Printable EO-Polymer Modulators

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Abstract: An EO polymer modulator is fabricated utilizing a combination of UV imprinting and ink-jet printing, and operation up to 15MHz is demonstrated. The measured V-pi of the modulator is 8V. This process will increase throughput and reduce cost.
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Introduction

Electro-optic (EO) polymers have found widespread application in several photonic devices, owing to their large electro-optic coefficient and ease of processing [1-4]. They also enable hybrid integration with a myriad of material systems. The most common method for device fabrication includes using high energy reactive ion-beam (RIE) to define the pattern into a resist, and further transfer the pattern to the optical polymer via plasma etching [5]. However, this method involves complicated fabrication process and low throughput. Molding/imprinting method is an effectively method to achieve structural patterns with high fidelity [6]. Furthermore, utilization of other R2R compatible methods, such as ink-jet printing or coating process, will enable the realization of a viable manufacturing technology. Such a roll-to-roll compatible process will not only enable high throughput manufacturing, but will also drive the cost of the system down considerably.

In this work, a roll-to-roll compatible "printing" technique is utilized to develop an EO polymer modulator. Using the modulator, operation up to 15MHz is experimentally demonstrated. The R2R compatible printing processes will enable high-rate development of several photonic devices on flexible as well as on rigid substrates possible.

Device Fabrication and Testing

A schematic top view of the Mach-Zehnder modulator structure is shown in Fig. 1(a). A cross sectional schematic showing the composition of the modulator is shown in Fig. 1(b).

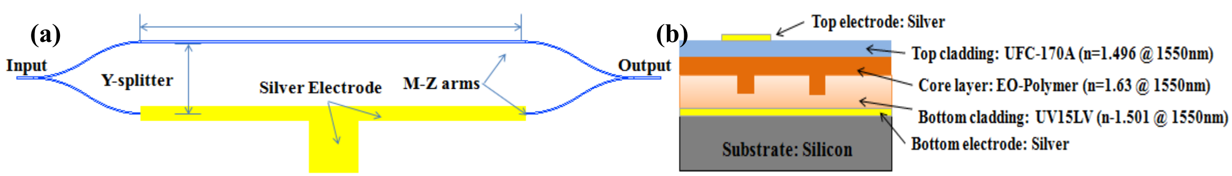

Fig. 1 (a) Schematic top view of the EO polymer modulator, (b) Schematic cross section showing the different materials comprising the EO polymer modulator.

In order to fabricate the device, we first fabricate a silicon hard mold, as shown in Fig. 2(a). Using the hard mold, an SSQ soft mold is replicated, as shown in Fig. 2(b). Using the flexible mold on the NIL tool, Mach-Zehnder (MZ) modulator patterns with an active arm length of 7.1mm are imprinted in a 4.18µm thick UV15-LV bottom cladding layer, as shown in Fig. 2(c). Imprinting produces inverse rib waveguide dimension of etch depth = 500nm, width = 4.75µm. An SEM image of the imprinted pattern is shown in Fig. 2(c).

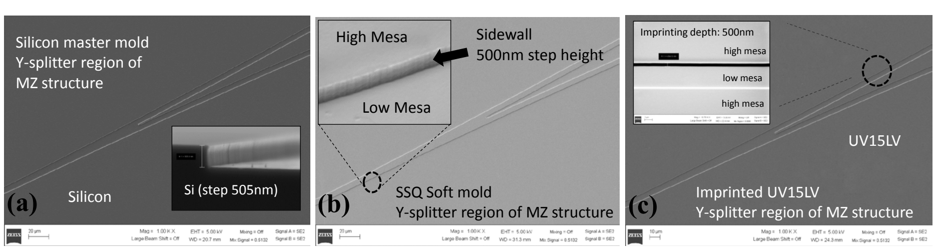

Fig. 2. SEM images showing (a) silicon master mold, (b) flexible mold on PET. (c) imprinted region in UV15LV bottom cladding layer.

In order to form the EO polymer core, a coating method is used for initial development. We have also achieved successful ink- jet printing of EO polymer material, however, due to high-cost of the EO polymer, we will focus on coating method in this work. Next, a 2.8µm thick UFC-170A polymer top cladding layer is coated on top and cured. Finally, 332nm silver top electrode is ink-jet printed and sintered. Alignment marks are utilized for achieving good alignment accuracy for electrode formation. An image of the fully fabricated device is shown in Fig. 3(a) An SEM cross section image of one of the arms in the fabricated MZ modulator is shown in Fig. 3(b). It can be seen that the imprinted trench is filled with EO polymer, and the top and ground electrodes are uniformly deposited with the top electrode located right on top of the rib waveguide.

