Thin-Film Lithium Niobate Polarization Rotator

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Introduction

Lithium-niobate-on-insulator (LNOI) waveguides have caught attention because of their electro-optic properties. Recently [1], we developed a coupled-mode theory (CMT) to describe polarization coupling in LNOI microrings. Now, we utilize our CMT model to design a passive polarization rotator, which directly transfers power from its fundamental TE mode to its fundamental TM mode.

We discuss the rotator's ideal-device length, crosstalk, and bandwidth. The proposed design yields compact (shorter than 1 mm), low-loss, passive polarization rotators for telecom wavelengths.

Coupled-Mode Theory

Let Δ be the difference in propagation constants between TE and TM modes; and κ, the TE-TM coupling coefficient. Because of LN's material anisotropy, they both depend on the waveguide orientation angle ϕ as [1]

$$\begin{aligned}\Delta(\phi) =& \Delta_0 + \Delta_1 \cos 2\phi, \\ \kappa(\phi) =& \kappa_0 \sin 2\phi.\end{aligned} \tag{1}$$

We may fully transfer power from one polarization to the other if we choose ϕ and L such that

$$\Delta(\phi) = 0, \tag{2}$$

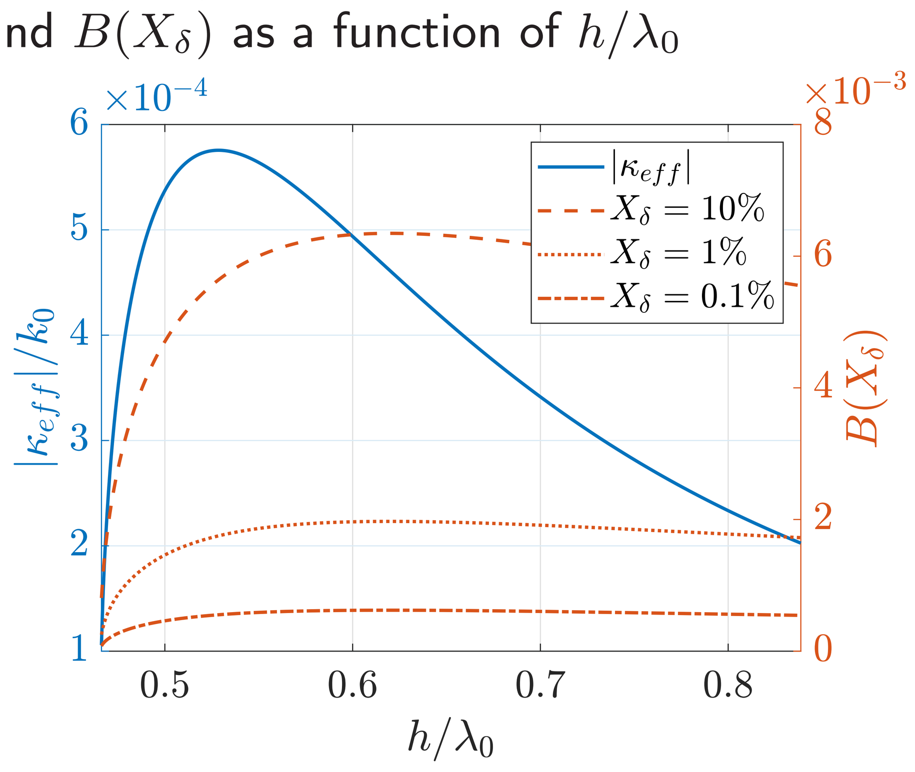
and

$$L = \frac{\pi}{2|\kappa_{\text{eff}}|}, \quad \text{where} \quad \kappa_{\text{eff}} \equiv \kappa_0 \sqrt{1-(\Delta_0/\Delta_1)^2}. \tag{3}$$

Length and Bandwidth

Two measures of performance for a polarization rotator are its length and bandwidth. We characterize these via two parameters. The first is $|\kappa_{\text{eff}}|$, which is inversely proportional to L. The second is the normalized, crosstalk-limited bandwith $B(X_\delta)$, over which crosstalk is lower or equal to X_δ.

