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Design of Feasible Silicon Interlayer Polarization Beam Splitter toward 3D Optical Integrated Circuits

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Abstract—A feasible interlayer polarization-beam-splitter was designed. By introducing vertical asymmetry directional coupler with different height of Si wire waveguides, a bandwidth of 60 nm with polarization crosstalk of lower than -20 dB was obtained.

Keywords- Si photonics; 3D optical integrated circuit; polarization beam splitter; vertical directional coupler

I. INTRODUCTION

Recently, three-dimensional Si photonic integrated circuits (3D-PICs) have been actively researched to realize on-chip high density signal transmission. There, hydrogenated amorphous silicon (a-Si:H) has been introduced for the upper layers in terms of compatibility with the low temperature (~350°C) CMOS back-end process [1,2]. Moreover, combination of the 3D-PICs and the present coherent communication technologies has potential to achieve further high transmission capacity, and a 3D integrated polarization division multiplexing (PDM) system is one of the promising communication architecture as well as a 3D integrated wavelength division multiplexing (WDM) system.

Generally, transmission characteristics of Si photonics devices strongly depend on the polarizations because the propagating light is concentrated into the nm-size rectangular Si waveguide core. Then, a polarization beam splitter (PBS) is indispensable for the PDM systems to manipulate polarized signal paths.

So far, several types of in-plane PBSs have been reported [3-7]. Among them, the asymmetrical directional coupler (ADC) based PBSs in which only TM-polarized light executes directional coupling and TE-polarized light goes through the input port has been frequently reported in terms of their broad bandwidth [4-6]. Also, this type of device has an advantage in application to the interlayer PBSs by using PECVD stacking process. For the interlayer ADC-PBSs, a-Si:H film thickness can be arbitrarily controlled in the deposition process unlike the in-plane ADC-PBSs. That gives flexibility to TE- and TM-mode effective indices for ADCs, and a PBS can be realized without elaborated designed waveguides such as slot waveguides, bending waveguides and so on.

In this paper, we designed a feasible interlayer ADC-PBS based on the simple structural straight Si wire waveguides.

II. CALCULATED CHARACTERISITCS

Overall structure of the proposed interlayer ADC-PBS is described in Fig. 1. This device consists of ADC, thickness and width converters. The thickness of c-Si 1st-layer waveguide and a-Si:H 2nd-layer waveguide except for ADC

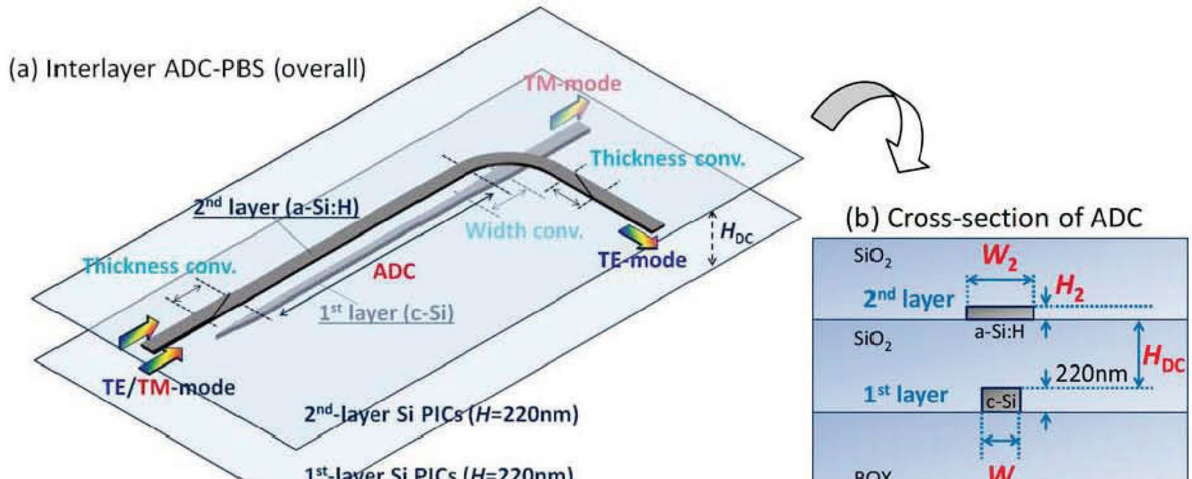

Fig.1 (a) Model of interlayer ADC-PBS which was composed of assymetry Si wire waveguides. (b) Corss-section of the PBS section. The height of the 1st layered c-Si waveguide was fixed to 220nm.

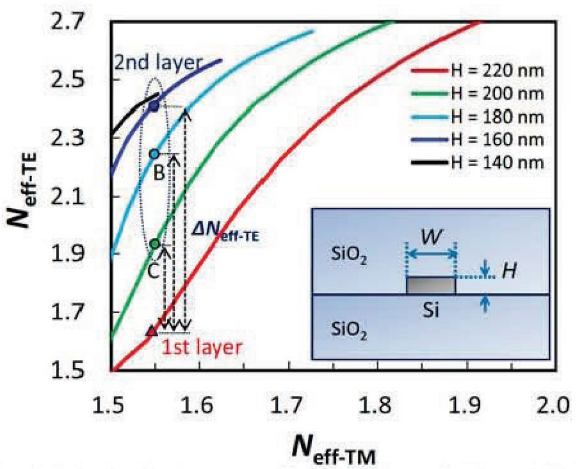

Fig. 2 Relationship between effective indices of TE- and TM-fundamental modes for Si wire waveguides. Inset shows the simulation model.

