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Optimization of Linear Taper Design of a Silicon-Slab Waveguide

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ABSTRACT

A linear taper is applied on a slab waveguide to control the divergence angle of the light. In this research, the slab waveguide design consists of silicon (Si) and SiO2 as the core and the substrate, respectively. The tapered design is optimized by measuring of *Full-Width Half Maximum* (FWHM) of the light after propagation in a *Finite Different Time Domain* (FDTD). The simulation results show that the optimized taper design is obtained when its length L_T and width $W_L$are 125 μm and 10 μm, respectively. This value is the optimal length to get the small diffraction angle of light during propagation in the waveguide. Thus, the divergence angle of the input light of the slab waveguide can be minimized by using this structure. One purpose of this research is to develop a miniaturized optical technology that is like the size of a chip.

1. Introduction

Presently, the applications of optical waveguide cover a wide range of technology, such as storage, sensors, securities, and image displays. The most dominant research of optical waveguides that are widely used is channel waveguides and slab or planar waveguides [1-2]. Both channel and slab waveguides have a high confinement factor, with the ability to sustain the single-mode condition [3-5].

This study examines a silicon-based optical slab waveguide in terms of design condition. Optical slab-based silicon waveguide design for the wavelength of 1550 nm has been extensively explored. The slab optical waveguide was constructed using silicon (Si) as the core and silicon dioxide (SiO_2) as the substrate. In our case, the incident light will be confined and propagated in the Si region [6-7].

The connection of multiple devices into an integrated photonic structure needs to have a connecting medium. One of the media that is often used to integrate it is taper design. Generally, tapers have different sizes on both sides. The function of the taper is to keep the divergence angle of light that is fed into the slab waveguide [8-10]. There are many types of taper design for the optical waveguide. The simplest one is a linear taper.

Main purpose of this research is to develop a miniaturized optical technology that is like the size of a chip. In addition, we want to look for a good design of the taper on the slab waveguide as well. Meanwhile, this research on the design of the taper on the slab waveguide is one of the efforts to develop a miniaturized optical technology in the size of a chip.

2. Methods

2.1. The Design Issue

Here, the slab optical waveguide is constructed from Si as a core, SiO_2 as a bottom layer, and Air as the top layer. In this design, the thickness of the slab is 0.21 μm, with an input width of 0.4 μm. These sizes are designed to carry the single-mode condition. In addition, Si and SiO_2 have index refractive n_f = 3.44 and n_s = 1.47 respectively, at 1550 nm[6-7]. Moreover, the linear taper design is applied to this waveguide, as shown in Fig. 1.

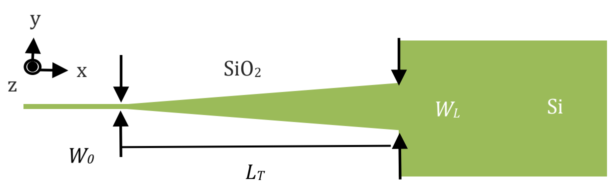

Fig .1: The design of linear taper on the slab optical waveguide.

The design of the taper is optimized by measuring the Full-Width Half Maximum (FWHM) of the light after propagation in a Finite Different Time Domain (FDTD) simulation. In this case, FWHM is representative of the power intensity on the slab waveguide.

A linear taper design sustains the propagation pattern of light at the constant divergence angle. The taper keeps the divergence angle of incident light small. Therefore, the optical power tends to be measured at a long-distance [11-15].

2.2. Simulation Condition

In the simulation software, the calculation of the intensity of light on each position is obtained by introducing a power monitor on each position as well.

Here, The FDTD solution by Lumerical is using on all of the calculation. Furthermore, Fig. 2. shows analysis of the intensity of light after the output of linear taper which is represented by the FWHM. The simulations have been carried out using the FDTD method to determine the effect of the tapered design against the propagation when the light through the slab waveguide.

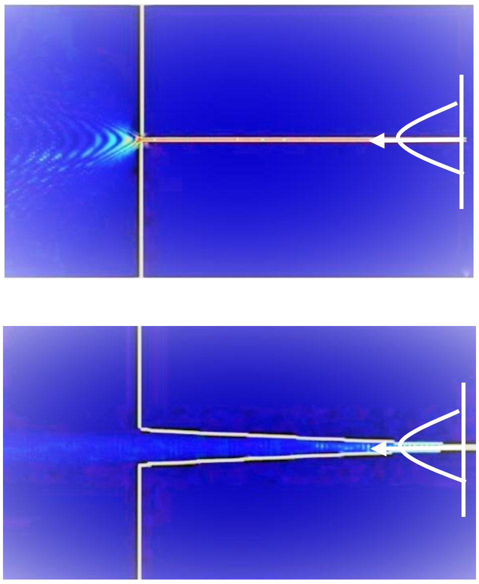

Fig. 2: (upper) propagation without taper design, (lower) propagation with taper design.

Generally, as shown in Fig. 2 (upper side), it seems that the channel waveguide with 0.4 µm in size directly connected to the slab waveguide and will make the propagation light spreading. So that the measurement by this method has the potential to produce higher propagation losses. Moreover, from Fig. 2 (lower side) it can be seen that the use of a design taper can make propagation light propagate perfecty to the slab waveguide. Meanwhile, the design of linear taper keeps the propagation of light confined and propagates with constant patterns as shown in Fig. 3.