Figure 4: $|\kappa_{\text{eff}}|$, normalized by the optical wavenumber k_0, and $B(X_\delta)$ as a function of h/λ_0

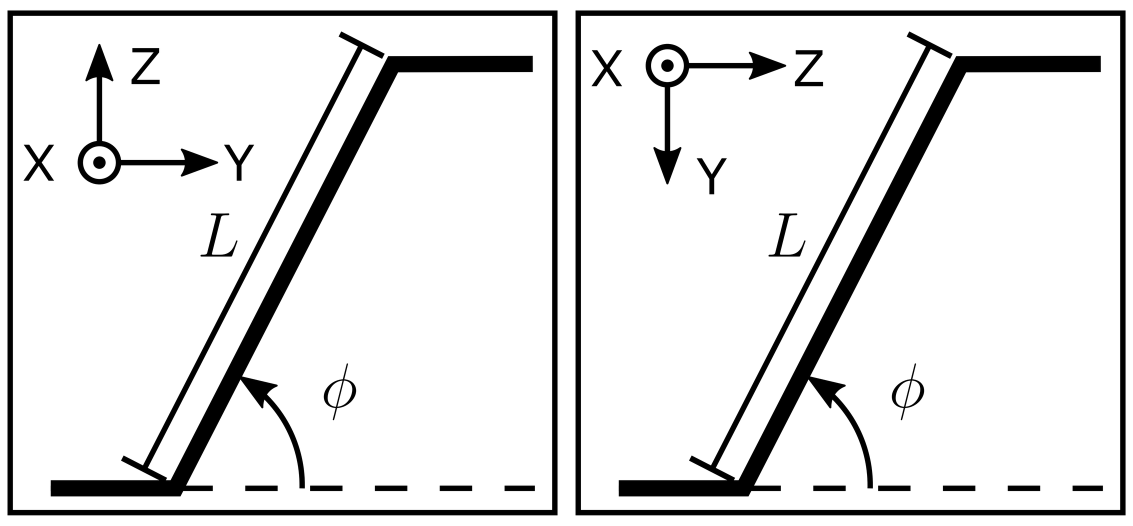


Rotator Geometry

The rotator design is shown in Fig. 1 and comes in two possible configurations. It consists of a LNOI waveguide with a tilted section of length L, joined at its two ends by straight segments. The direction of propagation along the tilted segment makes an oblique angle ϕ with that along the straight sections.

Along the straight segments, the direction of propagation is parallel to lithium niobate's (LN's) Y-axis or Z-axis. In Configuration Y, it is parallel to the Y-axis. In Configuration Z, to the Z-axis.

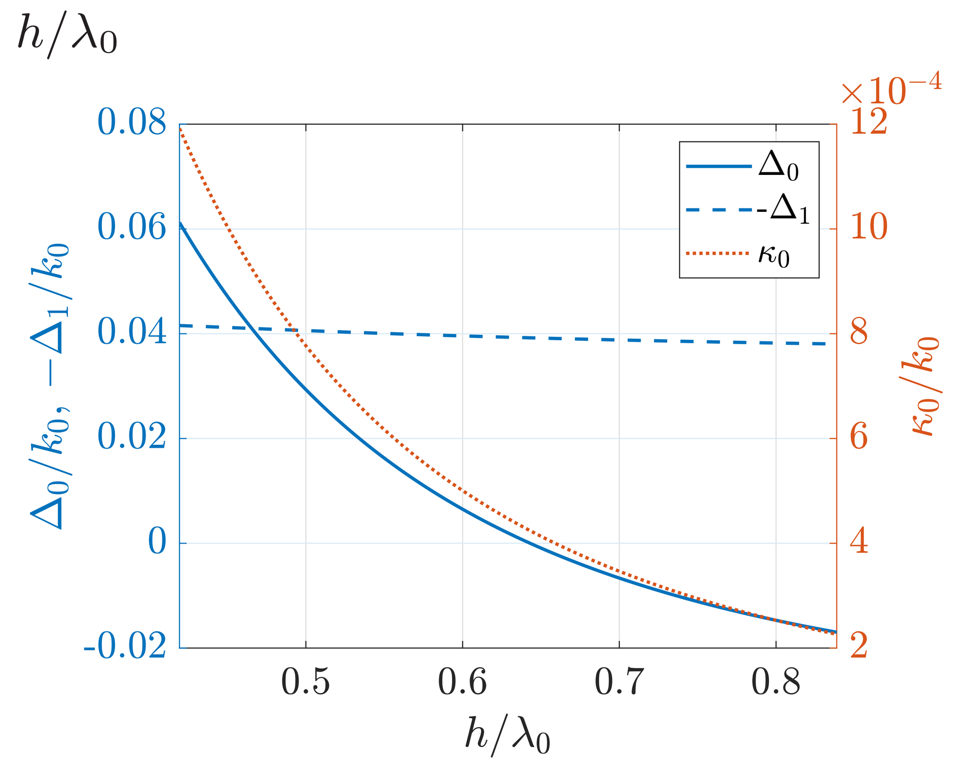
Figure 1: Polarization rotator geometry. Configuration Y (left), and Configuration Z (right). The crystallographic axes are shown in the upper left.



