A new approach in polymer waveguide fabrication

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Abstract

Waveguides are an excellent means of integrating sensor components in single use microfluidic polymer systems. However, most processes for producing on-chip waveguides require several process steps, some of which are not suited for mass production. We report a simple procedure in which two different grades of the cyclic olefin copolymer (COC) Topas® are used as substrate and core layer. In a spin coating process a Topas® grade with high refractive index is spin coated onto the injection moulded substrate with lower refractive index, thereby generating a core layer. A simple hot embossing process enables simultaneous structuring of waveguides and microfluidic channels in the core layer. In a final step the microfluidic structures can be closed with a lid, either by thermal bonding or by laser transmission welding.

The refractive index and glass transition temperature T_g can be altered by changing the ratio between the two copolymers of Topas®. The low optical transmission loss of the material, along with its chemical resistance and low water absorption, makes Topas® a good choice for making integrated optics in microfluidic systems.

Keywords: waveguides, hot embossing, cyclo olefin copolymer, Topas® COC

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1. Introduction

The majority of measurements performed with lab-on-a-chip devices are done optically. The integration of waveguides is a powerful way of getting a large flexibility when designing microfluidic systems for different purposes. Common measurement methods using optical sensors include fluorescence and absorption measurements. An example of a complex device measuring several different values is a flow cytometer, in which absorption, extinction, fluorescence, as well as large and small angle scattering are measured to characterize cells. It has been shown that these measurements can be performed in a microfabricated device with integrated waveguides and other microoptical features like collimation lenses [1]. A simpler example of integrated optics in microfluidic systems is absorption measurements to determine the dye concentration of a solution [2].

By integrating as many optical devices on the chip as possible, the number of necessary optical interconnections to external instruments can be greatly reduced. This lowers the complexity of a total system, thereby reducing the size and cost of the system. The successful integration of a dye laser with waveguides, an absorption measurement cell fed by a fluidic mixer, and photodiodes has been shown by Balslev *et al.* [3].

Because of the optical properties of glass fibers, most of the telecommunication market is focused on the 1300 nm and 1550 nm wavelengths. For lab-on-a-chip devices detection over a wider range of wavelengths is needed, since the absorbtion or flourescence to be measured can be found in all parts of the spectrum. This implies that materials used for optical waveguides should have the broadest transmission spectrum possible.

Topas® offers very good transmission down to 300 nm, This fact, along with the possibility of changing the refractive index and the glass transition temperature T_g by varying the ratio between the two copolymers, makes Topas® an obvious choice for making microoptical components. This choice is further accentuated by the chemical resistance against i.e. standard cleanroom processing, and the good machinability, making production of lab-on-a-chip system for harsh environments possible.

2. Fabrication of Topas® waveguides

Our fabrication approach is based on a bulk substrate onto which a layer of a material with a higher refractive index is spin coated. By embossing this two-layer structure, the thin upper layer is either "cut" or just driven out into the channels of the tool. The principle of this process is shown in Fig. 1:

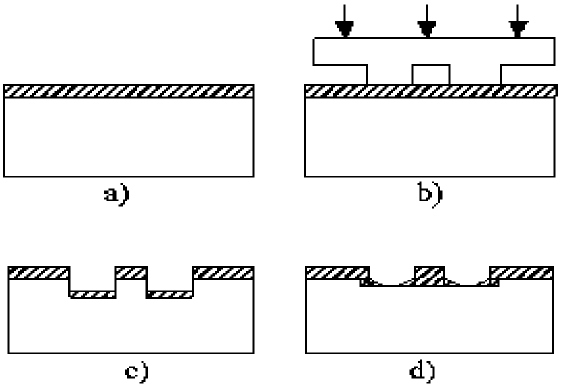

Fig. 1. a) Substrate with spin coated layer, b) embossing step, c) “cut” waveguide, d) “squeezed” waveguide.

With a residual layer of higher refractive index in the bottom of the channels, d) may not perform as well as the waveguide in c). With this procedure, however, it is possible to fabricate waveguides in a solid substrate without additional casting steps. Fluidic structures can be generated in the same step simply by adding features to the stamp.

