Optical Coupling Structures for Integrated Polymer Photonics

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Integrated polymer photonics is highly relevant to various fields in optical technologies ranging from optical communication to integrated sensor networks. Key components of such networks are low-loss coupling structures to connect light sources, detectors and other optical components. In this work, we present different fully polymer based coupling structures to connect horizontal and vertical emitting light sources to polymer waveguide structures.

Optical information technology is a promising research field. The integration of optical wave guiding and sensor structures into complex photonic networks becomes increasingly important [1, 2]. The main advantages of using optical waveguides and interconnects are the insusceptibility for electromagnetic interference, higher bandwidth, lower power consumption and production costs in contrast to classical electronic circuits [3].

Requirements which optical waveguides have to fulfill in order to replace current electrical systems are low attenuation values and efficient coupling structures. Most of the currently used optical systems rely on silicon based fabrication processes. Because they are inherently expensive and time consuming, using polymers is a promising approach suitable for mass production.

1 Waveguide processing

An established process to replicate small polymeric structures with high accuracy in numerous quantities is hot embossing. The process is schematically shown is Figure 1.

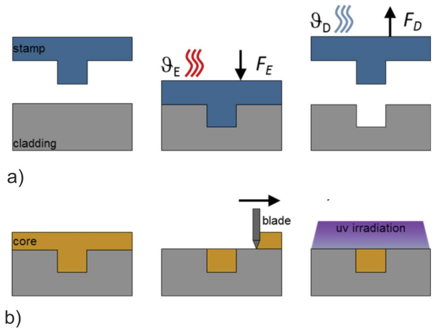

Fig. 1 *Waveguide fabrication through hot embossing: a) embossing trench structures into thermoplastic substrate; b) filling, doctor blading and UV-curing of core.*

Using the process described in Figure 1, waveguides with a core dimensions of $25\ \mu\mathrm{m} \times 25\ \mu\mathrm{m}$ and attenuation values of $0.76\,\mathrm{dB/cm}$ and $0.09\,\mathrm{dB/cm}$ for a wavelength of $633\,\mathrm{nm}$ and $850\,\mathrm{nm}$ were achieved, respectively.

2 Coupling structures

Established coupling structures used for silicon based waveguides are promising to be transferred to their polymer based counterparts. Hereby, mirror couplers, which are based on total internal reflection at a $45°$ edge are often used for multimode systems with core diameters larger than $50\ \mu\mathrm{m}$. In the single or few mode regime, evanescent field or grating couplers are usually used. Due to the required feature sizes in the nanometer range for evanescent field couplers, they are unsuitable to be used in flexible polymer films. Another technique which allows the connection of multiple wave guiding components are self-written waveguides (SWW). Here, we discuss various coupling structures and present first results of couplers integrated in a full polymer system.

3 Micro-mirror

The principle of a mirror coupler is shown in Figure 2.

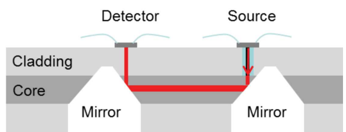

Fig. 2 *Schematic of a micro-mirror coupling structure.*

Mirror couplers can be realized with an additional process step after the hot embossing process. Hereby, a $45°$ edge has to be produced using a micro-milling machine or a cutting tool designed accordingly. One of the most decisive parameters concerning coupling efficiency of this structure is the surface roughness of the fabricated edge. In our experiments an additional micro-milling process was used to mill the coupling structure into the hot embossed waveguide. Thereby a coupling efficiency of $4.6\,\mathrm{dB}$ was achieved.

DGaO Proceedings 2016 - http://www.dgao-proceedings.de - ISSN: 1614-8436 - urn:nbn:de:0287-2016-A015-3

submitted: 23.Jul.2016 - published: 10.Aug.2016

4 Grating coupler

Normally, grating couplers are used as coupling elements for single and few mode wave guiding structures. We also examined this coupling concept for our fully polymer based multimode waveguides also aiming at the fabrication of single mode waveguides in future work. Two different types of gratings were tested to evaluate suitable designs. One of them is a combination of a straight grating with a taper structure, where the fabrication process is schematically shown in Figure 3(a).

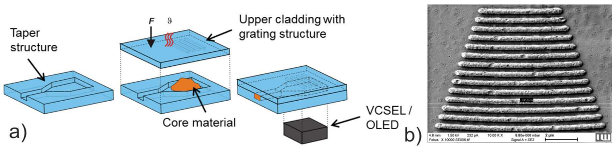

Fig. 3 *a) Schematic of the fabrication process of a combination of taper and straight grating structure using a hot embossing process. b) REM-image of the forefront of a focused grating*

The process sketched in Figure 3(a) shows how the fabrication using a hot embossing machine was realized. First, the taper and waveguide structure were embossed into the cladding substrate made from poly(methyl methacrylate)(PMMA). Subsequently, a second PMMA substrate was structured with a stamp containing the grating structure. Finally, the taper structure was filled with core material, both substrates were pressed onto each other and the core was cured by UV-exposure. Figure 3(b) illustrates the design of a focused grating. Using this structure, incoupling can be realized without an additional taper structure. Due to the radially arranged grating structures converging towards the waveguide, the vertically incoming beam emitted from the light source is directly diffracted into the waveguide. However, due to the low refractive index contrast between grating and cladding, the grating structure inside the foil only yields a diffraction efficiency of $1.2\,\%$. This value was increased to $57\,\%$ by coating the grating structure with a few nanometer thin silver layer.

5 Self written waveguides

Another possibility to couple light into waveguides is given by self-written waveguides (SWW). This technology is based on photosensitive monomers and has already been presented in [4]. The main limitation of this technology for writing interconnects was the requirement for writing wavelengths near the UV, while most polymer materials commonly used in integrated photonics exhibit a high attenuation in this spectral region. By extending this technology for different wavelengths, we were able to connect light sources such as laser diodes (LD) with polymeric waveguides creating a low loss SWW connection. This technology enables the integration of horizontal emitting light sources into thin polymer foil, as shown in Figure 4.

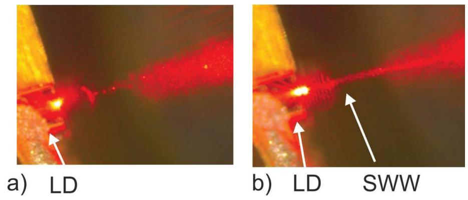

Fig. 4 *Fabrication of a SWW to connect a bare LD chip; microscope images taken during the writing process: a) few seconds after initiation of the writing process; b) final SWW after completion of the writing process.*

The technique was used to realize an interconnect between a LD with a lateral dimension of $200\ \mu\mathrm{m} \times 300\ \mu\mathrm{m}$ and a waveguide with a rectangular cross-section with a diameter of $25\ \mu\mathrm{m} \times 25\ \mu\mathrm{m}$. Coupling losses of $6.2\,\mathrm{dB}$ were achieved.

6 Summary

We presented various coupling structures and evaluated them concerning their applicability as efficient couplers for full polymer wave guiding systems. Hereby, the efficiencies are comparable with those commonly observed for silicon or hybrid silicon-polymer based integrated photonic devices. Additionally, the demonstrated structures enable incoupling of light into waveguides of various sizes. Even though this work focuses on full polymer optical systems, our couplers are directly transferable to integrated photonic devices made from other material classes.

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