Polarization Parameters and Waveguide Orientation

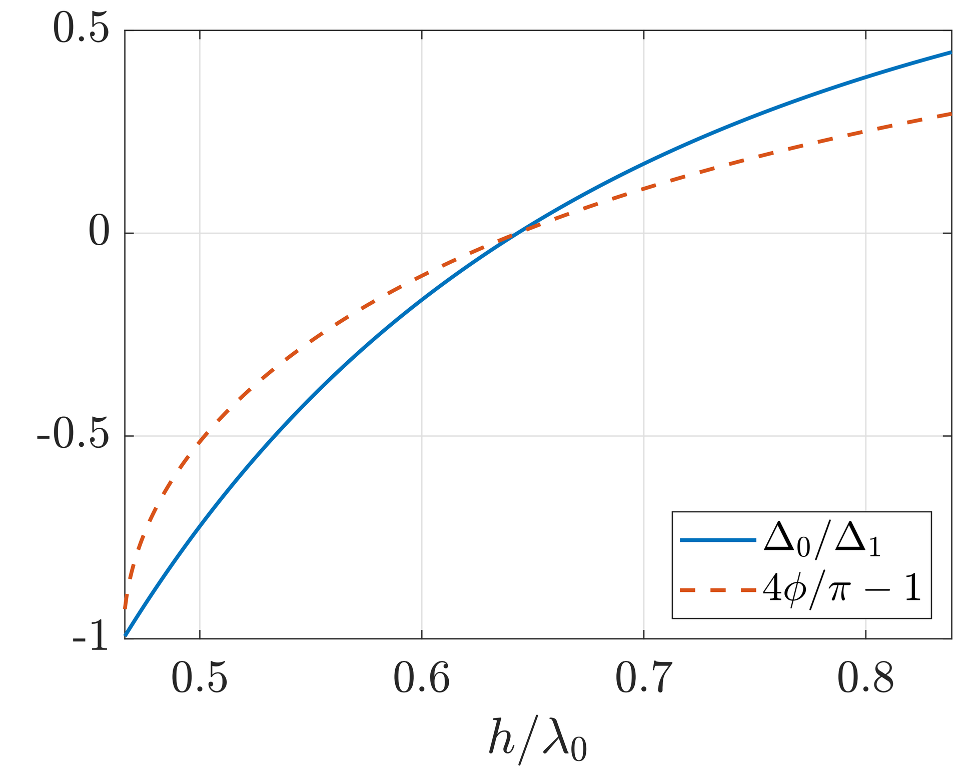
We design a LN rotator with SiO_2 as bottom cladding, and air as top cladding, under Configuration Y. Waveguide width has negligible effect on polarization coupling [1, 2], so we need only consider its thickness h in units of the optical wavelength λ_0.

Figure 2: Polarization parameters, normalized by the optical wavenumber k_0, as a function of optical thickness h/λ_0



Condition (2) can be satisfied if and only if $h > 0.4655\lambda_0$. This agrees with the previous studies of mode-hybridization in LNOI waveguides [2].

Figure 3: Parameter ratio (Δ_0/Δ_1), and its concomitant angle ϕ for phase-matched polarization coupling, as functions of h/λ_0



