Fabrication of LD-3 Polymer Directional Couplers

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ABSTRACT

LD-3 polymer directional couplers have the potential use as low-voltage modulators and switches. They can be integrated into module-to-module systems using currently available VLSI fabrication techniques. Modes of channel waveguides are calculated and coupling lengths are determined using BPM_CAD. We report the fabrication of LD-3 polymer directional couplers designed to operate at 1.3 μm.

Keywords: nonlinear-optical polymer, electro-optics, optical film, waveguide fabrication

1. INTRODUCTION

Many of today's commercially available electro-optic devices are made from inorganic materials such as lithium niobate. The drawback of such devices is that they cannot be easily integrated with electronic circuitry fabricated on silicon wafers. These difficulties prevent the reduction of the fabrication cost and hence their wide spread use. Compared with their inorganic counter parts, nonlinear-optical (NLO) polymeric materials have several well-recognized advantages such as compatibility with different substrates, ease of fabrication, and possibly low cost. As a result, a lot of NLO polymers have been synthesized in recent years [1,2,3,4,5]. A low-loss waveguide with a large and stable NLO coefficient is needed for a practical device. Polyimide NLO materials offer the best stability; however, the forms that possess an optical nonlinearity have relatively high optical loss (>3dB/cm) and often the case is that the loss and processability remain unreported [2]. Other less-lossy materials do not possess the thermal stability to satisfy commercial or military requirements [6]. Much higher stability can be achieved by crosslinking both of the ends of an NLO chromophore into the polymer network. Although many efforts have been made, only a few NLO materials have achieved long term stabilities near or up to 100 °C [1,2,3,5] and only one material (LD-3) has a long-term thermal stability satisfying the military requirement of 125 °C [4]. The polymer LD-3 is a thermally crosslinkable NLO polymer consisting of a poly (methyl methacrylate) (PMMA) backbone and an azobenzene-sulfone chromophore. It can be crosslinked using a diisocyanate. We use Dianisidine diisocyanate from Pfaltz &Bauer, Inc. An r_{33} value of 13pm/V at 633 nm is achieved and a long-term stability at 125 °C is proved through annealing a sample at this temperature for over 1250 hours [7].

2. BPM SIMULATION OF THE DIRECTIONAL COUPLER

The first step in the fabrication of the directional coupler is to calculate the modes of the channel waveguides using the beam propogation method. BPM_CAD by OPTIWAVE Corporation is used to calculate the modes of a 1.5 μm by 7 μm channel waveguide. The LD-3 waveguide has an index of 1.5463 and the index of the surrounding substrate and cladding material NOA-61 is 1.5409. These indices are based on an operating wavelength of 1.3 μm. The mode solver predicts the channel waveguide will support only a single mode with an effective index of 1.541187. The field distribution of the mode is saved and used as the input field for the directional coupler simulation. The directional coupler is simulated using two 1.5 μm by 7 μm channel waveguides separated by 10 μm. For this design, the coupling length is determined to be about 8.1 mm as shown in Figure 1.

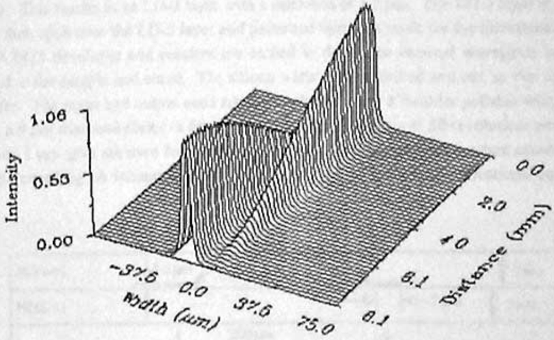

Fig. 1. BPM_CAD simulation of the intensity as a function of the width and propagation distance.

From the results of the BPM_CAD simulations, an Autocad drawing is made with a parallel coupling length region of 7.9 mm, a 10 μm channel separation, and a 7 μm channel width. At both the input and output ends of this directional coupler, arcs of 10 mm radius of curvature are designed to facilitate coupling of light into and out of each of the channels. The channels at both the input and output regions are separated by 200 μm. A schematic of the Autocad mask design is shown in Figure 2.

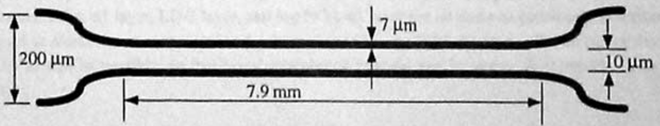

Fig. 2. Schematic of the Autocad drawing for the directional coupler

Using this Autocad file, an image reversed iron-oxide mask is made using an RDI pattern generator. To obtain an image reversed iron-oxide mask, the following steps are taken. AZ5209 photoresist is spin coated onto an iron oxide plate and dried at 90 °C for fifteen minutes. This plate is patterned with a RDI using an exposure time of 0.07 sec. The plate is then hard baked at 125 °C for seven minutes. Afterwards, the plate is subjected to a UV exposure of two minutes from a Karl-Suss mask aligner. The plate is developed with AZ425 developer for about 30 seconds. Another hard bake at 125 °C for fifteen minutes is done to fix the remaining resist that defines the channel regions. Finally, the plate is submersed in the iron-oxide etchant ME-10 for 20 seconds and then rinsed with DI water and dried.