3. Preparation of the polymer substrates

Topas® is available in a number of different grades with different glass transition temperatures. The 9506 grade has a T_g of 60°C while the 5013 grade has a T_g of 130°C. T_g increases with increasing norbornene content, while the refractive index decreases slightly [4].

The two layer substrate is fabricated by spin coating a layer of a Topas® solution onto a wafer made of a different Topas® grade having a lower refractive index than the spin on layer.

In our experiments we used Topas® grade 5013 or grade 8007 (T_g = 75°C) wafers (10 cm in diameter, 2 mm thick) as substrate. Toluene was used as solvent in the spin coating solutions (with ~15 wt% grade 8007 or 9506). The solutions were spin coated at rotational speeds of 500 to 1000 rpm, resulting in a layer thickness of about 200 µm. The solvent was removed by annealing the structures at a temperature slightly below the substrate T_g.

4. Embossing of the waveguides

The waveguide embossing was carried out using a brass tool (Fig. 2) fabricated by direct micro milling in order to save time and resources. This method should only be considered as a proof of principle due to the relatively high surface roughness. Alternative tool production methods such as silicon technology combined with electroplating are currently under investigation. The dimensions and parameters of the brass tools are shown in Tab. 1.

Table 1. Tool dimensions and milling parameters for the different brass structures fabricated.

Tool diameter [µm]	Structure height [µm]	Feed [mm/min]	Vertical step size [µm]
100	500	5	15
200	500	7	20
2000	400	30	100

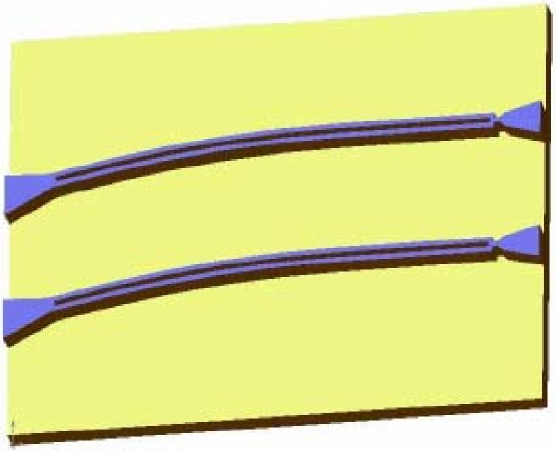

Fig. 2. Layout of a brass tool used for hot embossing of waveguides.

The embossing experiments were performed at 85°C applying a force of around 650 N in a homemade press placed in a conventional laboratory oven for about 60 minutes. After 10 minutes the force was readjusted to the initial value, since the force decreases due to thermal expansion and material flow.

In order to analyze the fabricated structures, the spin coated layer has been colored with an organic dye to visualize the otherwise transparent material boundary. Fig. 3 clearly shows the redistribution of the upper layer, generating a "cut" waveguide of the type depicted in Fig. 1 c).

Fig. 3. Cross section of hot embossed waveguide fabricated in Topas® grades 8007 (substrate) and 9506 (core). The waveguide is the dark rectangle in the middle surrounded by air from both sides. The dimensions of the waveguide are approximately 120 µm × 200 µm.

The waveguiding effect has been demonstrated by visual inspection through a microscope with the use of a laser pointer. Loss measurements have not yet been carried out, however, the losses are expected to be small due to the high transmission of the material. Also, given the relatively small dimensions of lab-on-a-chip systems, optical losses can be larger than in long distance telecommunication systems.

5. Conclusions and outlook

It can be concluded that this new approach of polymer waveguide generation by hot embossing is feasible for lab-on-a-chip applications. A single step procedure can be applied for the production of integrated waveguides and fluidic channels at the same time, and will therefore be a relatively inexpensive method of accessing mass production of integrated optical sensing elements.

Aknowledgements

The authors would like to thank the Danish Ministry of Science, Technology and Innovation for financial support (µKAP center contract).

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