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Research Article

Compact Low loss Design of SOI 1x2 Y-branch optical power splitter with s-bend waveguide and study on the Variation of Transmitted power with various Waveguide parameters

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Abstract

A simple technology–compatible design of silicon-on-insulator based 1×2 optical power splitter is proposed. For developing large area Opto-electronic Silicon-on-insulator (SOI) devices, the power splitter is a key passive device. The SOI rib- waveguide dimensions (height, width, and etching depth, refractive indices, length of waveguide) leading simultaneously to single mode propagation. In this paper a low loss optical power splitter is designed by using R Soft cad tool and simulated by Beam propagation method, here s-bend waveguides proposed. We concentrate changing the refractive index difference, branching angle, width of the waveguide, free space wavelength of the waveguide and observing transmitted power, effective refractive index in the designed waveguide, and choosing the best simulated results to be fabricated on silicon-on insulator platform. In this design 1550nm free spacing are used.

Keywords: *Beam Propagation Method, Insertion loss, Optical Power Splitter, Rib waveguide, Transmitted power.*

1. Introduction

Optical power splitter is one of the key passive components in subscribes networks of optical communications to split the power of the optical signal into two branches. Silicon- on – insulator (SOI) material is of interest for integrated optoelectronic circuits since it offers the potentiality of monolithic integration of optical and electronic functions on a single substrate. Moreover, the silicon film of silicon-on-insulator (SOI) substrates can be used as a low loss waveguide. The main advantages of the SOI device technology arise from the strong light confinement in very small waveguide due to the large refractive index difference between silicon and silicon dioxide, and the possibility of suing established silicon microelectronics technology. If refractive index difference is more prevalent to optical power splitters, so waveguide is depending on index difference between core and cladding. Further, silicon-on-insulator (SOI) material based splitters provide some additional advantages like low propagation loss, high reliability and good fiber coupling efficiency due to its excellent inherent mechanical and thermal material properties. This article reports on simulations results for optical power splitters by using a Beam Propagation Method.

2. Design

An Optical Waveguide is an electromagnetic feed line, it has various structural phenomenon, there are strip waveguide, buried waveguide, rib waveguide, strip loaded waveguides, and in practical 3D waveguides are straight waveguides, corner-bent waveguides, bent & S-bend waveguides, tapered waveguides, branching waveguides, crossed waveguides, directional couplers. Here we selected rib type branching waveguides, i.e., it is possible to get a single - mode propagation condition, even if the planar waveguide with the same thickness is multi-modal. It is also used for dividing and combing the optical power (H. Nishihara *et al*, 1989).

2.1. Geometry of rib waveguide

Figure 1 shows the rib waveguide cross-section. The two dielectric materials, SiO2 and Si, have $n_{3,\ 2}$ and n_1 refractive indices, respectively, taking into account the material dispersion at the wavelength of interest. There is a relation between the geometrical parameters of the waveguide (Graham T. Reed *et al*, 2004).

$$\frac{W}{H} \leq 0.3 + \frac{r}{\sqrt{1-r^2}}; \quad r = \frac{h}{H} \geq 0.5 \qquad (1)$$

Where in equation (1) W is the rib width, H is the inner rib height, r is the fractional height of the side regions compared to the rib center (the outer – inner ratio) as defined in Figure 1. For a better understanding, we will also consider the etching depth P = H (1 - r) which directly gives the edge height of the rib waveguide. In the published studies, waveguides that fulfill this relation have very broad sections, several micron of width and height, and the sensitivity to light polarization have not been

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considered. The properties of the guided waves are generally obtained through the properties of the modes of simple waveguide structures. The ridge waveguide consists of a core region that surrounded by a finite cladding.

