Contents

Polarization beam splitter

A compact efficient polarization beam splitter (PBS) can be realized on a silicon-on-insulator (SOI) platform using a directional coupler. In this article a PBS is simulated that integrates subwavelength grating (SWG) waveguides and slot waveguides [1]. This design employs the unique properties of SWG and slot waveguides to separate light based on polarization within a small footprint. The PBS consists of a SWG waveguide in the through path and a slot waveguide in the cross path. SWG waveguides are constructed using periodic subwavelength structures, creating an effective refractive index that can be finely tuned. In this design, the SWG waveguide serves as the through waveguide for TE-polarized light, allowing it to propagate with minimal coupling to the slot waveguide. Simultaneously, it supports broadband coupling of TM-polarized light into the slot waveguide. Additionally, a tapered transition in the SWG waveguide minimizes reflections at the interface with the strip waveguide, ensuring efficient coupling. The slot waveguide consisting of two closely spaced silicon sidewalls with a narrow silica gap. This configuration strongly confines the electric field for TE polarization within the low-index slot while for the TM polarization, the field distribution in the slot waveguide resembles that of a strip waveguide. The SWG dimensions are tailored to achieve the mode matching between the strip waveguide (through path) and the slot waveguide (cross path) exclusively for the TM polarization. This enables efficient coupling from the through path to the cross path, facilitating polarization-selective energy transfer.

Labels

Polarization beam splitter (PBS); Subwavelength grating (SWG) waveguide; Slot waveguide.

Design

The simulation of the polarization beam splitter (PBS) is performed using 3D-finite difference time domain (OptiFDTD) at an operating wavelength $ = 1550 $nm. In 3D OptiFDTD, the Finite Element Method (FEM) solver is used for accurate mode analysis to obtain the optical mode profiles for source injection, see table 1 for the settings of FEM general solver. The 3D design of the PBS is modelled using three sections: the input region, the coupling region, and the separation region. All the three sections are on the SOI platform, see Fig. 1, Fig. 2, and table 2 for further details regarding the geometrical specifications for the structure.

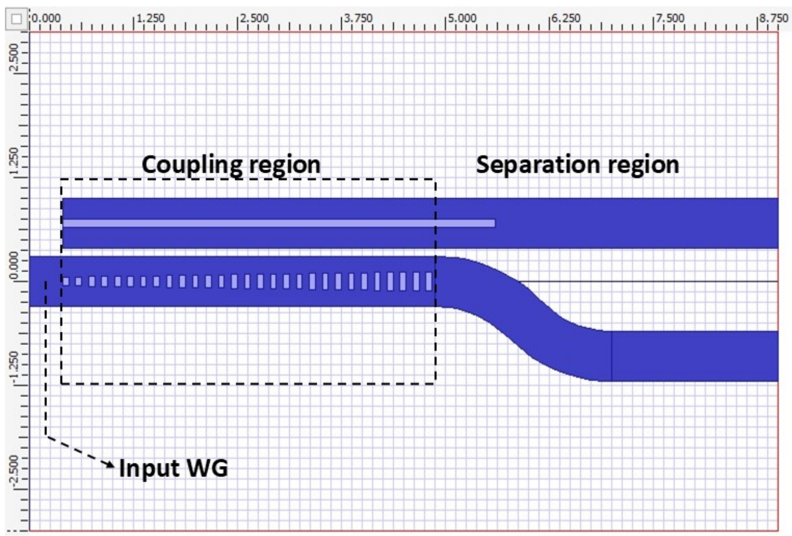

Figure 1: Schematic showing the top view of the PBS in OptiFDTD.

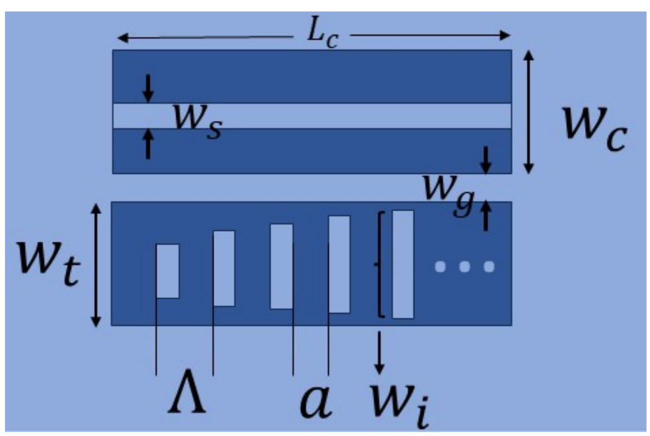

Figure 2: Schematic showing the coupling region of the PBS and related dimensions where $N = 29$ is the number of SWG units in the coupling region; $i = 1, 2, .., N$.

