Multimode PDMS waveguides fabricated using a hot-embossing technique

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Polymer optical waveguides are widely used nowadays. In particular, there has been an increasing interest in flexible waveguides. One of the application domains is optical sensing were mechanically flexible structures are often needed. Because of its very flexible nature and high optical transparency, poly(dimethylsiloxane) (PDMS) is a suitable material for these applications. Since commercially available PDMS is not photo-definable, soft-lithography techniques [1] are commonly used to pattern the material. These methods enable cheap fabrication but often produce a residual layer of core material between the waveguides. A novel hot-embossing based process which offers a solution for this production issue is presented. Furthermore, two commercially available PDMS materials (Dow Corning Sylgard®184 and Nusil LS-6943) were used to pattern the waveguide core and cladding rather than using proprietary solutions [2] or varying the process conditions [3] to introduce the required refractive index contrast.

The process flow for fabricating the waveguides is depicted in Fig 1. First, a cladding layer of Sylgard®184 was spin-coated onto a temporary substrate and subsequently thermally cured. Then, a liquid core material (Nusil LS-6943) was pressed between this cladding layer and a master mould. The resulting stack was placed into an embossing press to form the waveguides by applying both pressure and elevated temperature to cure the PDMS. Afterwards, the substrate with patterned waveguides was removed from the master mould. Finally, a PDMS cladding layer could be spin-coated on top of the waveguides.

To produce the master mould, 50µm high SU-8 structures were photolithographically patterned onto a silicon wafer. This mould was subsequently coated with a gold layer to prevent PDMS from sticking to it.

A cross-section of the resulting waveguides is shown in Fig 2. The waveguide dimensions were approximately 50x50µm² and pitches of 125µm were obtained. Additionally, there is no significant residual layer between the waveguides. From a CCD camera view (Fig 3) it can also be seen that there is no light leaking from the waveguide. It is believed that the soft PDMS cladding seals the solid master mould during waveguide fabrication in such a way that the liquid core material is almost completely pressed away.

The optical propagation losses at 850nm were determined using the cut-back technique. Therefore, a 4cm sample with PDMS waveguides was progressively cut-back in 1cm increments using a "hot-knife", a scalpel attached to a soldering iron. At each step, the optical losses were measured using a 50µm multimode fiber for coupling light into the waveguides and a 62.5µm fiber for capturing the light at the output. From the results plotted in Fig 4, a propagation loss smaller than 0.24dB/cm was found. This result is comparable to waveguides fabricated in traditional optical polymers. Furthermore, the losses largely depend on the sidewall roughness and thus on the master mould quality which was not yet optimized.

This novel method for patterning multimode PDMS waveguides produces high quality optical waveguides without a substantial residual layer after embossing. Furthermore, the process allows for low-cost fabrication since it relies on a replication technique and additionally only commercially available materials are used. The measured propagation loss is smaller than 0.24dB/cm and can be further reduced by improving the master mould quality.

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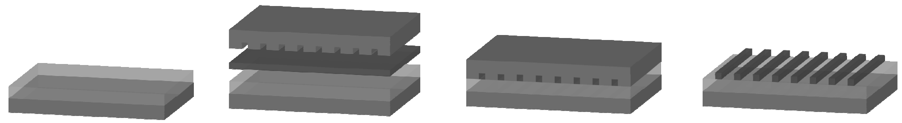

(a) (b) (c) (d)

Figure 1. Process flow. (a) Spin-coated Sylgard®184 cladding; (b) LS-6943 liquid core material applied; (c) PDMS pressed between cladding and master mould and thermally cured; (d) Master mould removed.

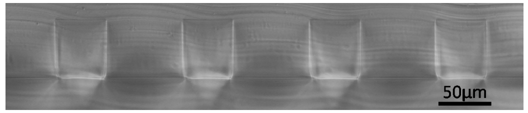

Figure 2. Cross-section of the PDMS waveguides. No substantial residual layer is observed between the waveguides after embossing.

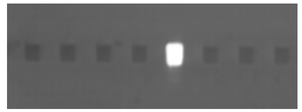

Figure 3. When light is coupled into a waveguide, it is visibly confined within the core.

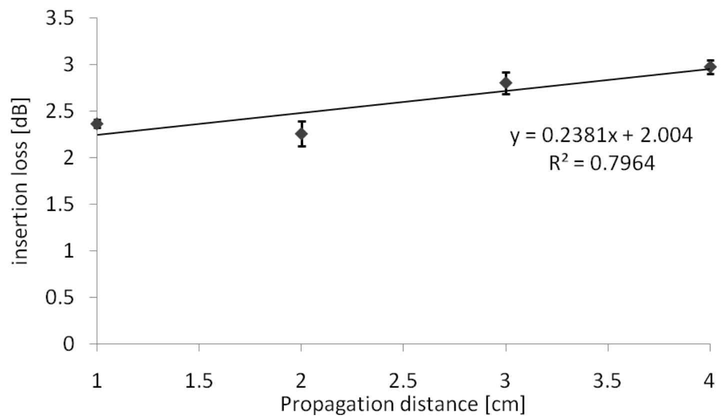

Figure 4. Measured optical loss at 850 nm, resulting from the cut-back technique. A propagation loss smaller than 0.24dB/cm was found.