Design of Polymer Wavelength Splitter 1310 nm/1550 nm Based on Multimode Interferences

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Abstract. *We report about a design of 1x2 1310/1550 nm optical wavelength division multiplexer based on polymer waveguides. The polymer splitter was designed by using RSoft software based on beam propagation method. Epoxy novolak resin polymer was used as a core waveguides layer, a silicon substrate with a silica layer was used as a buffer layer and polymethylmethacrylate was used as a protection cover layer. The simulation shows that the output energy for the fundamental mode is 67.1 % for 1310 nm and 67.8 % for 1550 nm wavelength.*

Keywords

Multimode interference couplers, polymer optical waveguides, epoxy novolak resin, beam propagation method.

1. Introduction

There is a growing interest in Multimode Interference (MMI) couplers in a design of photonics circuits due to huge potential in new optical communications systems such as Fibre to the Home, not only for optical internet but also for videoconferencing, multichannel video services, etc. The MMI couplers are also getting increasing popularity due to many advantages including an easy design, compact size, low loss, etc. In passive optical network systems wavelength channels 1310 nm and 1550 nm are commonly used thus the MMI wavelength multi/demultiplexer operating at these wavelengths has a huge potential.

In the literature there are several papers reporting about various materials [1], [2] used in the design and realization of MMI based structures, most of them are semiconductors. Among them only two papers deal with the MMI structure based on polymer materials [3], [4]. Polymers are attractive materials due to suitable optical properties, easy fabrication process and low cost.

In this paper we are going to report about designing of 1 x 2 1310/1550 nm optical polymer wavelength division multiplexer. Epoxy Novolak Resin (ENR) was chosen as the core optical layer because of easy fabrication process and excellent optical properties (optical losses 0.15 dB/cm at 1310 nm, 0.46 dB/cm at 1550 nm) while the silicon substrate provides good compatibility with the silicon-based technology.

2. Design of Single Mode Waveguides

A typical optical polymer waveguide structure consists of three dielectric regions, including a cover (n_c), a core (n_f) and a substrate (n_s). The basic requirement for refractive indices of a planar waveguide is that the refractive index of the waveguiding layers has to be higher than the refractive index of the used substrate:

$$n_f > n_s \ , \ n_f > n_c \, . \tag{1}$$

The structure of our polymer waveguide is shown in Fig. 1. For integrated optics it is desirable to deposit all the components onto silicon substrates but a silicon layer has a very high refractive index for this purpose and therefore it is necessary to insert so called transition buffer layer between the silicon substrate and the core waveguide layer. The most commonly used buffer layer for silicon substrates is a silica layer because of its easy fabrication and suitable properties. The polymethylmethacrylate (PMMA) layer was finally chosen as the protected cover layer due to its easy fabrication process.

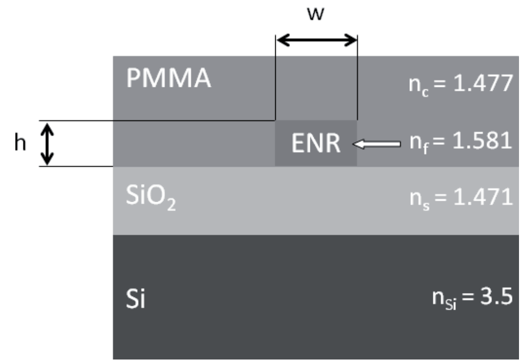

Fig. 1. Cross-section of the single mode optical polymer waveguide structure operating at 1310 nm and at 1550 nm.

Refractive indices of the prepared optical layers were measured by ellipsometry (J.A.Woollam & co) in the spectral range from 400 nm to 1600 nm prior to the proposal of the design was laid down. Though, generally, the refractive index values are different for different wavelengths, for those ones used here (1310 nm and 1550 nm) they remain the same. The obtained values (n_s= 1.471 for SiO_2 buffer, n_f= 1.581 for ENR core and n_c= 1.477 for PMMA cover layer) were used in (2) as well as for the RSoft modeling (see below) to make the simulation more accurate (see Fig. 1). The design of the waveguides was then done for two wavelengths 1310 nm and 1550 nm, i.e. the wavelengths most often used in telecommunication systems.

The minimum thickness h of the core optical waveguides film was calculated by using the modified dispersion equation [4]

$$h_n = \frac{\lambda_0}{2\pi\sqrt{n_f^2 - n_s^2}}\left\{n\pi + arctg\left[p\sqrt{\frac{n_s^2 - n_c^2}{n_f^2 - n_s^2}}\right]\right\} \quad (2)$$

where λ_0 is the operating wavelength (in our case 1310 nm), n is integer number n= 0, 1, 2 …, p is p = 1 for TE mode and $p = (n_f/n_c)^2$ for TM mode.

The minimum width w of the core waveguide was determined using the same equation as for the minimum thickness h of the waveguide (2). The dimensions of the waveguides were then specified by modeling of the RSoft software. Based on the RSoft simulation, the width w and height h of the fundamental mode waveguides were set to 1.3 µm.

