OPTICAL WAVEGUIDE INTEGRATED WITH A COUPLING PRISM AND MICROLENSES

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ABSTRACT

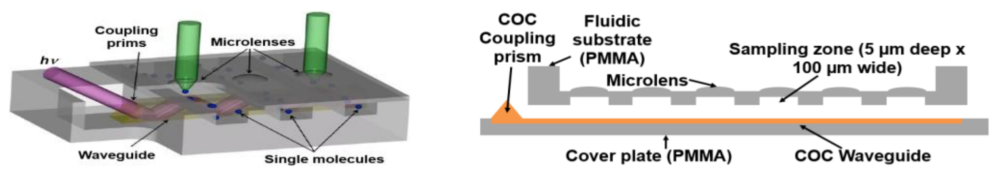
A polymer-based, optical waveguide with an integrated coupling prism and microlenses was designed and fabricated to improve overall optical performances. The use of flycutting allowed accurate control of the polymer waveguide thickness. A large prism facilitated better coupling of the light to the waveguide. The highest intensity evanescent excitation of the waveguide was obtained at the critical angle of the waveguide. Fluorescent radiation was highly focused by the array of microlenses. The microfabricated waveguide will allow the rapid, low-cost detection of the fluorescent samples in biomedical applications.

KEYWORDS: Waveguide, Hot Embossing, Prism, Microlenses

INTRODUCTION

Polymers such as poly(methyl methacrylate) (PMMA), polycarbonate (PC), and cyclic olefin copolymer (COC) have been widely used for biomedical applications owing to their capability for mass replication and integration [1, 2]. The development of the appropriate detection method is indispensable for complete lab-on-a-chip systems. Optical waveguides in polymers have been demonstrated for detection of the fluorescent samples with limited optical performances [3, 4].

A polymer-based, optical waveguide with an integrated coupling prism in a cover plate (or a waveguide substrate) and microlenses in a fluidic substrate (Figs. 1(a) and (b)) was designed to improve its overall optical performances. The light launched through the prism propagates in the waveguide by total internal reflection, the evanescent field excites the fluorescent samples in the microchannels, and the output is collected through the microlenses. After fabricating and assembling the fluidic substrate and the cover plate, the assembled waveguides were characterized to evaluate their optical performances.



(a) (b)

Figure 1: (a) Diagram of the assembled waveguide integrated with the coupling prism and microlenses, and (b) schematic for fabrication of the waveguide, consisting of a fluidic substrate and a cover plate.

EXPERIMENTAL

Two brass molds, one for the microlenses and the other for the sampling zone microchannels, were designed for the fabrication of the fluidic substrate. The top mold was micromilled with hemispherical recesses on rectangular boxes and the bottom mold for the shallow sampling zone microchannels with a depth of 5 µm. The fluidic substrate was double-sided, hot embossed in PMMA using the two molds.

Another two brass molds were designed and fabricated for the cover plate: one for the PMMA cover plate with an embedded microchannel for formation of a COC waveguide and the other for the PMMA reliefs to make the PDMS stencils, which are to be used to fabricate the COC waveguide and prism. After hot embossing the microchannel in the PMMA cover plate, the COC embedded waveguide was formed by injecting the melted COC through the injection port of the PDMS stencil to fill the microchannel

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cavity (Fig. 2(a)), followed by curing and peeling off of the PDMS (Fig. 2(b)). Flycutting was used to planarize the excess COC (Fig. 2(c)).

Assembly of the fluidic substrate with the cover plate was carried out by thermal bonding (Fig. 2(d)) using a pressure-assisted boiling point control system [5]. The COC coupling prism was integrated using another PDMS stencil (Fig. 2(e)), resulting in the completed waveguide (Fig. 2(f)).

For characterization of the optical waveguide, the excitation laser was generated from a laser diode and coupled into a fiber optic cable. The laser beam was passed through a beam expander in reverse mode to minimize light loss. After depositing the fluorescent dye on the waveguide without assembling the fluidic substrate, the effect of the light launch angle to the light output intensity was investigated by adjusting the light launch angle by a goniometer (Fig. 2(g)). The assembled waveguide was characterized by the same setup to show the evanescent excitation of the dye in the sampling zone microchannels.

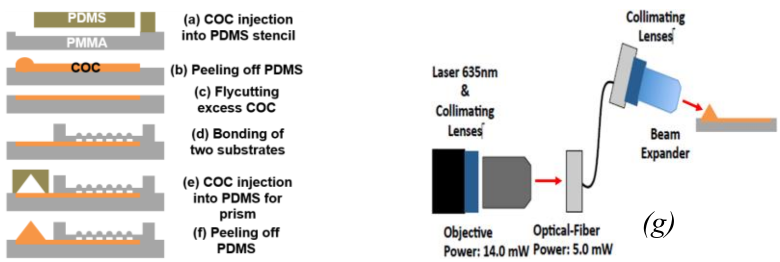
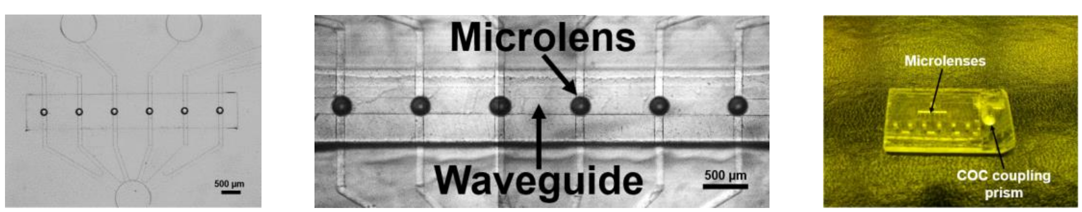