3. DEVICE FABRICATION

The following steps are taken in the fabrication of a directional coupler. First, a bottom cladding layer of NOA-61 is spun onto a silicon wafer to form a 3-μm layer. The NOA-61 layer is then cured with UV light. Next, LD-3 is spin coated onto the NOA-61 layer. This results in an LD-3 layer with a thickness of 1.2 μm. The LD-3 layer is corona poled and cured. AZ5209 photoresist is then spun onto the LD-3 layer and patterned using the mask for the directional coupler. The sample is then developed with AZ425 developer and reactive ion etched to define the channel waveguide regions. A top NOA-61 cladding is then applied to the sample and cured. The silicon wafer is then scribed and cut, so that the ends of the device are at the edges of the wafer. The input and output ends are then polished using a Beuhler polisher with diamond abrasive films of various grits. First, a 9 μm diamond abrasive film is used for fifteen minutes at 50 revolutions per minute. Then abrasive films of 6 μm, 3 μm, and 1 μm grits are used for the same amount of time and angular rotation speed. The polishing resulted in a smooth interface for coupling. A schematic of the cross section of the input to the directional coupler is shown in Figure 3.

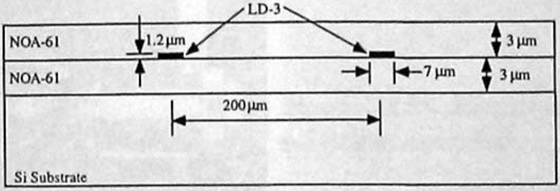

Fig. 3. Schematic of cross section.

For the fabrication of an active device, electrodes need to be patterned above and below the channel waveguide regions. This is accomplished by first evaporating a metal such as gold or aluminum onto the silicon substrate. The electrode region is then patterned and defined using another mask made specifically for the electrode structure. The spin coating of the bottom NOA-61 layer, LD-3 layer, and top NOA-61 layer are all done as previously described. Finally, a top metal layer of gold or aluminum is evaporated and patterned onto the top NOA-61 layer. For an active device, the cladding regions should be as thin as possible, so that lower modulation voltages can be used. A schematic of an active device is shown in Figure 4.

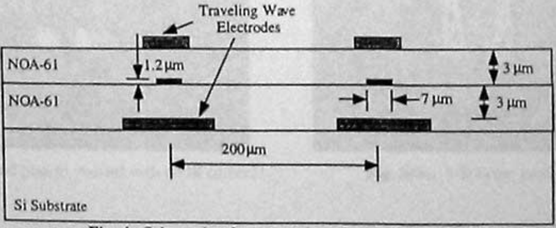

Fig. 4. Schematic of cross section of an active device.

4. COUPLING SETUP AND RESULTS

The directional coupler sample is mounted between two microscope objective lenses in a butt-coupling arrangement as shown in Figure 5(a). Output from a 1.3 µm Santa Fe Nd:YAG Laser is coupled into the waveguide using a 60× objective and the light is coupled out using a 40× objective. The near field pattern is imaged onto a screen about a foot away from the output coupler and viewed with an infrared camera. For our test sample, the input and output taper regions have been removed. Therefore, straight channels 10 µm apart remain as shown in Figure 5(b). Only the parallel section of the channel waveguides are used because we first want to show that 1.3 µm light can be successfully waveguided. The laser beam can be coupled into either channel waveguide individually or both channels at the same time due to the narrow separation of the channels. For light coupled into both channel waveguides, Figure 6(a) shows the near field pattern. The pattern is also analyzed with a beam profiler and the results are shown in Figure 6(b).

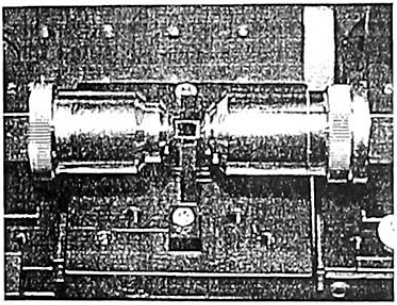

Fig. 5(a). Butt-coupling setup.

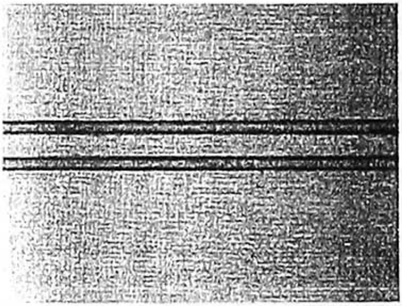

Fig. 5(b). Top view of the parallel channels, which are separated by 10 µm.

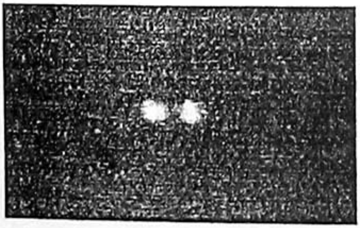

Fig. 6(a). Near-field pattern viewed with an IR camera.

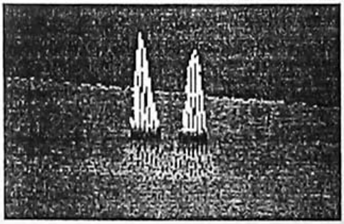

Fig. 6(b). 3-D beam profile.

5. CONCLUSION

[illegible] coupler [illegible] are modeled using BPM CAD. Modes of [illegible] channel waveguides are calculated and coupling [illegible] using this beam propagation-method software. [illegible] mask for the directional coupler is made [illegible] from the simulations. Directional couplers are successfully fabricated with

LD-3. Initial testing shows that light is coupled into the parallel channel waveguides. We are currently measuring the performance of a complete directional coupler with input and output coupling regions.

ACKNOWLEDGEMENTS

This research is sponsored by the AFOSR, the BMDO, the DARPA's Center for Optoelectronics Science and Technology (COST), and the ATP program of the State of Texas.

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