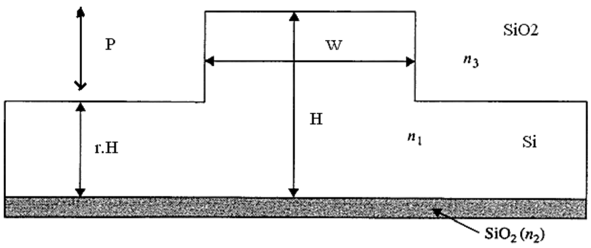

Figure 1: Cross-Section of rib waveguide

2.2. Top view of optical power splitter

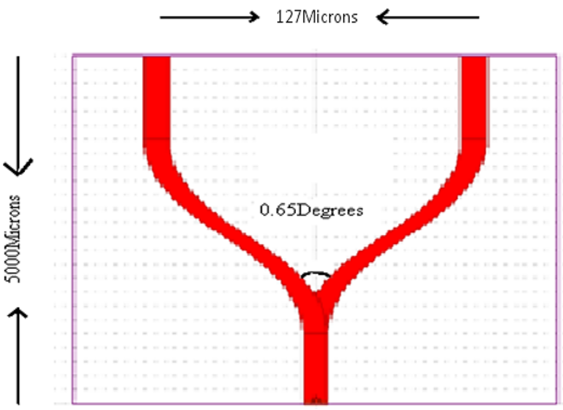

Figure 2: A schematic diagram of the 1×2 optical power splitter with Y-junction

The basic unit of the 1×2 Y-branch section optical splitter comprises of an initial straight waveguide, an S-bend waveguide. A pair of S-bend branching waveguides is considered in this case because of its continuity in light propagation path with the S-bend waveguide, which results in a slight improvement in overall performance of the splitter. By symmetrically optical power splitter has been designed after considering silicon-on-insulator (SOI) material parameters. This design was found in figure 2, through RSOFT cad tool. Silicon- on insulator (SOI) an attractive host material for various applications due to large electro-optic and nonlinear integrated property which can be used as an alternative to ferroelectric materials. This low loss single mode 1x2 Y-branch optical power splitter is formed of a straight input waveguide, two S-bend sin arc waveguides that meet at the straight waveguide, and again add straight waveguide at the two outputs. The output waveguide is symmetrical about the propagation axis which is along the length of the device. The distance between the two output waveguide is 127µm (center-to-center) which is the minimum gap for packing the device and width of the waveguide is 5µm, the length of the waveguide is 5000µm, branching angle between two ports is 0.65°, the slab height ofwaveguide is 3.5µm, height of waveguide is 5µm and propagation light wavelength is 1550nm (SonaDas *et al*, 2009).

3. Simulation and its Results

In the figure 3 the transmission power is shown initially with Red Color where the input power is 1W, the output transmitted power is shown as Blue line on the scale indicating the power to be approximately 1W indicating very less loss.

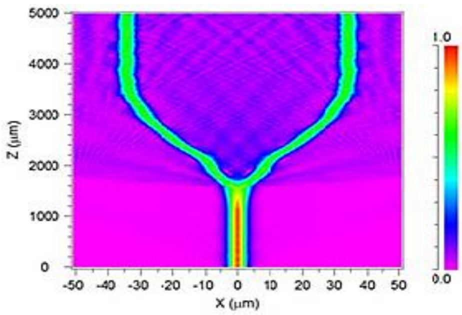

Figure 3

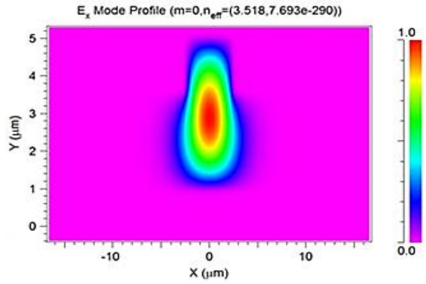

Figure 4

The simulation has been done using BPM tool by considering the propagation of an optical signal of fundamental TE mode through the 1×2 optical splitter, where Figs 3,4 show the corresponding simulated results at 1550nm, in terms of the variation of optical/electrical field and effective refractive index along the device length and across the device-width respectively.