The use of a non-uniform mesh, as detailed in table 3, allows for optimized computational efficiency by applying finer mesh elements only in regions with small feature sizes such as the gap, w_g, between the waveguides.

The coupling region includes a strip waveguide with a linearly tapered SWG and a slot waveguide.

The separation region includes an S-bend with 2.1 μm and 0.9 μm offset along z and x direction, respectively.

The refractive indices for silicon (Si) and Silica (SiO_2) are taken as 3.47 and 1.44, respectively. The boundary settings are selected as anisotropic perfectly matched layer (APML) in x, y, and z direction. The wafer dimensions in the simulation region are chosen as length = 9μm and width = 6μm.

Table 1: Details of general solver settings in the FEM solver.

General Solver Settings	Value
Minimum angle (degree)	15
Min Edge Length (μm)	1e-6
Max Edge Length (μm)	0.6
Max Triangle Area (μm^2)	1
Element Order	1
Mode Index Estimate (real part)	use max index

Table 2: The waveguide parameters in the coupling region.

WG parameters	Value (nm)
w_c =w_t	600
w_g =w_s	100
Δ	156
a	86
w_1	106
w_{29}	231
L_c	4600

Table 3: The nonuniform mesh parameters.

Direction	Min mesh size	Start position	End position
X direction	0.005	-1.6 μm	1.0 μm
Y direction	0.005	-0.4 μm	0.4 μm
Z direction	0.005	0 μm	9 μm

Results

The 3D simulation is performed for the TE and TM polarization using a continious wave (CW) modal input field. The electric field intensity for the dominant components of TE (E_x) and TM (E_y) polarizations are illustrated in Fig. 3 with the modes having effective refractive indices of 2.58 and 1.86, respectively.

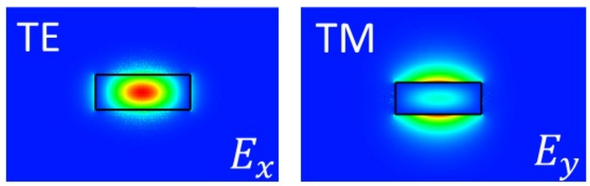

Figure 3: The electric field intensity for TE and TM polarization at the input waveguide with the dominant components of E_x and E_y, respectively.

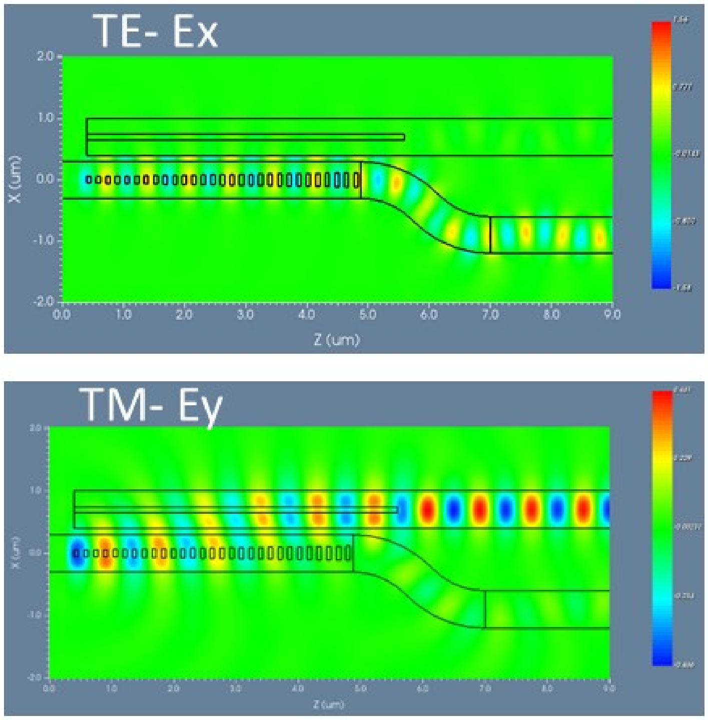

Figure 4: The real part of the electric field for TE (top) and TM (bottom) polarization in the xz plane with the dominant components of E_x and E_y, respectively.

The TE-polarized input wave is guided predominantly through the SWG waveguide with minimal coupling to the slot waveguide, see Fig. 4. In contrast, the TM polarization achieves maximum coupling into the slot waveguide, see Fig. 4 (bottom). These two states demonstrate the design's effectiveness in splitting TE and TM polarizations.

References

1. S. Mao, C. Cheng, C. Zhao, and H. Y. Fu, "Ultra-broadband and ultra-compact polarization beam splitter based on a tapered subwavelength-grating waveguide and slot waveguide," Opt. Exp., vol. 29, no. 18, pp. 28066-28077, Aug. 2021.