Photonic Integrated Circuits by DUV-induced Modification of Polymers for Telecom and Sensor applications

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Abstract: *The results of polymer Y-splitters, codirectional couplers and multimode interference couplers, realized by deep UV lithography are presented.*

1. Introduction

The expansion of high capacity optical transmission techniques into price-sensitive areas such as telecom, datacom and access networks requires a major cost reduction of optical components. Polymer waveguides are attractive because they are very simple to process and are promising for low-cost devices.

Deep UV-induced modification of the dielectric properties of polymers [1] is a useful technique for low cost realization of integrated optical circuits for telecommunication and sensor applications. The technique presented has several advantages with respect to common methods. Here only a single polymer layer is used, which serves as the substrate and waveguide as well and no further etching or development step is required. The integration of the waveguide circuits in a polymer micro optical bench [2] offers the possibility of combining the devices with semiconductor based optical circuits and also achieve easy fibre-chip coupling.

In this work, results of fabricated Y-junctions, directional couplers and multimode interference (MMI) couplers will be given.

2. Experimental Results

The structuring of the devices was carried out by conventional photolithography using a quartz/chromium mask as sketched in Fig. 1.

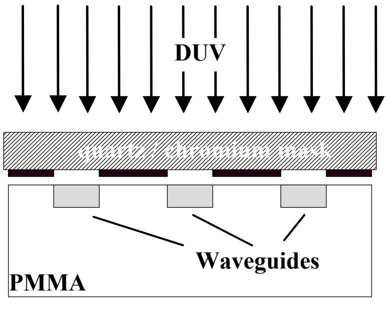

Fig.1. Waveguide fabrication.

The refractive index of the polymer which is UV-exposed increases, that of the unexposed region does not. A thin surface layer of a few micrometers is modified by the DUV-light, therefore only a single polymer layer is required, which serves as substrate and waveguide as well. The use of a single polymer substrate avoids the large mismatch of coefficients of thermal expansion (CTE) between polymeric and inorganic materials, which leads to birefringence in the polymer layers and results in temperature sensitive devices. Thus athermal and polarization insensitive polymer devices can be fabricated by employing a single substrate with a coefficient of thermal expansion matching that of the modified surface waveguide layer due to only marginal structural modification.

The devices were designed and fabricated for the 1.55 µm wavelength region and have a waveguide loss of < 1 dB/cm. The waveguide width is 7.5 µm. The fiber-chip coupling loss is < 0.5 dB per facet. The polarization dependency is < 0.15 dB.

The necessary refractive index distribution is derived from m-line-spectroscopy using an inverse WKB-method. Then, based on the index distribution a three-dimensional semi-vectorial BPM-method calculation was carried out. For loss minimization the dependence on the width of the waveguide, bending radius, branching angle and refractive index distribution due to fabrication process parameters was investigated.

2.1 Y-Splitter

Symmetrical 1 x 2 splitters (Fig. 2) with different angles were fabricated by combining pairs of s-bend structures which compose of two identical arcs. After waveguide fabrication the polymer wafers are separated by a wafer saw. No further polishing of the end faces is required.

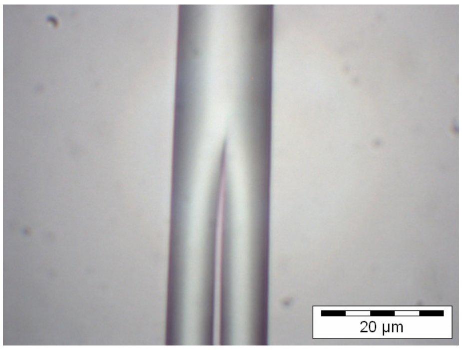

Fig.2. Photograph of a symmetrical 1 x 2 splitter.

Splitters were fabricated by varying the branching angle from 1° to 2.5°. For small angles the measured curves exhibit a higher loss due to processing imperfections caused by a limited photolithographic resolution at the Y-junctions. As an example the spectral insertion loss characteristic of the two output ports of a 1 x 2 splitter with branching angle of 1.75° are depicted in Fig. 3. For comparison the spectral insertion loss of a straight waveguide is shown, too. The additional loss due to splitting is in the range of 0.5 dB. The uniformity of the output ports is within the measurement accuracy of 0.1 dB.

