# Low-cost Fabrication of All-Polymer Planar Optical Waveguides

Maher Rezem*, Axel Günther*, Maik Rahlves*, Bernhard Roth*, Eduard Reithmeier**

*Hannover Centre for Optical Technologies, Leibniz University Hanover, Germany
**Institute of Measurement and Automatic Control, Leibniz University Hanover, Germany

mailto:maher.rezem@hot.uni-hannover.de

We present a low-cost fabrication process of all-polymer multimode optical waveguides, which is based on hot embossing and doctor blading. We investigate the use of different polymer materials and characterize their optical propagation losses. We discuss the fabrication of multilayer optical waveguides based on thermal and adhesive bonding and present potential applications.

## 1 Introduction

Compared to silicon photonic devices, polymer based micro-optical devices show great promise due to their low material and fabrication costs. Polymer materials enable the use of various fabrication techniques, such as laser writing [1], printing [2] and hot embossing [3]. Polymer micro-optical devices have a wide range of applications, such as optical communication [4] and sensing [5]. In this work, we present our recent results in the fabrication of all-polymer optical waveguides on thin polymer foils, which represent the building block of planar micro-optical devices. We discuss a low-cost fabrication process of optical waveguides, investigate the use of different polymer materials and characterize their refractive indices and propagation losses. We also discuss the fabrication of multilayer waveguides based on thermal and adhesive bonding and describe their possible applications in the field of optical sensing.

## 2 Fabrication of Optical Waveguides

The presented waveguide fabrication technique is based on hot embossing of polymer cladding material, doctor blading of UV curable core material and UV curing. The hot embossing step is conducted in a commercial hot embossing machine (HEX03, Jenoptik AG). As an embossing stamp, a silicon wafer was microstructured through photolithography and etching by Micromotive GmbH. The silicon stamp comprises rib-structures having a width of 25 µm and a height of 28 µm. The rib structures were then replicated in 500 µm thin PMMA sheets (Plexiglas XT99524, ThyssenKrupp), representing the cladding material, thus obtaining trench structures in the thermoplastic cladding material. The replication process was performed at a molding temperature of 140°C and an embossing force of 4000 kN, which was maintained for 120 s. The following waveguide fabrication step consists of doctor blading. Liquid UV curable core materials were deposited on the microstructured cladding sheets. Using a razor blade, the excess material on the cladding surface was removed manually. The final waveguide fabrication step consists of UV curing of the deposited core material. As core materials, we used OG198-54 and OG142 (Epotek, USA). The fabrication process is summarized in Fig. 1 and a cross section of the resulting multimode optical waveguide is shown in Fig. 2.

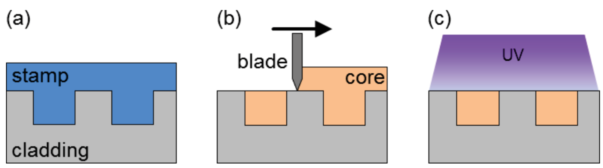


***Fig. 1*** *Waveguide fabrication process: (a) Hot embossing, (b) doctor blading, and (c) UV curing.*

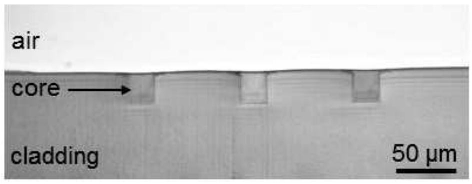


***Fig. 2*** *Cross section of fabricated planar optical waveguide using PMMA and OG198-54.*

## 3 Waveguide Characterization

The fabricated waveguides were then characterized with respect to refractive index and propagation losses. The refractive index measurements were conducted at a wavelength of 638 nm using a refractive index profiler (Rinck Elektronik GmbH) based on the refracted near-field method. The obtained indices of OG198-54 and OG142 amount to 1.524 and 1.568, respectively. The measurement of propagation losses of the investigated waveguides is based on the cutback method [6] and was conducted at the wavelengths of 633 nm and 850 nm using a helium-neon laser (25-LHP-991, Melles Griot, USA) and a fiber coupled laser diode (MCLS1-850, Thorlabs, USA), respectively. The output power was measured using a fiber coupled photodiode power sensor (S151C, Thorlabs, USA). The investigated samples and the input and output fibers were positioned using pre-

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cision stages. For the core material OG198-54, we obtained propagation losses of 0.97 dB/cm at a wavelength of 633 nm and 0.3 dB/cm at a wavelength of 850 nm. For the core material OG142, we measured propagation losses of 2.56 dB/cm and 1.05 dB/cm at the wavelengths of 633 nm and 850 nm respectively.

## 4 Multilayer Optical Waveguides

On the basis of the fabricated single layer waveguides, we investigated the fabrication of multilayer waveguides. Through the use of multilayers the integration density can be increased. Furthermore, multilayers enable applications such as 2D-sensing and automatically calibrated sensing. For example, 2D-strain sensing can be achieved through the bonding of two orthogonal 1D-strain sensing layers [7]. Automatic calibration can be achieved through the use of a surface sensing layer to interact with the environment, while using a second buried layer to produce a reference signal.

Multilayer waveguides were first produced using thermal bonding. After positioning two waveguide layers in the hot embossing machine, a bonding force of 50 N and a bonding temperature of 140°C were applied for 60 s. Subsequently, the applied force was released and the sample was cooled and removed. We also investigated the fabrication of multilayers through adhesive bonding. For this, adhesives having lower refractive indices than that of the core materials are needed. Furthermore, the used material should exhibit satisfactory adhesion on PMMA-foils. In the present work, we used the UV curing adhesives OG675 (Epotek, USA) and NOA85V (Norland, USA). An adhesive layer was applied through spin coating on the surface of a first layer. The second layer was positioned on top of it, before curing the sample in a UV curing system. The cross sections of obtained multilayers are shown in Fig. 3.

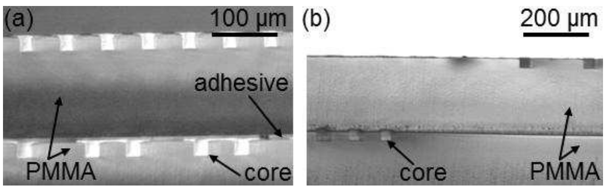


***Fig. 3*** *Cross section of fabricated multilayer waveguides through (a) adhesive and (b) thermal bonding.*

## 5 Summary and Outlook

In this work, we presented a low-cost fabrication technique for all-polymer planar multimode optical waveguides based on hot embossing and doctor blading of UV curing materials. The refractive indices and the propagation losses of the fabricated waveguides were characterized. We also used the fabricated single layers to manufacture multilayer waveguides through thermal and adhesive bonding. For the next steps of our work, the design of optical sensing elements will be investigated for various applications, such as sensing in life sciences and structural health monitoring. The presented fabrication technique can then be used for the large scale low-cost fabrication of foil-integrated components.

## Acknowledgements

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