Polymeric Optical Splitter Based on Multimode Interference Mechanism

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Abstract – **A 1x2 and 1x3 planar optical splitter based on BenzoCyclobutene (BCB 4024-40) polymeric material is proposed. The device is designed based on symmetric interference mechanism, utilizing a BK7 glass as a substrate and thin layer of SiO_2 as a cover. Simulation results show that the splitting uniformity is better than 0.5 dB at 1550 nm optical wavelength.**

Keywords: BenzoCyclobutene polymer, optical splitter, chemical etching technique, multimode interference (MMI), polymer optical waveguide.

I. INTRODUCTION

Optical splitters are key components in photonic integrated circuits both for signal routing and signal processing. Standard splitters that realized based on X- and Y-junctions design suffer from high reflection and radiation loss due to branching complexity [1]. In the past couple of years, there has been a growing interest in the application of the multimode interference (MMI) effect in integrated optics [2][3]. Due to their excellent properties and ease of fabrication, MMI based splitters are becoming increasingly popular for various applications in integrated optics. Their main advantages are ultra-compact size, low loss, and large fabrication tolerances [2]. They are quite easy to design and are compatible with both weakly-guided and strongly-guided structures [3].

The demand in optical networking for photonic components that meet performance criteria as well as economic requirements has opened the door for technologies capable of high yield and low cost manufacturing while delivering high performance and enabling unique functions. Polymeric materials are particularly attractive because of their ability to be processed rapidly, cost-effectively, and with high yields. Of that matter, polymer material has been accepted as a new generation material for optical integrated circuit due to its various advantages as compared to other optical materials.

In this paper, we will report on the design of 1x2 and 1x3 optical splitters using organic BenzoCyclobutene (BCB 4024-40) polymer from The Dow™ Chemical Company. The motivation of this paper is to visualize the applicability of chemical etching based polymer, BCB 4024-40 as an optical material as it may lead to extremely lower cost manufacturing of optical devices.

II. THEORY

MMI splitters work on the principle of self-imaging effect, a property of multimode waveguides by which an input field is reproduced in single or multiple images at periodic intervals along the propagation direction of the guide [2]. As shown in figure 1, the typical structure of MMI consists of (i) single mode input waveguides, (ii) a multimode section and (iii) single mode output waveguides of the input geometry.

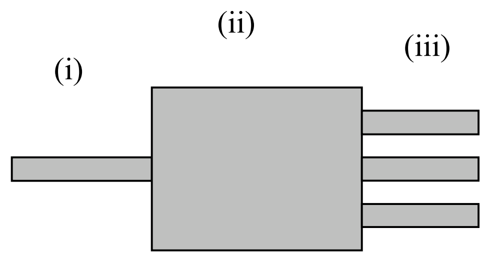

Fig. 1: Schematic of MMI optical splitter.

The single mode optical field excites a weighted sum of the lateral modes of the multimode region, in which the relative weights of the modes being determined by the input modal field shape. The lateral modes have different propagation constants. At certain distances, a beating phenomenon occur where constructive interference between the modes will produces single or multiple self images of the input field. These images can then be coupled to single mode waveguides at the end of multimode region which can be further used as a passive *N* way optical splitter. In a special case whereby, the odd modes are not excited in the multimode waveguide, the 1 to *N* beam splitters can be realized with multimode waveguides four times shorter [3]. This condition can be achieved by centre- feeding the multimode waveguide with a symmetric field profile [2]. The imaging is obtained by linear combinations of the even modes (symmetrical) and this type of MMI mechanism is called symmetric interference.