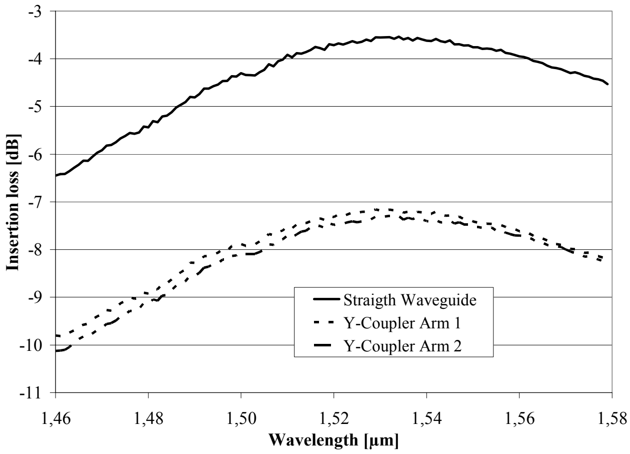

Fig.3. Wavelength dependent insertion loss of a symmetric Y-splitter.

2.1 Codirectional coupler

Another important device is a 2 x 2 codirectional coupler. This type of coupler can be used for equal splitting of the power independent from the input channel in the whole wavelength region, as well as to realize splitting ratios other than 3 dB. The separation between the waveguides in the coupling region is the critical element regarding the fabrication. The resolution of the photolithography defines the minimum coupling gap, which is 1 µm in our case.

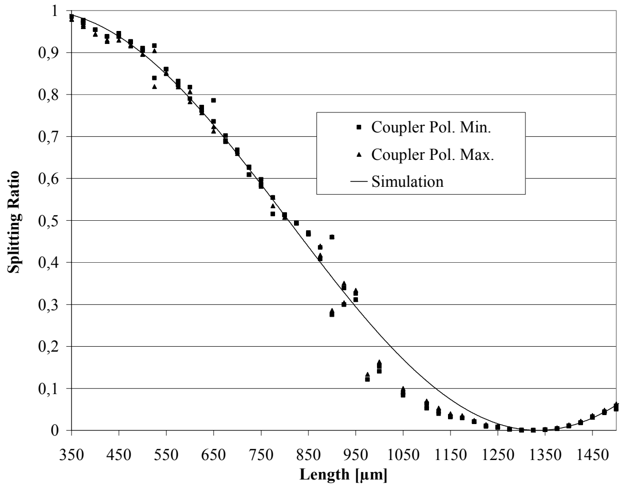

Fig.4.Measurement result of a codirectional coupler with a gap of 2 µm.

The measured result of a codirectional coupler with a coupling gap of 2 µm and different coupling lengths is shown in Fig. 4. The additional losses of the couplers are less than 0.5 dB. The measured values confirm the simulation quiet well.

2.1 Multimode interference coupler – MMI

Another basic component which is implemented for a variety of optical signal processing and routing functions is a multimode-interference coupler (MMI).

These multimode interference devices offer important advantages such as compact size, low imbalance and crosstalk. In comparison to codirectional couplers the main advantage is the fabrication tolerance. So far most of these devices have been fabricated in high index contrast materials like InP. To date there has only been limited application of polymer materials for MMI devices due to the low index contrast. However, our simulation show tolerable loss and imbalance at the best image point, which justify the fabrication of a weak guiding MMI coupler. The designed MMI coupler has a width of 27 µm. There are 4 modes which are supported in the broader multimode section. In the range between 1650-1950 µm, the intensity of the MMI is divided equally at both of the output ports. The best image point in terms of 3 dB splitting ratio, low loss and imbalance is around 1800 µm. The device has a length tolerance of ± 150 µm for a 5 % imbalance in splitting ratio. These first results show that MMI devices can be realized in polymers. Further design and fabrication improvements will increase the device performance.

3. Conclusions

We have introduced a process of UV-induced fabrication of single mode waveguides in methacrylate polymers that offers the feature of a simple waveguide fabrication process. Y-Couplers, codirectional couplers and 3 dB MMI couplers have been fabricated to demonstrate the capability of this technology. Beside applications in telecommunication the fabrication process opens up new applications in the field of sensor technology.

4. Acknowledgement

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5. References

[1] P. Henzi, D. G. Rabus, U. Wallrabe, J. Mohr, “Fabrication of Photonic Integrated Circuits by DUV-induced Modification of Polymers,” paper 5454-08, in Proceed. SPIE Photonics Europe, 26–30 April 2004, Strasbourg, France.

[2] P. Henzi, D. G. Rabus, U. Wallrabe, J. Mohr, “Low Cost Singlemode Waveguide Fabrication Allowing Passive Fibre Coupling using LIGA and UV flood exposure,“ paper 5451-06, in Proceed. SPIE Photonics Europe, 26–30 April 2004, Strasbourg, France.