3. Design of the MMI Coupler

The principle of operation of the multimode interference (MMI) filter shown in Fig. 2 is based on the 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. This effect has been already described in [5], [6].

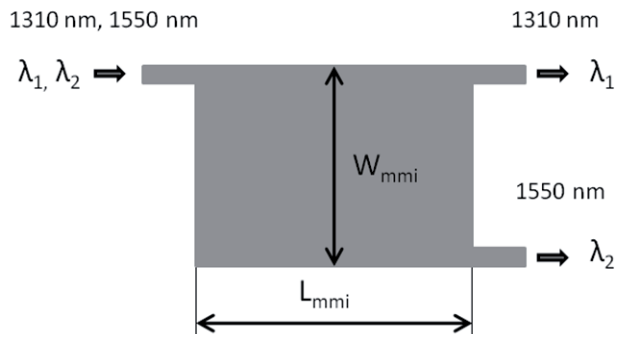

Fig. 2. Schematic diagram of the MMI demultiplexer operating at 1310 nm and 1550 nm.

If we state that the MMI coupler width is W_{mmi} then a certain length L_{mmi} can be found that would (at given wavelengths) allow for splitting the incoming optical radiation so that it would interfere and give two single-mode separate waveguides. Such L_{mmi} can be approximately defined as

$$L_{mmi} = \frac{\pi}{\beta_0 - \beta_1} \approx \frac{4 \cdot n_{core} \cdot W_{mmi}^2}{3 \cdot \lambda_0} \quad (3)$$

where β_0 and β_1 are the propagation constants of the fundamental and the first-order lateral modes and n_{core}, W_{mmi} and λ_0 are the effective refractive index of the MMI core, the effective width and the wavelength of the input signal, respectively. According to the self-imaging principle, an input field in a multimode waveguide is reproduced at periodic intervals along that waveguide. The lateral modes in the MMI section have different propagation constants. At certain distances, a beating phenomenon occur where constructive interference between the modes will produce single or multiple self images of the input field. In general, the shortest length (L_{mmi} as in Fig. 2) is searched for that would allow, through the resonation mechanism, for separating both wavelengths in their maximal intensity. Such a length can be calculated [6] from the following equation:

$$L = 3 \cdot p \cdot L_{mmi}. \quad (4)$$

A direct or mirrored image of the input field is formed if p is an even or odd integer, respectively. In the case of restricted resonance where every third mode (2, 5, 8, ..) in the MMI section is not excited, then the resonant images is defined as:

$$L = p \cdot L_{mmi}. \quad (5)$$

This result allows to shorter the L_{mmi} to one third. The proposed 1 x 2 restricted MMI structure [5] has been used to separate two wavelengths λ_1 and λ_2. The wavelength separation can be performed if the length L_{mmi} of the restricted MMI coupler has been designed so that it is equal to an even number of $L_{mmi,\lambda 1}$ and to an odd number of $L_{mmi,\lambda 2}$, as expressed below

$$L_{mmi} = pL_{mmi,\lambda 1} = (p+q)L_{mmi,\lambda 2}). \quad (6)$$

As stated above, our simulation was done by using RSoft software on the polymer waveguide structure shown in Fig. 1. The width w and height h values were for the single mode waveguides calculated approximately as 1.3 µm for both wavelengths (1310 nm and 1550 nm). The dimension of width of W_{mmi} was set to the value of 8.4 µm. Simulation of L_{mmi} is demonstrated in Fig. 3 showing the resonance of the power intensity for both wavelength 1310 nm and 1550 nm where both maxima coincide. The simulation set the value of the resonance for both 1310 nm and 1550 nm to 21001.5 µm. This value includes also the length of the input waveguide 2000 µm, therefore the real resulting value of the L_{mmi} is 19001.5 µm.

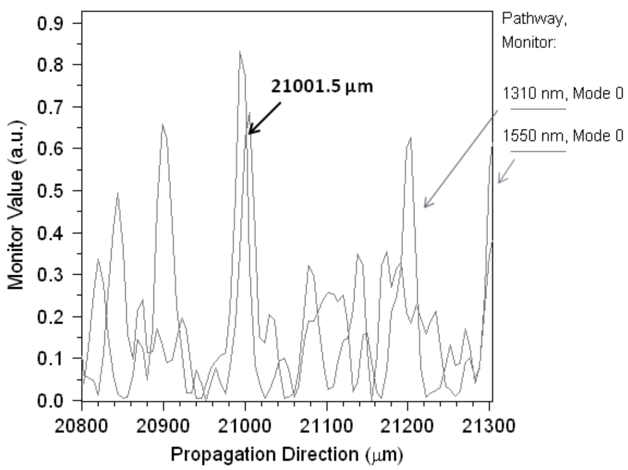

Fig. 3. Output power of a 1 x 2 MMI coupler for the input signal 1310 nm and 1550 nm (Propagation direction means in fact propagation distance while the monitor values give the input powers for 1.3 and 1.5 µm beams.) It illustrates the interference of two wavelengths, which will give the value of the L_{mmi}.