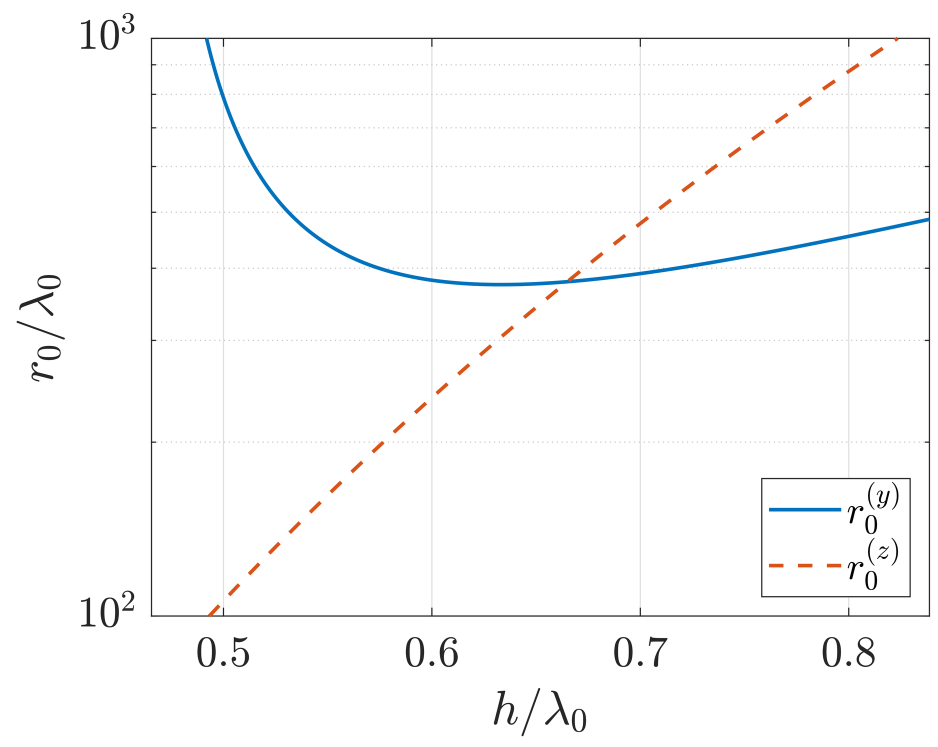
Crosstalk due to Finite Joint-Curvature

In practice, the waveguide joints have non-zero bending radius r. This results in crosstalk X_r due to polarization coupling along the joints. X_r is calculated via perturbation theory, and is found to be bounded as

$$X_r \le (r/r_0)^2. \tag{4}$$

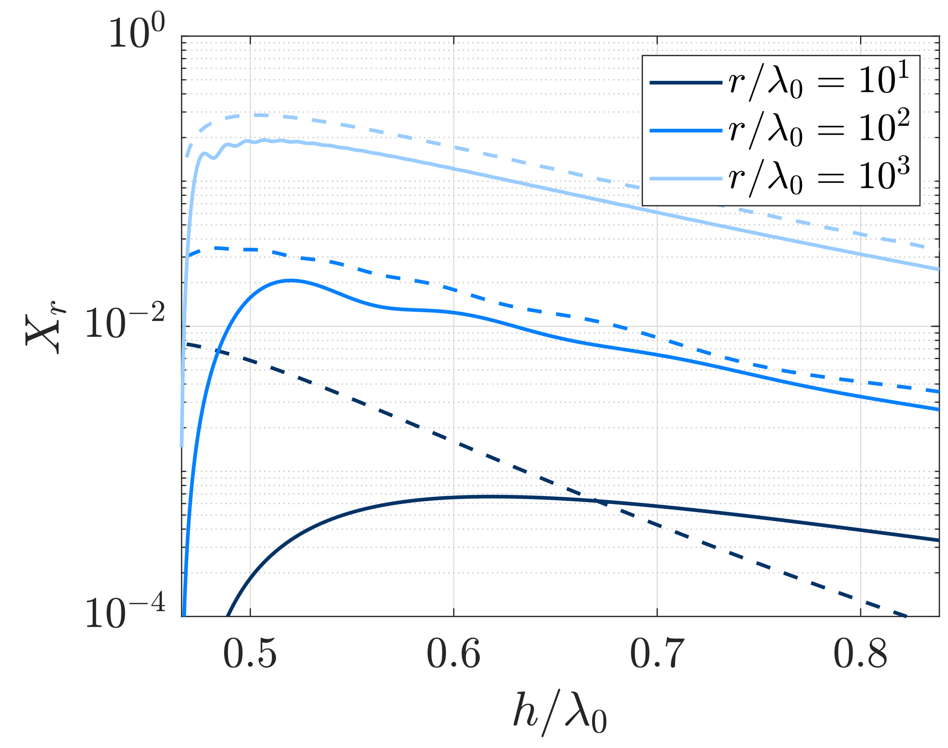
Both X_r and r_0 differ between Configuration Y and Configuration Z.

Figure 5: Radius bound r_0 as a function of h/λ_0 for both configurations



The crosstalk X_r approaches Bound (4) only when r is small enough for the accumulated phase-mismatch to be negligible. As r increases, phase-mismatch inhibits the growth of X_r.

Figure 6: X_r as a function of h/λ_0 for various values of r and both configurations. Solid lines are used for Configuration Y; dashed lines, for Configuration Z.



References

[1] L. Cortes-Herrera, X. He, J. Cardenas, and G. P. Agrawal, "Coupled-mode theory of the polarization dynamics inside a microring resonator with a uniaxial core," *Physical Review A*, vol. 103, no. 6, p. 063517, 2021.

[2] J. Wang, P. Chen, D. Dai, and L. Liu, "Polarization coupling of x-cut thin film lithium niobate based waveguides," *IEEE Photonics Journal*, vol. 12, no. 3, pp. 1–10, 2020.

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