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FABRICATION OF POLYMERIC OPTICAL POWER SPLITTER

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Abstract: We present fabrication of 1 × 4 optical power splitter in a photosensitive polymer. Process to fabricate single mode polymeric channel waveguide based optical splitters using simple direct UV photolithography is optimized. Optical Adhesive NOA 61 was used as under- and over-clad. Channel waveguides are obtained on development after a crosslinkable negative tone epoxy SU-8 2002 polymer is exposed to UV through a photomask. Temperature and duration of baking and curing were found to play a significant role in this fabrication.

1. INTRODUCTION

Polymer based technology has been known to provide low cost solution in production of components. Photosensitive materials are rapidly finding broader applications in micro-scale design. In recent years, a relatively new type of resist, SU-8 has received a lot of attention in the field of micro-fabrication because of its mechanical stability, biocompatibility, and suitability for fabricating high aspect ratio features [1]. Cured SU-8 is highly resistant to solvents, acids and bases, and has excellent thermal stability making it well suitable for applications in which cured materials are permanent structures of the device. Norland Optical Adhesive 61 (NOA 61) is a clear, colorless, liquid photopolymer that is cured when exposed to ultraviolet light. When fully cured, NOA 61 has very good adhesion and solvent resistance. The refractive index of cured NOA 61 is 1.54 while that of SU-8 is 1.57 at 1550 nm, permitting fabrication of waveguides employing NOA 61 as the clad and SU-8 as the material for the guiding region.

2. SINGLE MODE 1×4 OPTICAL POWER SPLITTER

The simplest passive optical component is the splitter, which distributes the incident optical power into specified power fractions at the output ports. A symmetrical 1 × N splitter divides the power into N ports with a fraction 1/N of the incident power at each output port. Thus, the input power is reduced by 6 dB at the outputs of 1 × 4 splitter. The power splitter presented in this work is designed for single mode operation at 1550 nm, which is the low loss window for long-haul telecommunication links. In order to obtain single mode propagation, the waveguide on which the splitter is based should also be single moded at the desired wavelength. Thus in order to ensure only fundamental mode operation at the desired wavelength, the guide thickness should be kept below 2.5 μm [2].The modal characteristics of the waveguides were independently verified by BeamPROP™, the same software being used to design the 1×4 power splitters. In all Y-branching arms, cosines type S-bends were used to minimize the radiation lobe at the splitting junction. The splitting junction depends only on the symmetry and is a wavelength independent 3dB-splitter. The total device length for 1×4 splitter is 16 mm with a propagation loss of 6.02 dB. The design is optimal for fabrication on a 3-inch silicon wafer. How ever, the actual insertion loss depends on quality of fiber used for pigtailing, mode field diameter matching between fiber and waveguide, and several other parameters.

3. FABRICATION PROCESS

Fabrication of single mode polymeric optical splitters is based on simple direct UV photolithography process [3].

Table 1: Fabrication steps for polymeric waveguides

Fabrication Process Steps	
1	Dehydrate the substrate at 140°C for two hours after piranha cleaning
2	Spin coat NOA-61 at 4000 rpm for 30 sec., followed by UV curing for 10 min. at an average intensity - 48 mW /cm^2, then left for stabilization at 60°C for 15 hours.
3	Spin coat SU-8 2002 at 1400 rpm for 30 sec. followed by soft bake of 65°C for 5min. and 95°C for 20 min.
4	UV exposure over MA56 Mask Aligner for 90 sec followed by PEB bake of 65°C for 2 min. and 95°C for 5 min.
5	Development in SU-8 Developer for 70 sec followed by IPA rinse for 10-15 sec.
6	Over Cladding coat as in step 2
7	Hard Bake at 140°C for 1 hour.

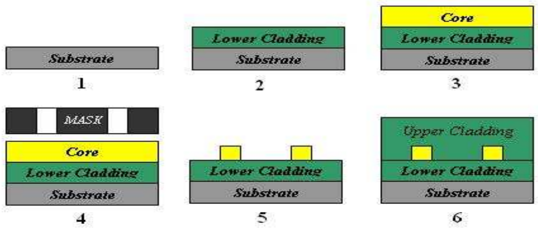


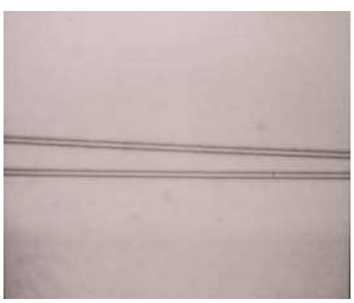
Figure 1: Schematic diagram of fabrication process for polymeric waveguides