4. Results

The results of the simulation of interference pattern of the structure depicted in Fig. 2 are shown in Fig. 4a for the wavelength 1310 nm and in Fig. 4b for the wavelength 1550 nm.

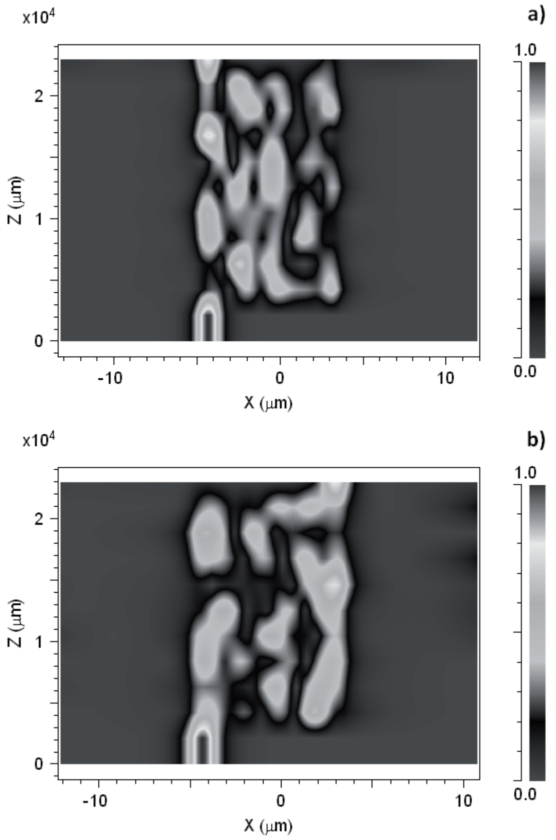

Fig. 4. Interference pattern of the MMI coupler at the wavelength of a) 1310 nm, b) 1550 nm.

The height h and width w of the input and output of the single-mode polymer waveguides were set to 1.3 µm. The width of the multimode part of W_{mmi} was set to 8.4 µm while the multimode interference length L_{mmi} was found to be 19001.5 µm. The simulation shows that the output energy for the fundamental mode is 67.1 % for 1310 nm and 67.8 % for 1550 nm, respectively.

The output amplitude for both output waveguides is shown in Fig. 5. Fig. 5 shows that there is also a simultaneous energy transfer to the opposite outputs showing that energy transfer at the wavelength at 1550 nm is 0.4 % in the 1310 nm output and the energy transfer at the wavelength at 1310 nm is 4.71 % in the 1550 nm output.

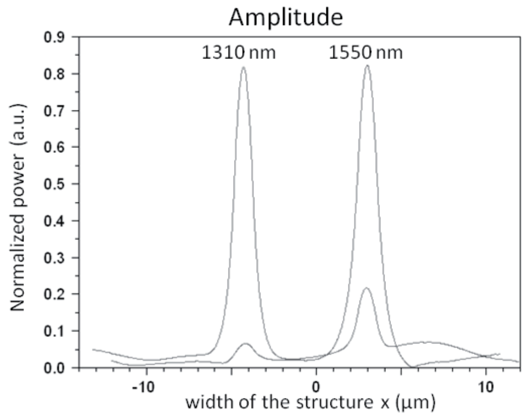

Fig. 5. Normalized output amplitude for the wavelength 1310 nm and 1550 nm.

5. Conclusion

We have proposed a 1 x 2 wavelength polymer demultiplexer based on multimode interference couplers operating at 1310 nm and 1550 nm. The polymer splitter was designed by using RSoft software based on beam propagation method.

Epoxy novolak resin polymer was used as the core waveguides layer due to its low optical losses. The silicon substrate with a silica layer was used as the buffer layer due to the compatibility with silicon based technology and polymethylmethacrylate was used as a protection cover layer because of its easy fabrication process.

First, single-mode polymer waveguides were proposed. The simulation shows that height h and width w of the input and output of the single-mode polymer waveguides have to be 1.3 µm. After that the multimode interference part was designed. The modeling shows that for width of the multimode part of W_{mmi} 8.4 µm the multimode interference length L_{mmi} was found 19001.5 µm. The simulation shows that the output energy for the fundamental mode is 67.1 % for 1310 nm and 67.8 % for 1550 nm wavelength. The crosstalk for 1310 nm wavelength was 0.4 % and the crosstalk for 1550 nm wavelength was 4.71 %.

Acknowledgements

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Václav PRAJZLER was born in 1976 in Prague, Czech Republic. In 2001 he graduated from the Faculty of Electrical Engineering of the Czech Technical University in Prague, Department of Microelectronics. Since 2005 he has been working at the Czech Technical University in Prague, Faculty of Electrical Engineering, Department of Microelectronics as a research fellow. In 2007 he obtained the PhD degree from the same university. His current research is focused on fabrication and investigation properties of the optical materials for integrated optics.

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