Simulation result gives the transmitted power which is tabulated and the insertion loss (power loss) and the attenuation coefficients are then calculated using the following formulas

$$\mathbf{IL = 10log10\ (P1/}\boldsymbol{P2}\mathbf{)}\ \text{dB} \qquad (2)$$

Where **IL** is the Insertion loss of an optical splitter and is usually measured in decibels (dB).
P1 is the given input power (1 Watt) and
P2 is the output transmitted power in Watts.

$$\boldsymbol{\alpha} = \boldsymbol{IL}/\mathbf{L}\ \text{dB /µm} \qquad (3)$$

Where **α** is the attenuation coefficient measured in decibels.
IL is the insertion loss in dB/µm. **L** is the length of the power splitter

3.1 Effects of refractive index difference

An Optical Waveguide transmitted power is depending on the refractive index difference. If we increase the refractive index difference, the transmitted power is slowly decreasing then it is minimum and stable then again increasing, because of the Si material explained by figure 5. The red colour inside the straight input waveguide of the device indicates that the input power is 1W. The blue colour indicates rib nature of waveguide. In TE mode the effective refractive index is 3.518 which decide the nature of waveguide (L. Vivien *et al*, 2002).

Table 1 Variation of refractive index difference with transmitted power

Refractive index differences	Transmitted power (dB)	Power loss (dB)	*Attenuation coefficient (dB/μm)1×10 $^{(-5)}$*
2.163	0.983	0.074	1.48
2.164	0.982	0.078	1.577
2.165	0.981	0.083	1.66
2.166	0.981	0.083	1.66
2.167	0.981	0.083	1.66
2.168	0.982	0.078	1.577
2.169	0.985	0.065	1.31

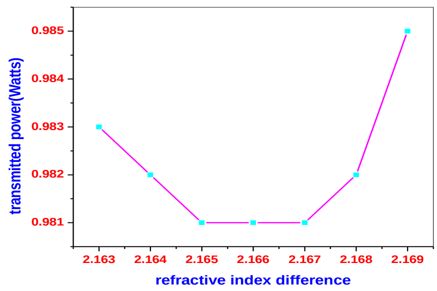

Figure 5

3.2 Effects of branching angle

An Optical Waveguide transmitted power is depending on the branching angle of the waveguide.

Table 2 Variation of branching angle with transmitted power

Branching angle(2θ) (Degree)	Transmitted power (Watts)	Power loss (dB)	Attenuation coefficient (dB/μm)1×10$^{(-5)}$
0.60	0.980	0.087	1.75
0.61	0.983	0.074	1.48
0.62	0.982	0.078	1.577
0.63	0.982	0.078	1.577
0.64	0.984	0.070	1.4
0.65	0.985	0.065	1.31
0.66	0.984	0.070	1.4
0.67	0.984	0.070	1.4
0.68	0.984	0.070	1.4
0.69	0.984	0.070	1.4
0.70	0.984	0.070	1.4

The branching angle (2Ө) is varying 0.6 to 0.7 degrees then the transmitted power is observed. The transmitted power is gradually increasing with branching angle then becomes maximum and stable; through these results 0.65° gives maximum power transmission 0.985W for the input power is 1W with other parameters put constant. These are given in the table 2 and figure 6.

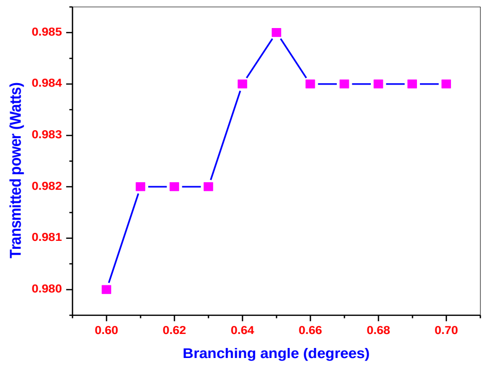

Figure 6

3.3 Effects of width

An Optical Waveguide transmitted power is depending on the width (core) of the waveguide. The width is varying 3µm to 5µm then the transmitted power is observed. The transmitted power is gradually increasing with width then becomes maximum. Through these results 5µm gives maximum power transmission 0.985W and desired effective refractive index for the input power is 1W with other parameters put constant. These are given in the table 3 and figure 7.