Fabrication includes preparing the substrate surface for under-clad coating with NOA 61 followed by UV curing and baking. Prior to coating NOA61 on Si wafer, the wafer was thoroughly cleaned using piranha etch at room temperature. The cleaned wafers were then dehydrated as mentioned in table 1. We found that the quality of NOA 61 films were critically dependent on the wafer surface. A clean dry wafer enabled proper adhesion of the spun film to the substrate. For UV curing of NOA61, we used a high wattage (400W) UV lamp (Dymax 5000EC). The SU-8 2002 core material was spun on top of NOA 61 coated silicon substrate and then soft baked using two-step process to remove any traces of solvent after exposure. Channel waveguide widths of 1.8, 2, 2.2, 2.4, 2.6 and 4μm are realized by UV exposure in contact with photomask using a Karl Suss MA56 mask aligner. A post exposure two-step baking process is used to crosslink the polymer. The photoresist-coated UV-exposed substrate is developed in PGMEA and then rinsed in IPA. Coating of NOA61 as over-clad is the final step in device development. The fabrication process is summarized in table 1 supported by the schematic diagram of fabrication process in fig 1.

4. RESULTS AND DISCUSSION

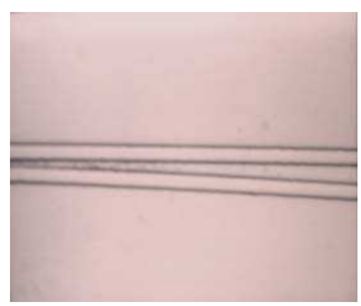
Waveguide patterns obtained are clear and smooth. The core pattern formed through direct UV lithography had smooth surface and its size and shape were as designed. The thickness of core before exposure and hard bake was found to be 2.37 μm and after pattern development before hard bake the height of waveguides lies in range from 1.8-2.2 μm. Optical micrographs of portions of devices are collectively shown in fig 2.

Few factors were found to significantly affect fabrication of the device. Optimum baking temperature and time can overcome adhesion problem between the polymers. Soft and hard baking of coated polymers should be done on hot plate instead of in conventional ovens. Surface cracks were developed on baking in conventional ovens. Results were satisfactory with two-step pre-exposure bake and post exposure bake. Optimum curing of NOA 61 is necessary and otherwise leads to poor adhesion between core and cladding. Exposure and development times have to be optimized before fabrication of final device.

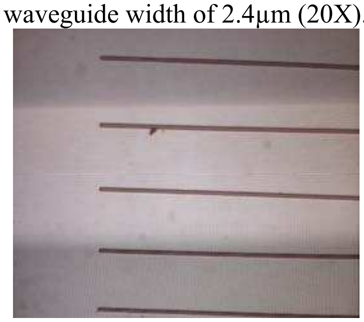


(a) Y-separation in device with the waveguide width of 2.4μm (20X).

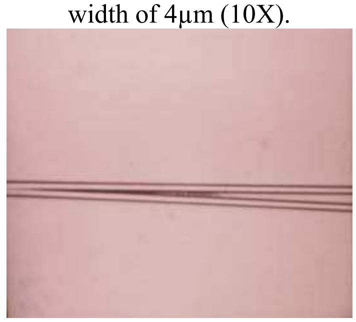
(c) 1×4 splitter with the waveguide width of 4μm (10X).



(e) Y-junction of the device with the waveguide width of 4μm (40X).



(b) Output ends of the device with the waveguide width of 2.6μm (5X).



(d) Y-junction of the device with the waveguide width of 4μm (20X).

Fig. 2: (a) – (e) Optical Micrographs of 1×4 optical power splitters

As seen from the photomicrographs, the fabricated waveguides are smooth walled. There is no cracking or any kind of defect in the fabricated devices. However, in spite of using an optimum device design, where the Y-junctions employed a linear taper and guides at the output end of the taper were optimally designed, a small amount of residual resist remained in the region between the Y-junction guides. Efforts are underway to determine the effect of this on the device performance

5. CONCLUSION

Fabrication of 1 × 4 optical power splitter in a photosensitive polymer is presented. Optical Adhesive NOA 61 was used as under- and over-clad. Channel waveguides are obtained on development after a crosslinkable negative tone epoxy SU-8 2002 polymer is exposed to UV through a photomask. Temperature and duration of baking and curing play a significant role in this fabrication Since SU-8 processes are nowadays considered as classical, many a device based on SU-8 rib waveguides can be commercially fabricated. In addition to fabrication of the optical devices, low-cost packaging of pigtail fibers and optical waveguides is essential for optical devices. Packaging technique is to align a single mode fiber with the waveguides of the optical splitter. Passive alignment is a critical issue and is being undertaken presently.

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