# Polarization splitter based on form birefringence for micron-scale Silicon photonics

*(Student Paper)*

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**ABSTRACT**

Polarization splitter and rotator are important building blocks for on-chip polarization management. Here we present Mach-Zehnder interferometer on a 3 µm-thick silicon on insulator (SOI) platform with different waveguide widths in the two arms, so to ensure the desired polarization dependence. Despite a suboptimal design of the device, we achieved extinction ratio (ER) >14dB for both polarizations on a bandwidth of 40 nm. However, when focusing on a single polarization only, high ER >20 dB is observed, meaning that higher polarization extinction is possible with further optimization.

**Keywords**: Silicon Photonics, Polarization, splitters, birefringence, Mach-Zehnder interferometer.

**1. Introduction**

Over the last decade, Silicon photonics has become one of the most important integration platform due to its compatibility with mature CMOS technologies for low cost high volume production [1]. As one of the fundamental building blocks for silicon photonics, polarization beam splitters have been developed successfully in the past years for high-index contrast (HIC) waveguides [2-3], targeting applications like coherent receivers, polarization multiplexed transmission systems and sensing [4-5]. Previously, polarization control devices have been reported for Indium phosphide (InP) based photonic-integrated platform [6-7].

The micron-scale silicon photonics has the advantage of low propagation losses, relaxed fabrication tolerances and small polarization dependency, at variance with submicron waveguides that exhibit strong polarization dependencies [8]. On VTT micron-scale silicon photonics platform, rib waveguides can have birefringence as low as $1\times10^{-4}$, whereas strip waveguides with optimized aspect ratio can achieve nearly zero birefringence [9]. VTT silicon photonic platform has low polarization dependency, which can be an advantage when both polarizations are handled the same way but becomes a challenge when the two polarizations must be treated independently. Indeed, several telecom and sensing applications rely on polarization diversity, meaning that at least polarization splitters are required.

In this paper, we investigate how to achieve an on-chip polarization splitter based on interferometric designs on our platform, despite the challenge of low polarisation dependence of our waveguides.

**2. Polarization splitter Design**

In this paper, we demonstrate polarization splitters based on form birefringence, both theoretically and experimentally. The device under consideration is shown in Fig.1 and consists of two 3-dB multimode interferometer (MMI) couplers joined by two arms of same length but different birefringence. An ideal polarization splitter should work such that spectra for both polarizations are centred on same wavelength. The length and the width of the 1×2 MMI is $L_1$ and $w_0$, respectively, the width of the upper arm waveguide is $w_1$ whereas the width of lower arm waveguide is $w_2$. The length of the 2×2 MMI is $L_2$ and width is $w_0$. $L$ presents the length of birefringent section. An analytical model described by transfer matrices is developed for these MZI based polarization splitters. Final transmission vector $T_{\text{out}}$ is shown in equation (1), where $\text{TE}_{11}$ and $\text{TE}_{12}$ present transmission of TE-polarized light from input port 1 to output port 1 and output port 2 whereas $\text{TM}_{11}$ and $\text{TM}_{12}$ present transmission for TM-polarized light.

$$T_{\text{out}} \equiv \begin{bmatrix} \text{TE}_{11} \\ \text{TE}_{12} \\ \text{TM}_{11} \\ \text{TM}_{12} \end{bmatrix} = \begin{bmatrix} c_1 & -k_1 & 0 & 0 \\ -k_1 & c_1 & 0 & 0 \\ 0 & 0 & c_2 & -k_2 \\ 0 & 0 & -k_2 & c_2 \end{bmatrix} \begin{bmatrix} e^{-i\phi_{\text{TE}_{11}}} & 0 & 0 & 0 \\ 0 & e^{-i\phi_{\text{TE}_{12}}} & 0 & 0 \\ 0 & 0 & e^{-i\phi_{\text{TM}_{11}}} & 0 \\ 0 & 0 & 0 & e^{-i\phi_{\text{TM}_{12}}} \end{bmatrix} \begin{bmatrix} \frac{1}{\sqrt{2}} & 0 \\ \frac{1}{\sqrt{2}} & 0 \\ 0 & \frac{1}{\sqrt{2}} \\ 0 & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} \text{TE}_1 \\ \text{TM}_1 \end{bmatrix} \equiv \mathbf{M_2 J M_1} T_{\text{in}} \quad \textbf{(1)}$$

In equation (1) $\mathbf{M_2}$ presents matrix for 2x2 MMI coupler at output, $\mathbf{J}$ presents the birefringent section matrix, $\mathbf{M_1}$ presents 1x2 MMI coupler, whereas $T_{\text{in}}$ presents 2x1 input vector for TE and TM polarizations. The matrix elements $c_1$ and $k_1$ present the transmission for TE-polarized light whereas $c_2$ and $k_2$ present transmission for TM-polarized light at the through and the cross port of 2x2 MMI. The $\phi_{\text{TE}_{11}}$ and $\phi_{\text{TE}_{12}}$ present the phase shifts due to TE- polarized light, whereas $\phi_{\text{TM}_{11}}$ and $\phi_{\text{TM}_{12}}$ show phase differences due to TM- polarized light in both arms of MZI.

Simulation results for ideal device are presented in Fig.2. Thanks to a birefringent length section of $L$ = 216 µm, TE-polarized light can be observed at lower output port whereas TM at upper output port. ER >20 dB is achieved for both polarizations in the wavelength range 1511-1551 nm, and ER >40 dB is observed around 1540 nm wavelength.