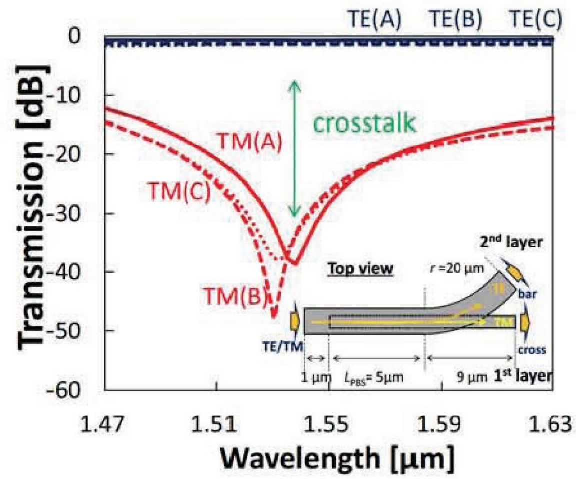

Fig.3 Calculated spectra of the 2nd layered bar ports for each condition desicribed in the table. 1. Inset shows the simulation model.

Table 1 Dimensions of the ADC-PBSs. ($N_{eff\text{-}TM}$ = 1.55)

Model	(A)	(B)	(C)	1st layer
H	160 nm	180 nm	200 nm	220 nm
W	800 nm	490 nm	340 nm	260 nm
$N_{eff\text{-}TE}$ (Δ)	2.42(+0.78)	2.26(+0.62)	1.94(+0.3)	1.64 (-)
H_{DC}	650 nm	620 nm	610 nm	-

section was designed to 220 nm. Then, the height converters were introduced to the both sides of the 2nd-layer ADC section. The PDM signals are inputted from the 2nd layer, and TE-mode light goes through the input port and TM-mode light couples to the 1st layer in the ADC.

The right side of Fig. 1 shows the cross-sectional model of the ADC. The waveguide widths (W_1, W_2), waveguide height (H_2) for 2nd layer, and interlayer thickness (H_{DC}) were set to variables. Here, to realize the PBS operation, TM-mode effective indices ($N_{eff\text{-}TM}$) for the both-layer waveguides must be matched each other, and TE-mode effective indices ($N_{eff\text{-}TE}$) must be separated.

First, relationship between $N_{eff\text{-}TE}$ and $N_{eff\text{-}TM}$ of Si wire waveguides was calculated by the finite difference method (FDM) as shown in Fig. 2. Combination of $N_{eff\text{-}TE}$ and $N_{eff\text{-}TM}$ determines the waveguide dimensions uniquely. In this work, comparable small $N_{eff\text{-}TM}$ of 1.55 was adopted toward broad bandwidth PBS operation, and the waveguide dimensions of the 1st layer with H of 220 nm and W of 260 nm were calculated. For the 2nd-layer waveguide, three types of waveguide height with 160, 180, and 200 nm were chosen. Table 1 describes the dimensions of the ADC-PBSs for each waveguide dimension. As 2nd-layer waveguide becomes thinner, difference in $N_{eff\text{-}TE}$ between 1st- and 2nd-layer waveguides increases. Then, the interlayer distances H_{DC} were designed to be about 600 nm for a TM-mode coupling length of 10 µm, and these interlayer distances satisfy sufficiently-low crosstalk at the three-dimensional waveguides crossing [8].

Next, spectral characteristics for the ADC-PBSs in Table 1 were calculated by Engen-Mode Expansion (EME) method. Figure 3 shows the spectra from the 2nd-layer bar port with an inset of the simulation model. The coupling length in the ADC was set to 5 µm because the center wavelengths is adjusted to near 1.55 µm. TE-mode lights were mainly outputted to bar port with the insertion losses of 0.7, 1.4 and 1.7 dB including bending losses, respectively. The polarization crosstalk with TM modes was calculated lower than -20 dB in the wavelength range of as broad as 60 nm for any models. The polarization crosstalk of the cross port was lower than that of bar port in the wavelength range.

Finally, the overall device-size of the PBS described in Fig. 1 is as small as tens-µm square.

III. Conclusion

An interlayer ADC-PBS was designed. By introducing vertical asymmetry directional coupler with different heights of Si wire waveguides, a bandwidth of 60 nm with polarization crosstalk of lower than -20 dB was calculated. This device is feasible to use for the on-chip 3D integrated PDM-PICs.

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References

[1] R. Takei et al., Group IV photonics 2013, ThC6 (2013).
[2] J. Kang et al., IEEE J. Sel. Top. Quantum Electron. 20 (2014) 8202308.
[3] W. Bogaerts et al., Opt. Express 15 (2007) 1567.
[4] D. Dai et al., Opt. Express 19 (2011) 18614.
[5] S. Lin et al., Appl. Phys. Lett. 98 (2011) 151101.
[6] Y. Xiong et al., Opt. Lett. 39 (2014) 6931.
[7] J. Wang et al., IEEE Photonics journal 6 (2014) 2700608.
[8] K. Furuya et al., Jpn. J. Appl. Phys. 51 (2012) 04DG12.