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Polarization converter using a tapered silicon ridge waveguide

Tapered waveguides with an adiabatic change with respect to the propagation direction are very useful for enhancing of the coupling efficiency between two waveguides with different widths. Mode hybridization can occur in asymmetrical silicon on insulator (SOI) waveguides for certain waveguide widths, where the effective indices of two guided modes match [1-2]. Consequently, the field components of TE and TM modes are comparable and the polarization conversion becomes possible. The TE and TM modes refer to the modes with dominant E_x and E_y component, respectively.

In this article, OptiFDTD is used to model a polarization converter (TM0 to TE1) using an SOI taper waveguide connecting two SOI waveguides with different widths [1].

Labels

Polarization converter; Taper waveguide; Ridge waveguide; Guided modes; Journal confirmation.

Design

The 3D design of the polarization converter is modelled by three sections i.e. the input waveguide (width w_1), the taper waveguide, and the output waveguide (width w_2). All three sections have an SOI ridge structure, see Fig. 1 and tables below for further details about the geometrical dimensions.

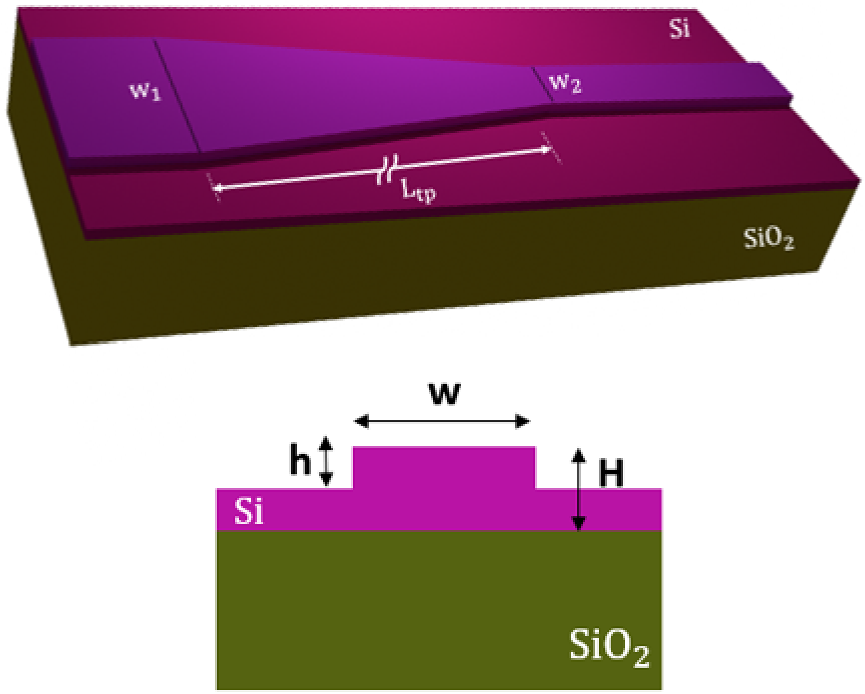

Figure 1: The schematic of the polarization converter using a taper SOI ridge waveguide (top). The cross-sectional view of the waveguide (bottom).

Table 1: The dimensions of the input waveguide. The parameter w_1, H, and h are illustrated in Figure 1. L_1 denotes the input waveguide length.

Input WG	Value (μm)
L_1	1 (z = 0 to 1)
H	0.4
h	0.2
w_1	1.5

Table 2: The dimensions of the tapered waveguide. The parameters w_1, w_2, L_{tp}, H, and h are illustrated in Figure 1.

Tapered WG	Value (μm)
L_{tp}	250 (z = 1 to 251)
H	0.4

Tapered WG	Value (μm)
h	0.2
w	1.5 to 0.8

Table 3: The dimensions of the output waveguide. The parameters w_2, L_{tp}, H, and h are illustrated in Figure 1. L_2 denotes the output waveguide length.

Output WG	Value (μm)
L_2	6 (z = 251 to 257)
H	0.4
h	0.2
w_2	0.8

Table 4: Details of the simulation domain.

simulation domain	Value
Length (μm)	257
Width (μm)	8
Substrate material	SiO_2 (1.445)
Substrate thickness (μm)	1
Cladding material	Air
Cladding thickness (μm)	1
Ridge WG material	Si (3.455)

All boundary conditions in x, y, and z directions are chosen as absorbing perfectly matched layer (PML).

To create the ridge waveguide, a channel waveguide profile with Si and thickness h is created and assigned to a linear waveguide with length and width matching that of the simulation domain.

The input and output waveguides are created on top of the Si slab using a linear waveguide set to the same channel waveguide profile as the slab. The taper section is created using an exponential taper waveguide with the alpha parameter is set to zero.

The optical source was configured using the input plane (positioned at z = 0.5 μm) set to “Modal”, see table 3 for further details.

Table 5: Details of the optical source employed in the simulation.