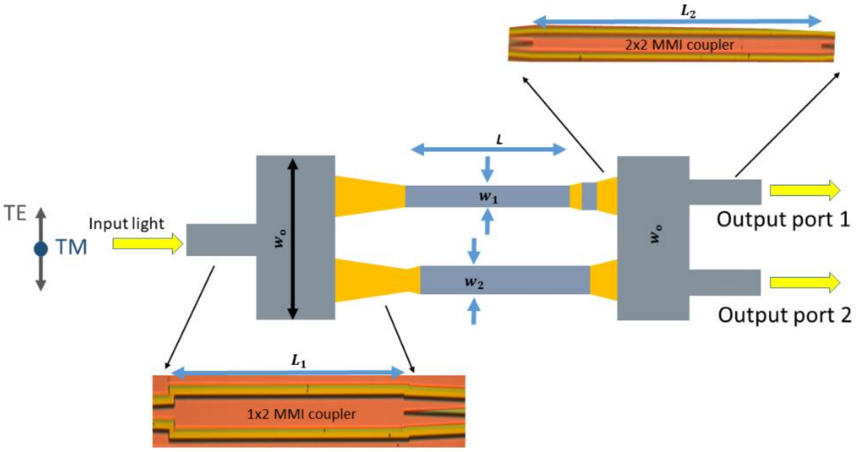


*Figure 1. Schematic and microscopic pictures of polarization splitter based on Mach-Zehnder interferometer design.*

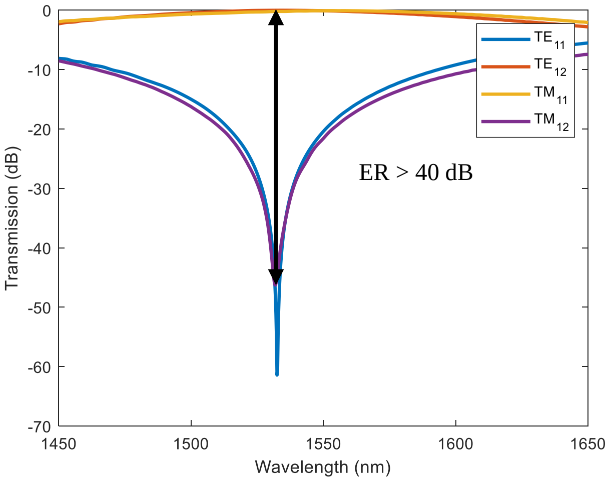


*Figure 2. Simulation of ideal polarization splitter.* $w_1$ = 1.58 µm, $w_2$ = 2.5 µm, $L_1$ = 236.5 µm, $L_2$ = *793.6 µm,* $w_o$ *= 13.5 µm, and L = 216 µm is used for simulation.*

## 3. Experimental results and discussion

The device is fabricated at Micronova cleanroom facility Espoo. Measurement results are presented in Fig. 3 with solid lines. The measured spectra are normalized to the measured losses from a straight rib waveguide. The measured insertion losses are less than 1 dB. When input light is TE-polarized, ER >20 dB is achieved in the wavelength range of 1550 - 1580 nm, and >14 dB ER is observed on 40 nm bandwidth. In case of TM-polarized light, ER is approximately 14 dB in the wavelength range of 1475 - 1515 nm. As compared to ideal simulation results, transmission peaks are shifted for TE- and TM- polarized light. The main reason for the shifting of spectra is 100 µm extra length in the birefringent section due to a variation in mask layout, but simulations show that this is not enough to fully match the measured results. The residual discrepancy can be attributed to non ideal factors such as waveguide width variation. The dotted lines in Fig.3 shows analytical model results when assuming 40 nm width variation in $w_1$. Two main factors that limit the device bandwidth are MMI itself and the wavelength dependence of phase shifters, i.e. change in refractive indices w.r.t wavelength.

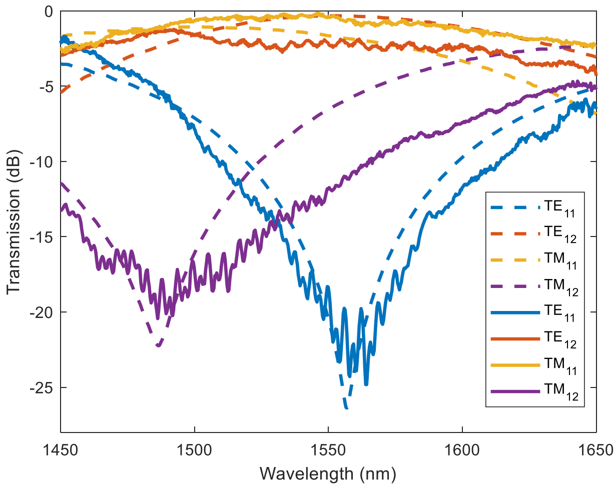


*Figure 3. Analytical model results compared with measurement results. The dotted lines present the simulation results and straight lines present the measurement results.*

## 4. CONCLUSIONS

We have designed a polarization splitter based on MZI on 3 µm-thick SOI platform. In case of ideal device, the ER >20 dB for both polarizations on 40 nm bandwidth is achieved for same wavelength range. However, due to suboptimal birefringent length section and variation in the fabricated narrower waveguide width, only ER >14 dB is achieved for both polarization on 40 nm bandwidth with less than 1 dB insertion losses. We can further optimize the design by using tuning heaters on one arm of the MZI and by optimizing the design. The device can be useful in variety of application such as coherent receivers and polarization multiplexed transmission systems.

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