Table 3 Variation of width with transmitted power

Component Width (µm)	*Transmitted power (Watts)*	*Power loss (dB)*	*Attenuation coefficient (dB/μm)1×10 $^{(-5)}$*	**Effective refractive index (n_{eff})**
3	0.979	0.092	1.84	3.518,7.108e
4	0.980	0.087	1.75	3.518,6.264e
5	0.985	0.065	1.31	3.518,3.663e

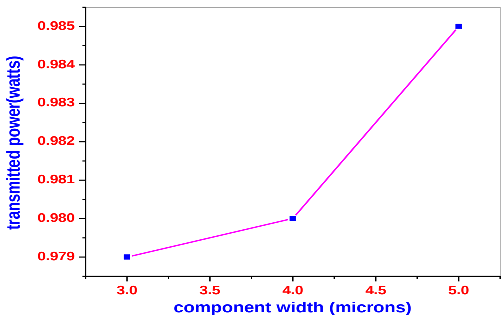

Figure 7

3.4 Effects of free space wavelength

An Optical Waveguide transmitted power is depending on the free space wavelength of the waveguide. The free space wavelength is varying 1.52µm to 1.58µm then the transmitted power is observed. The transmitted power is gradually increasing with wavelength then becomes maximum. Through these results 1.55µm gives maximum power transmission 0.985W for the input power is 1W with other parameters put constant. These are given in the table 4 and figure 8.

Table 4 Variation free space wavelength with transmitted power

Free space wave length (μm)	Transmitted power (dB)	Power loss (dB)	*Attenuation coefficient (dB/μm)1×10 $^{(-5)}$*
1.52	0.981	0.083	1.66
1.53	0.984	0.070	1.4
1.54	0.984	0.070	1.4
1.55	0.985	0.065	1.31
1.56	0.986	0.061	1.22
1.57	0.983	0.074	1.48
1.58	0.984	0.070	1.4

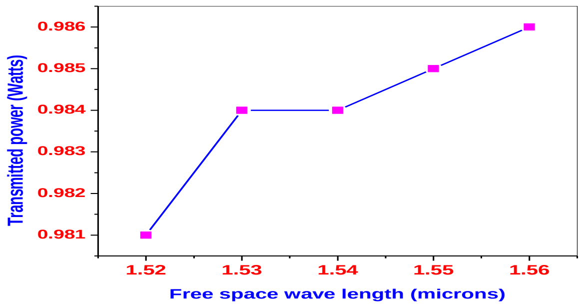

Figure 8

Conclusion

Photonic devices lie at the heart of the communications revolution, and have become a huge and important part of the electronic engineering field. Photonics is discipline concerning the handle of light, or photons, for useful applications, much as micro electronics has to do with electrons (Md. Masruf Khan *et al*, 2013).

On the Silicon on Insulator (SOI) platform the Y-branch power splitter is designed and simulated. With the help of simulation results the variation of different refractive index differences, branching angle, width of the waveguide, free space wavelength with transmitted power is studied.

The insertion loss and the attenuation coefficient are calculated using the above mentioned formulae. The graphs between Transmitted power and refractive index differences, branching angle, width of the waveguide, free space wavelengths are plotted. It is found that this optical device is giving maximum output at wavelength 1550nm, refractive index differences 2.166, branching angle 0.65°, width of the waveguide 5µm, free space wavelength 1.55µm. It is found that the power loss is less than 0.1 dB. This low loss results from SOI based waveguides. This can be used for high accuracy interferometer sensors and optical fiber transceiver applications. One of potential application is an integrated optic gyroscope.

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