Optical source features	Value
Wavelength (μm)	1.5
Time domain shape	Sine-Modulated Gaussian Pulse
Mode solver method	Finite-Difference
Number of modes	3

Observation areas (XY) are located at z = 0.7 μm and z = 254 μm for observing the mode profile inside the input and output waveguides, respectively.

A non-uniform mesh is used to reduce the simulation time. The minimum and maximum mesh size are chosen as 0.0434 μm and 0.1 μm, respectively, in the x and y direction. The predefined regions of the minimum mesh size for the x and y direction are defined from x = -0.75 μm to x = 0.75 μm and y = 0 μm to y = 0.4 μm, respectively. Testing also confirmed that 50e3 time-steps are required for accurate results.

Results

The mode solutions and corresponding refractive indices for the input and output waveguides using the OptiMode solver are shown in table 4. Note that the third mode of the input waveguide is TM0, which is the desired input mode. As OptiMode injects the last mode, the “number of modes” in table 3 is set to three.

The mode profiles for the first three modes of the input and output waveguides i.e. TE0, TE1 and TM0 can be seen in Fig. 2.

Table 6: The mode analysis for the input ($w_1 = 1.5$ μm) and output ($w_2 = 0.8$ μm) waveguides.

Input waveguide modes	Effective index	Output waveguide modes	Effective index
TE0	3.129	TE0	3.058
TE1	3.026	TM0	2.853
TM0	2.912	TE1	2.761
TE2	2.859		
TM1	2.807		
TM2	2.668		

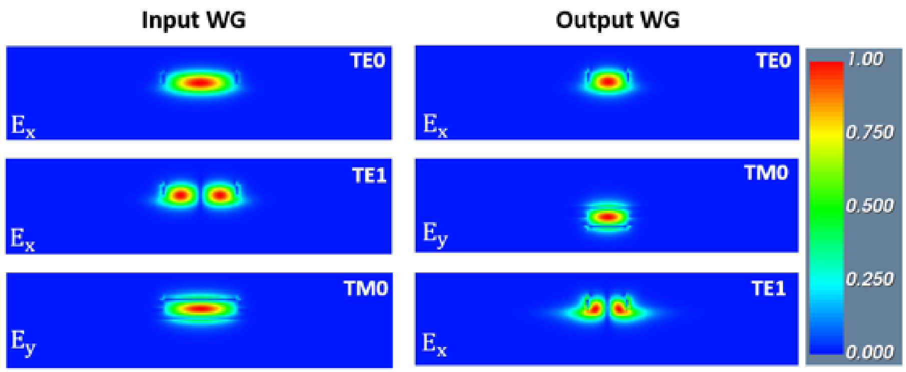

Figure 2: First three possible guided modes in the input and output waveguides obtained by OptiMode solver.

Figure 3 shows the mode profiles obtained through the observation areas (XY) when the structure is injected with the TM0 mode. The mode profile observed at the output waveguide demonstrates the polarization conversion from TM0 to TE1.

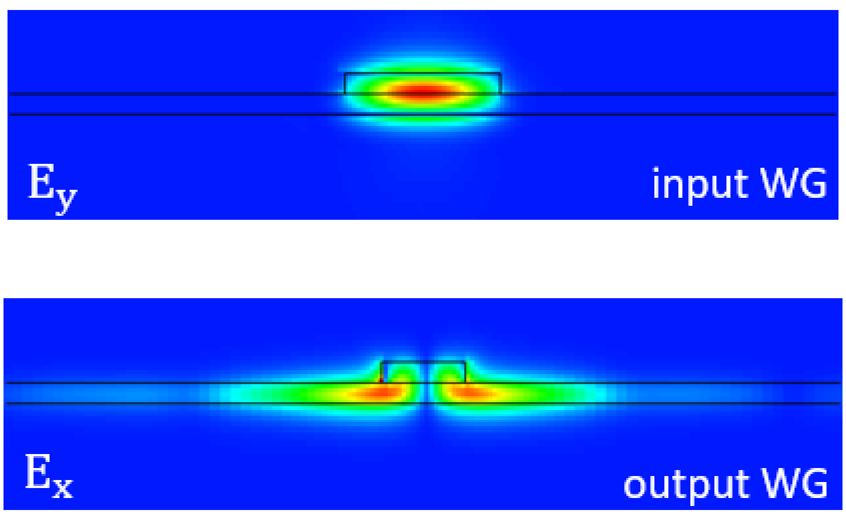

Figure 3: The mode profile of the input and output waveguides when the TM0 mode is injected in the input waveguide. The output mode profile corresponds to the TE1 mode proving a polarization converter functionality.

References

1. D. Dai, Y. Tang, and J. E. Bowers. "Mode conversion in tapered submicron silicon ridge optical waveguides," Optics express, Vol. 20, No. 12, pp. 13425-13439, 2012.
2. D. Vermeulen, K. V. Acoleyen, S. Ghosh, W. D. Cort, N. A. Yebo, E. Hallynck, K. D. Vos et al. "Efficient tapering to the fundamental quasi-TM mode in asymmetrical waveguides," In 15th European conference on Integrated Optics (ECIO), 2010.