1 x 2 and 1 x 3 Multimode Interference Couplers Fabricated by Hot Embossing and DUV-induced Modification of Polymers

Mathias Bruendel[1] and Dominik G. Rabus[2]

[1] Institute for Microstructure Technology, Forschungszentrum Karlsruhe GmbH, P.O. Box 36 40, 76021 Karlsruhe, Germany
Phone +49 7247 82 4684 Fax +49 7247 82 4331 e-mail: mathias.bruendel@imt.fzk.de

[2] University of California, Santa Cruz, Baskin School of Engineering, 1156 High St., Santa Cruz, CA 95064, USA

***Abstract*— We present 1 x 2 and 1 x 3 multimode interference couplers (MMI) for the 1.5 µm wavelength region fabricated by hot embossing and deep UV modification of the used polymer.**

I. Introduction

The all optical networks requires a major reduction in the cost of optical components. Polymer waveguides are attractive because they are very simple to process and are promising for low-cost devices [1]. A basic component which is implemented for a variety of optical signal processing and routing functions is a multimode-interference coupler (MMI) [2]. These multimode interference devices offer important advantages such as compact size, low imbalance and crosstalk. In comparison to co-directional couplers the main advantage is the fabrication tolerance. Replication technologies have attracted a lot of attention lately and have been used to realize MMI couplers and Y-splitters in polymers [3], [4].

Planar MMIs in polymethylmethacrylate (PMMA) using deep UV refractive index modification of the polymer has recently been demonstrated by our group [5]. This process is transferred to realize rib waveguide based MMI devices which are described in this paper.

II. Fabrication Method

Hot embossing and soft lithography of micro optical components has become a routinely used replication technology for polymers [6]. Low flow rates and slow molding speeds ensure that even the smallest details in the nanometer range are replicated perfectly. Hot embossing is particularly suited for structuring plane plates and foils, as only a small amount of plastic has to be molded. In contrast to injection molding, the polymer flows a very short way from the foil into the microstructure during hot embossing. As a result, very little stress is induced into the polymer and the molded parts are well suited as optical components, such as waveguides and lenses. Optical waveguides made of hot embossed ridge structures of methylmethacrylate polymers require an additional deep UV exposure in order to partly change the refractive index of the polymer at the rib surface [7]. Figure 1 summarizes the principle processing steps for the manufacturing of the embossing tool, the replication of the molded part, and the realization of a photochemically altered surface layer for increasing the refractive index.

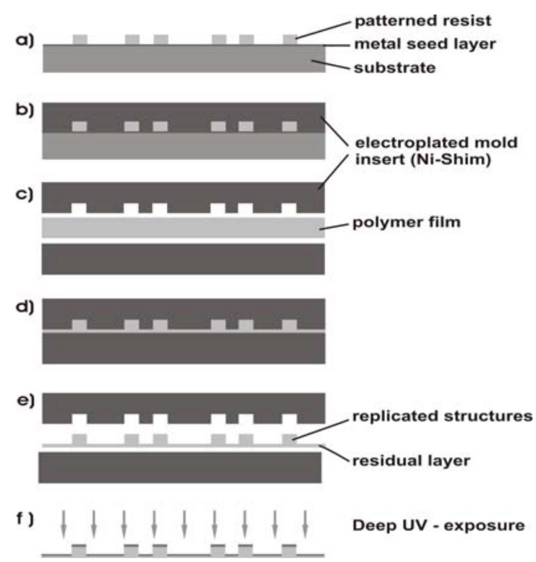

Fig. 1 Process steps for tool manufacturing, hot embossing of ridge waveguide structures and deep UV flood exposure.

III. Simulation

The device simulation and optimization is performed using Beamprop from RSoft. Structures are designed and fabricated for the 1.5 µm wavelength region. Due to the absorption of the deep UV radiation in the material, the waveguide is regarded as vertically diffused with an exponential decay of the refractive index. The upper limit for single mode behaviour is calculated to be a width of the rib of about 20 µm. A width of 17 µm was chosen for input/output waveguides and S-bends to compensate manufacturing tolerances. The distance between the top of the rib and the surface of the substrate has to be large enough to avoid light coupling between them. The simulation shows that a minimum rib height of 17 µm is needed to fulfil this condition. To compensate computing errors and tolerances in the manufacturing process, a minimum structure height of 19 µm was chosen. The optimum 3 dB coupling length of the 1 x 2 MMI was obtained from simulation to be 1213 µm. The width of the 1 x 2 MMI is 50 µm. The designed 1 x 3 MMI coupler has a length of 1297 µm and a width of 63 µm. S-bends are used to realize a waveguide spacing of 250 µm at the facet. The length of the elements was varied to compensate manufacturing tolerances and inaccuracies in the simulation model.

