Reflectance of guided waves at facets of Thin-Film-Lithium-Niobate channels

Candidate: — requested —
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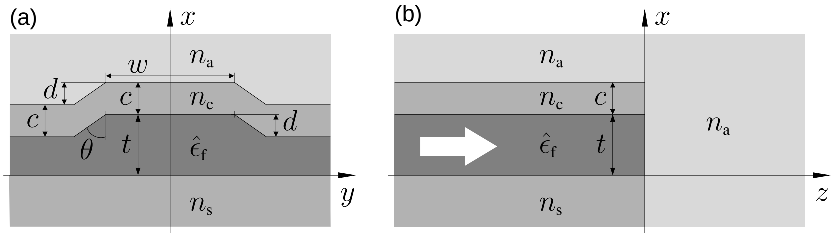
Embedding: Theoretical Electrical Engineering (TET)

Dielectric waveguides constitute one of the fundamental components of integrated photonic circuits. For this project, we look at what happens at an abrupt end (a "facet") of a waveguide channel. More specifically, we consider facets of typical thin-film lithium niobate waveguides that are investigated experimentally elsewhere at our university. Following the successful completion of a preparatory project, the candidate can be expected to be familiar with the modal properties of the TFLN channel waveguides (core anisotropy) and with the COMSOL simulation environment (2-D mode analysis, eigenvalue problems). Building on those experiences, this project aims at rigorous numerical investigations, in 3-D, of realistic, practically relevant facets.



Facet of a LNOI TFLN waveguide, cross sections perpendicular to (a) and along the waveguide axis (b). An anisotropic lithium niobate core of thickness t and width w, with etching depth d, sidewall angle θ, and with relative permittivity $\hat{\epsilon}_f$, is sandwiched between isotropic substrate and cladding media (thickness c) with refractive indices n_s and n_c, with an air cover (n_a). Coordinates x and y span the waveguide cross section plane, light propagates along the z-axis perpendicular to that plane. For $z < 0$, the channel is constant along z, while the half-space $z > 0$ beyond the facet is filled with the cover material with constant refractive index n_a.

Tentative program, certainly negotiable and to be adapted according to the progress of the work, and not necessary in the order as given:

- Clarify the theoretical background of the problem in question, for the 3-D guided wave scattering problems: Maxwell equations in the frequency domain for uncharged, linear, nonmagnetic, and lossless media; scattering matrix formalism, reflection and tranmission coefficients for guided modes, power reflectance and transmittance. Refer to standard textbooks or lecture notes on integrated optics, optical waveguide theory.
- Re-familiarize yourself with the COMSOL simulation environment [1], specialize to scattering problems in the frequency domain (3-D).
- Literature search: Look for a potentially simpler waveguide facet structure, for which reliable (simulation) results for reflectances are available. Set up a respective model in COMSOL, compare results.
- Adapt your COMSOL model to waveguide facets as introduced in the figure, including the core anisotropy, with potentially oblique alignment of the direction of propagation with respect to the axes of the core crystal, in the first place with a facet that is strictly perpendicular to the waveguide axes.
- Obtain (↔ supervisors) a set of "realistic" parameters, preferably data that is of interest in ongoing experimental research (waveguide loss measurements [2]). Carry out a series of simulations for waveguides of varying width, for different orientations of the wavguide and facet with respect to the LN crystal axes. Characterize the reflectance properties of the facet for guided mode incidence, with some emphasis on potential mode and/or polarization coupling.
- As far as time permits: Effects of angled, non-perpendicular, "imperfect" facets; prediction of transmission resonances of a potentially multimode waveguide segment of finite length (↔ loss experiments); analysis of the reversed, in-coupling problem (direct simulations of incoming beams, alternatively prediction on the basis of reflectance simulations, using reciprocity arguments).
- Prepare your thesis and accompanying presentation.

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[1] *COMSOL*, Comsol Multiphysics GmbH, Göttingen, Germany,
[2] M. Hammer, S. Babel, H. Farheen, et al., Optics Express 32 (13), 22878-22891 (2024)