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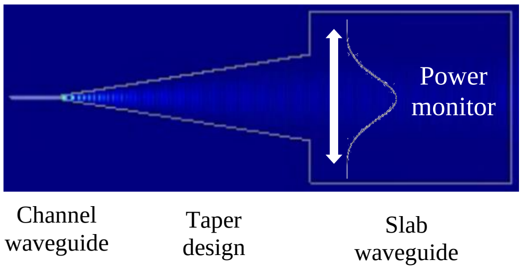


Fig. 3: Optical waveguide consists of the channel and slab waveguide. It is needed the connecting bridge between two kinds of an optical waveguides.

Moreover, from Fig. 2 (lower side) it can be seen that the use of a design taper can make propagation light propagate perfectly to the slab waveguide.

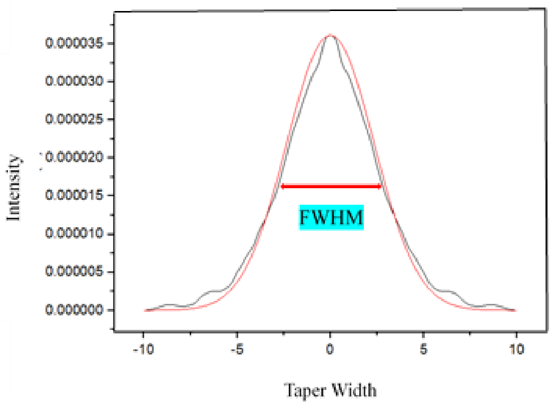


Fig. 4: FWHM is representative of the intensity, it analyzed on the Origin software.

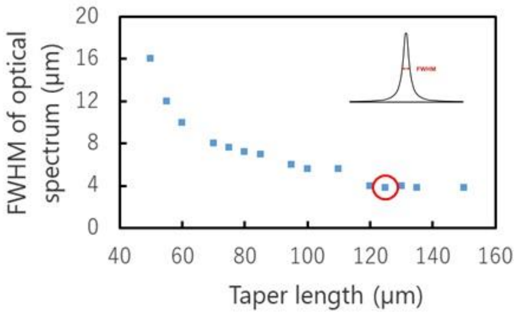
Based on the graph as shown in Fig. 4, the *x*-axis is representative of a measured parameter taper length as shown in Fig. 5(a), and *x*-axis on Fig. 4. described taper width as shown in Fig. 5(b). Meanwhile, the *y*-axis is representative of intensity. By plotting this graph of FWHM, the narrowest curve has the highest intensity and vice versa. Furthermore, the black line is the original data from FDTD simulation software and the red line is plotting data by Origin software.

3. Results and Discussion

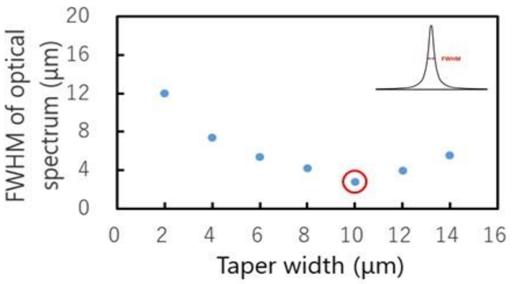
The optimization of the taper illustrated by the shortest taper length but still captured as much intensity as possible. It is important to apply the dimension in the small and short design on the chip.

According to the explanation before, the dependencies of taper length and taper width were calculated to get the optimum value of taper length and taper width as shown in Fig. 5. In this simulation, an ideal condition is set, without any scattering losses on the optical waveguide.

Based on our design, the taper length (T_L) is influenced by the taper width (W_L). To propagate the incident light at the single-mode condition on slab waveguide, some researchers suggest using 5-10 µm likes an optical fiber[16].



(a)



(b)

Fig. 5: a. Taper length dependency of FWHM(the red circle of show the lowest value of FWHM), b. Taper width dependency of FWHM(the red circle of show the lowest value of FWHM).

Based on the results as shown on Fig. 5 (a) and (b), the optimized taper design is obtained when its length L_T and width W_L are 125 µm and 10 µm, respectively. These values are the optimum length and width to get the smallest diffraction angle of light during propagation in the waveguide. By using this structure, the divergence angle of the input light of the slab waveguide is narrowest.

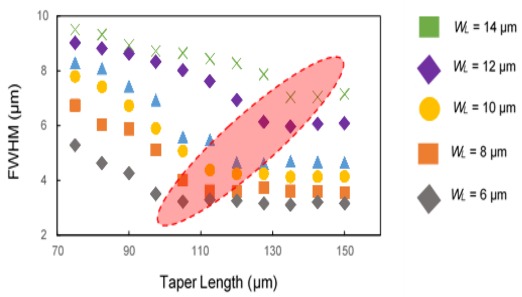


Fig. 6: Taper length dependency of FWHM on the variant of taper width.

According to the graph in Fig. 6. The length of the taper on that design has been corresponding to the taper width to get the optimum value of taper length. Moreover, when the taper width is narrower, the taper length is getting shorter, vice versa. However, according to the graph, the trend of increasing the optimum taper length occurs when the taper width is also getting wider. Therefore, taper width selection to propagate in single-mode conditions has adjusted to a certain application.

Although the taper length is influenced by the smaller taper width, and according to Fig. 6.The taper width smaller than 10 µm produce the shorter taper length as well. However, the spectral peaks of intensity are not much different with the 10 µm. The author suspects that there is a slight losses on the design.

4. Conclusion

We designed and simulated the linear taper on the slab waveguide to control the divergence angle of the light propagation. This value is the shortest taper length that can be used to get the smallest diffraction angle of light during propagation in the waveguide. By using this structure, the divergence angle of the input light of the slab waveguide is minimum. This result can applied to be connecting bridge between channel and slab waveguide.

5. Conflict of Interest

The authors declare that they have no conflict of interest.

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