IV. Experimental Results

A. Straight waveguide

The insertion loss of a waveguide of length 17.4 mm at a wavelength of 1550 nm was determined using the cut back method to be 4.9 dB including fiber-chip coupling loss. The fiber chip coupling loss is calculated to be 3.0 dB for both facets, resulting in a waveguide loss of 1.1 dB/cm and a fiber to chip coupling loss of 1.5 dB per facet. The waveguide loss is comparable to planar waveguides fabricated with deep UV technology [5]. The width of a single mode waveguide is 17 µm.

B. 1 x 2 Multimode interference coupler

The insertion loss of the 3 dB 1 x 2 MMI devices (Fig. 2) measured at each of the two output ports is 9 dB. This means that 1 x 2 MMI couplers have 1.1 dB additional losses compared to a rib waveguide of the same length. The length and width of the device are 1213 µm and 50 µm, respectively.

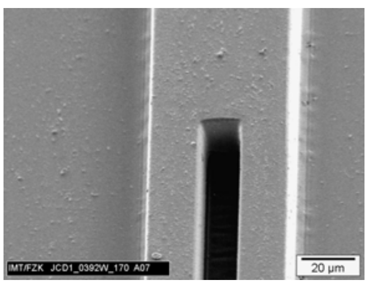

Fig. 2. Photograph of the output region of an embossed 1 x 2 MMI coupler.

A nearfield photograph of the output waveguides of a 1 x 2 MMI coupler is shown in Fig. 3. It can be clearly seen that the output waveguides are single mode and symmetric.

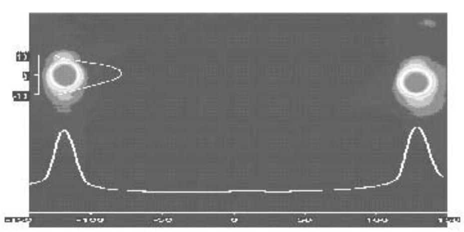

Fig. 3. Nearfield image of the facet of a 1 x 2 MMI coupler.

C. 1 x 3 Multimode interference coupler

The length and width of the device are 1197 µm and 63 µm, respectively. The device has an insertion loss of 11.8 dB per output waveguide with a deviation of ±0.5 dB. This means that the additional loss of the coupler is 2.1 dB higher compared to a straight waveguide of the same length.

The wavelength dependency of the intensity of the three output ports is presented in Fig. 4.

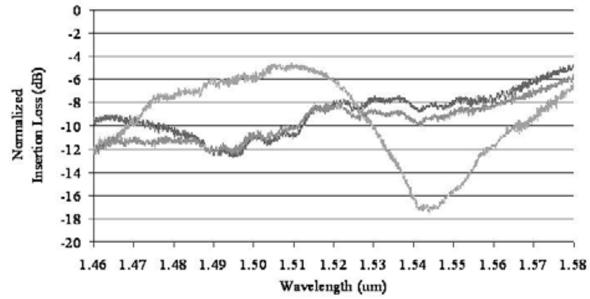

Fig. 4. Wavelength dependency of the output ports of a 1 x 3 MMI coupler

The two outer output waveguides show a nearly symmetric behavior. The center output waveguide is strongly intensity dependent and the total length of the MMI coupler has to be adjusted correctly to assure a symmetric output coupling behavior for all three ports. There are two wavelength regions for achieving this, at 1.525 and 1.58 µm.

V. Conclusion

In conclusion, 1 x 2 and 1 x 3 MMI couplers have been presented which have been fabricated by hot embossing and deep UV modification of the used polymer for increasing the refractive index. The additional losses of the 1 x 2 and 1 x 3 MMI couplers are 1.1 dB and 2.1 dB, respectively. Symmetric coupling behavior for both types of MMI couplers has been demonstrated. This technology enables the reduction of fabrication costs and can be used to realize various photonic integrated circuits in polymers.

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