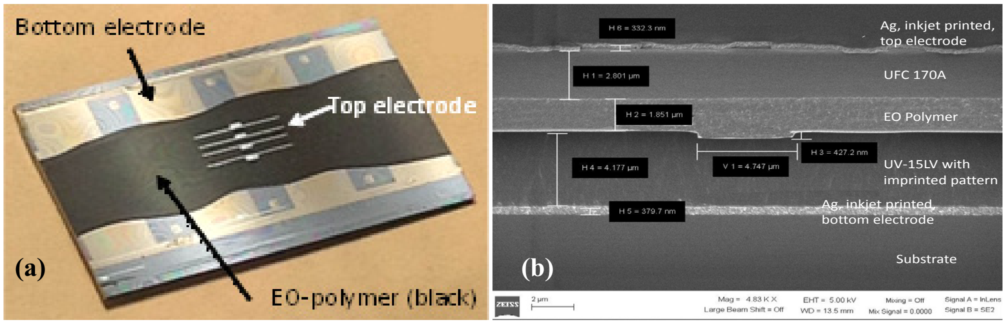

Fig. 3 (a) Microscope image of ink-jet printed printed EO polymer modulator, (b) SEM picture showing the cross section of the modulator

The EO polymer is poled using an electric field of about 80V/µm. Upon completing the poling process, TM polarized light at 1550nm wavelength from a tunable laser is launched into the device using a lensed fiber and the output light is collected by a single mode lensed fiber. Output response of a 15MHz sinusoidal input [Fig. 4(a)] applied to the modulator is shown in Fig. 4(b). Note that the operating frequency is only limited by our signal source, and the EO modulator can operate at a much higher frequency. The measured V-pi of the modulator at an operating frequency of 3kHz is 8V.

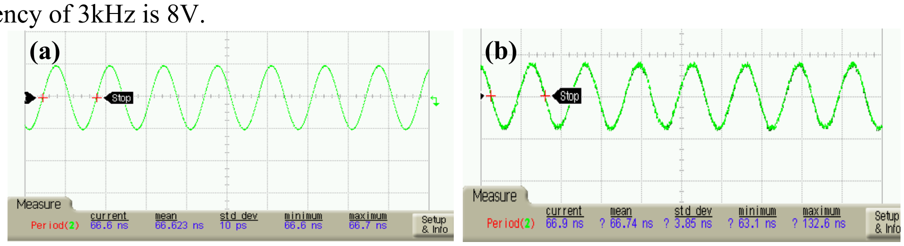

Fig. 4 Screen shots showing (a) Input 15MHz sinusoidal signal, (b) modulated 15MHz output signal.

Conclusion

We have developed a scheme to achieve roll-to-roll fabrication of polymer photonic devices using compatible printing techniques. An EO polymer modulator is fabricated utilizing UV imprinting, coating and ink-jet printing methods. UV imprinting using a soft mold is utilized to achieve the modulator pattern in an UV15LV bottom cladding polymer. The other waveguiding layers are deposited using coating. The layers can also be deposited using ink-jet printing. The top and the bottom electrodes are formed using ink-jet printing. Using the fabricated device, operation of the modulator up to 15MHz is achieved. This demonstration shows great promise for the roll-to-roll manufacturing of a wide variety of useful photonic devices on rigid as well as on flexible substrates.

References

1. X. L. Wang, C. Y. Lin, S. Chakravarty, J. D. Luo, A. K. Y. Jen, and R. T. Chen, "Effective in-device r(33) of 735 pm/V on electro-optic polymer infiltrated silicon photonic crystal slot waveguides," Opt Lett 36, 882-884 (2011).
2. C.-Y. Lin, A. X. Wang, B. S. Lee, X. Zhang, and R. T. Chen, "High dynamic range electric field sensor for electromagnetic pulse detection," Opt. Express 19, 17372-17377 (2011)
3. D. Chen, H. R. Fetterman, A. Chen, W. H. Steier, L. R. Dalton, W. Wang, and Y. Shi, BDemonstration of 110 GHz electro-optic polymer modulators,[Appl. Phys. Lett., vol. 70, no. 25, pp. 3335–3337, Jun. 1997.
4. M. Lee, H. E. Katz, C. Erben, D. M. Gill, P. Gopalan, J. D. Heber, and D. J. McGee, BBroadband modulation of light by using an electro-optic polymer,[Science, vol. 298, no. 5597, pp. 1401–1403, Nov. 2002.
5. X. Y. Zhang, B. Lee, C. Y. Lin, A. X. Wang, A. Hosseini, X. H. Lin, and R. T. Chen, "Improved performance of traveling wave directional coupler modulator based on electro-optic polymer," Optoelectronic Interconnects Xii 8267 (2012).
6. S. H. Ahn, and L. J. Guo, "High-speed roll-to-roll nanoimprint lithography on flexible plastic substrates," Adv Mater 20, 2044 (2008).

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