Light intensities in the MMI waveguide exhibit various distributions as they propagate at the positions relative to the beat length, L_π defined by [2]

$$L_\pi = \frac{\pi}{\beta_0 - \beta_1} \approx \frac{4nW_e}{3\lambda_0} \quad (1)$$

where β_0 and β_1 are propagation constants of the fundamental and the first order lateral modes respectively, λ_0 is a free space wavelength, n is an effective index and W_e is an effective width of the multimode waveguide. According to the symmetric interference mechanism, the single images of the input field will be obtained at the multimode section length of [2]

$$L = p\left(\frac{3L_\pi}{4}\right) \quad (2)$$

for p=1,2,…

while the *N* fold images are obtained at distances [2]

$$L = \frac{p}{N}\left(\frac{3L\pi}{4}\right) \quad (3)$$

III. SIMULATION RESULTS

In our design, we have considered a MMI splitter based on a ridge structure of BCB 4024-40 polymer on BK7 glass as a substrate and thin layer of SiO_2 as a cover. An integration of effective index method [7] and two-dimensional beam propagation method (2D-BPM) from Optiwave® is employed for the analysis. The design analysis is based on our recent material characterization work [6]. It was shown that for optical window of 1550 nm, the refractive index of the polymer is 1.5556 and to produce a single mode structure, a ridge thickness of 4 µm and a mask opening of 4 µm are adopted.

Due to our analysis, for 50 µm wide multimode section, the 3 dB length for 1x2 splitter is 1321 µm, while for 1x3 splitter, the required multimode length to produce triple outputs is 1761 µm for 70 µm wide. The fields at the output of these splitters using the 2D-BPM analysis are shown in figure 2. It is seen that the insertion loss for 1x2 splitter is 2.75 dB, while for 1x3 splitter, the design works well with insertion loss of 4.57 dB.

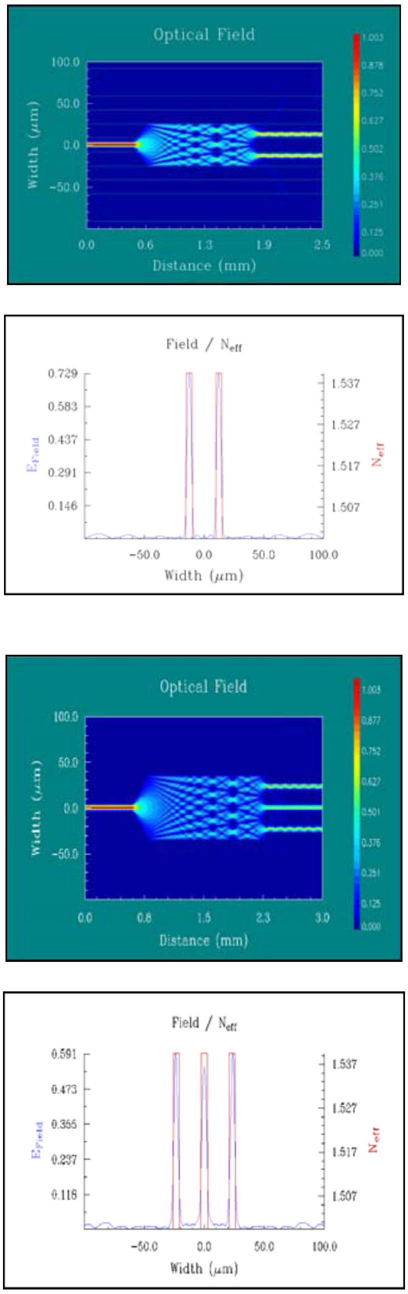

Fig. 3: 2D-BPM analysis of 1x2 and 1x3 optical splitters.

IV. DISCUSSION AND CONCLUSION

A performance of optical splitter is classified by imbalance parameter which is defined as a measure of deviation of the 4 um io from the ideal case [3]. It can be defined as:

$$\text{Imbalance} = 10\log_{10}\left(\frac{P_i}{P_{ref}}\right) \quad (4)$$

where P_i is the optical power in a given output waveguide and P_{ref} is the optical power of an arbitrary chosen reference port.. Our simulation results show that the simulated imbalance of 1x2 splitter is always less than 0.2 dB, while for 1x3 splitter, the average measured imbalance is always better than 0.5 dB.

The obtained results shows the applicability of chemical etching based polymer, BCB 4024-40 to be employed as an optical device material, whilst reducing the realization cost.

V. REFERENCES

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