskless lithography. A silicon wafer or silica microscope cover slide serves as substrate for a photosensitive resist layer (Shipley S1813 or Microsresist Ormocomp). After thermal pretreatment, the resist is exposed to light by utilizing a self-developed lithography setup shown in Fig. 1.

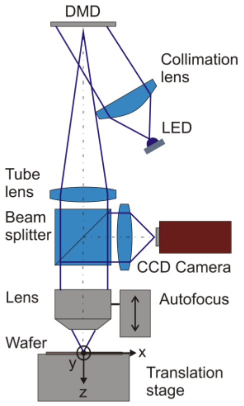

Fig 1 *Maskless lithography setup.*

The setup consists of a standard microscope (Carl Zeiss) including a microscope lens (Carl Zeiss Epiplan 10x) with a numerical aperture of 0.3 and a magnification of 10.

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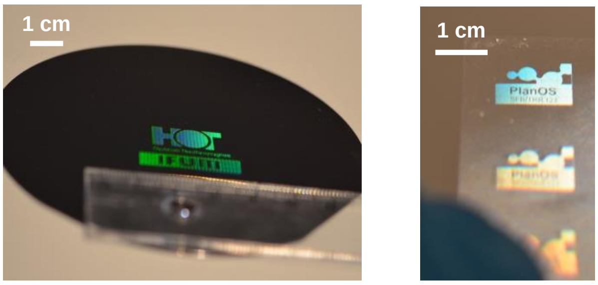

Fig. 2 *Diffractive optical elements on silicon substrate (left) and PMMA foil (right).*

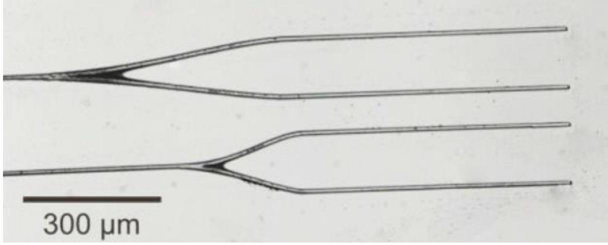

Fig. 3 *Waveguides and beam splitters fabricated on PMMA substrate.*

A digital mirror device (DMD, Texas Instruments) is mounted onto the microscope which generates the intensity pattern to be projected onto the substrate. Two light emitting diodes (LED) serve as light sources which run at a wavelength of 650 nm and 405 nm, respectively. To obtain a homogenous intensity distribution on the DMD, the emitted light by the LED is collimated by an achromatic doublet (Thorlabs). The DMD image is projected via the microscope onto the substrate, which is placed onto a xy-translation stage (consisting of two SLC-1780-S stages, Smaract). The translation stage allows for performing a stitching process including sequential exposures to achieve a maximal structurable area of 5 x 5 cm^2. To assure a constant focal position during each exposure run, the setup includes an autofocus system consisting of a linear translation stage (SLC-1780-S, Smaract) which serves as variable mount for the microscope lens. The best focal position is determined by projecting a black and white checkboard pattern onto the substrate and determining the optical feedback by an additional camera (pike F421, AVT). Autofocusing is carried out at a wavelength of 650 nm while the LED with a wavelength of 405 nm is only switched on for a defined time during an exposure run (details are given in [7]). The exposure time depends on the resist and was 10 s and 180 s in the case of S1813 and Ormocomp, respectively. After development, the substrate was placed in a lab-made hot embossing machine described in detail in [4]. The micro-pattern was transferred into PMMA at an embossing temperature of 140°C and an embossing force of approximately 4kN. Demolding was carried out at room temperature manually.

For waveguide fabrication, a liquid core monomer (390119 UV Supraflex, Jänecke+Schneemann Druckfarben) was applied onto the hot embossed substrate, spread through a manual doctor blading process and cured by UV exposure.

Results

Fig. 2 (left) shows diffractive optical elements fabricated by maskless lithography consisting of diffraction gratings with a period length of 5.4 µm. Such grating structures were transferred into PMMA substrate through hot embossing and are shown in Fig. 2 (right). First results of fabricated waveguides and Y-shaped beam splitters are shown in Fig. 3. Confocal topography measurements reveal a remaining peak-to-valley surface waviness of 20 nm inside the waveguide region. However, wave guiding and splitting was achieved and will be characterized in future work.

3 Conclusion

Diffractive optical elements as well as waveguides and waveguide based beam splitters with a feature size of 1.35 µm were fabricated by means of maskless lithography. Propagation losses and optical properties of the fabricated waveguides will be studied in future work. Also, we aim at the fabrication of more complex integrated optical sensing structures such as Mach-Zehnder interferometers and micro-spectrometers.

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