Figure 2: Process flow for fabrication of the optical waveguide for COC embedded waveguide and coupling prism ((a)~(f)), and (g) optical characterization setup for waveguide capability and evanescent excitation of the optical waveguide.

RESULTS AND DISCUSSION

The alignment accuracy for the double-sided hot embossing of the fluidic substrates (Fig. 3(a)) was evaluated by using edge extraction of the two consecutive images focused at the microlenses side and the microchannel side. The overall alignment accuracy was 12.5 µm ± 7.5 µm. Flycutting to remove the excess COC allowed for accurate control of the waveguide thickness down to 50 µm, which can provide the high signal-to-noise ratio [3]. Assembly done by thermal bonding of the fluidic substrate and the cover plate (Fig. 3(b)) provided the leakage-free sealing. The relatively large prism was successfully integrated for coupling of the light to the waveguide for evanescent excitation (Fig. 3(c)).



(a) *(b)* *(c)*

Figure 3: Images of (a) a fluidic substrate, (b) close-up view of thermally bonded waveguide, and (c) the assembled waveguide with the coupling prism.

The investigation of the waveguide capability through the prism showed the intensity variation of the collected light depended on the light launch angle, revealing the highest intensity at the critical angle (76^{o}) of the waveguide (Figs 4(a) and (b)). The characterization of the assembled waveguide confirmed the evanescent excitation of the fluorescent dye in the sampling zone microchannels and the higher fluorescent signals through the microlenses (Fig. 4(c)). There was a clear distinction between the signals from the sampling zone microchannel and the spaces without channels (Fig. 4(d)). The microlenses increased the amplitude of the fluorescent signals by a factor of two (Fig. 4(e)).

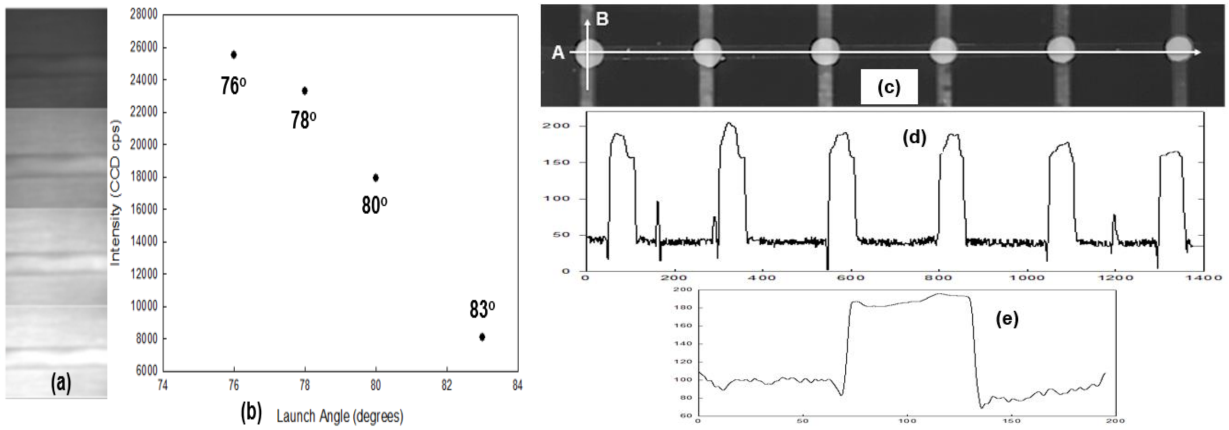


Figure 4: The results for waveguide capability with (a) fluorescent images at four different light launch angles (A: 83º, B: 80º, C: 78º, D: 76º) and (b) a graph for intensity versus light launch angle; the results of the evanescent excitation of (c) fluorescent image of the dye in the sampling zone microchannels, and intensity data (d) along the waveguide (scan line of A) and (e) along the microchannel (scan line of B).

CONCLUSION

A polymer-based, optical waveguide was designed and fabricated with an integrated coupling prism in the cover plate and microlenses in the fluidic substrate. The fluidic substrate and the cover plate were fabricated using hot embossing of PMMA. The embedded COC waveguide and the COC coupling prism were fabricated with PDMS stencils. Optical characterization of the waveguides demonstrated easy coupling of the light to the waveguide through the large prism, the highest intensity of evanescent excitation at the critical angle of the waveguide, high sampling efficiency by the use of the shallow sampling zone microchannels, and highly focused fluorescent radiation from the microlenses. The microfabricated, polymer-based waveguide will provide the capability for rapid detection of the fluorescent samples at low cost, for example, the rapid screening of stroke.

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