Leakage suppression for TM modes in optical waveguides with shallow etching

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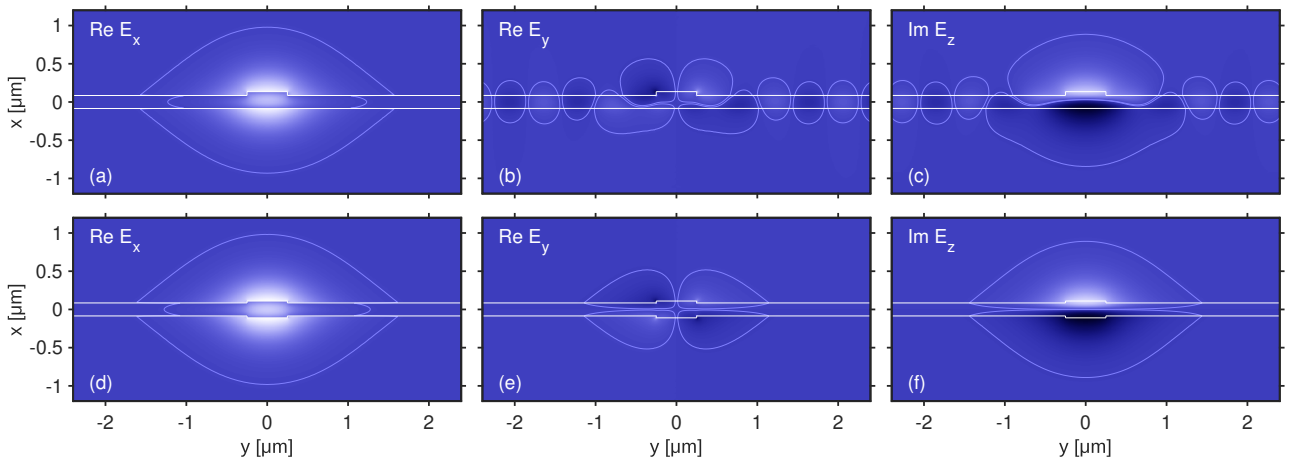
Abstract: Dielectric optical rib waveguides are among the most popular types of channels in integrated photonic circuits. While generally these waveguides support a guided fundamental TE mode, the lowest order TM mode is affected by lateral leakage, if the etching depth is below a certain limit. Exceptions are singular, rather critical "magical widths" [1], at which also guided TM modes exist. This feature can be of advantage in certain contexts. In other situations, however, one might wish to reliably operate waveguides with shallow etching for guided light of both polarizations. Examples could be found in the field of quantum photonics, where low losses are of the utmost importance for the processing of (single, entangled, ...) photons associated with orthogonal polarization states.

As a way out, in this contribution we discuss a slightly modified waveguide geometry, where a downwards and an upwards protruding rib, each of half the former etching depth, together with the lateral film, form a waveguide core with a "plus" shaped cross section. The figure below shows an example for the TM modes guided by such a plus waveguide, and by a corresponding rib. It turns out that the plus structure supports strictly guided TM modes for *any* core width, regardless of the etching depth.

The effect can be explained in terms of local slab modes. Vertical symmetry of the overall waveguide with respect to the central horizontal plane ($x = 0$, figure) is required. Symmetry properties then prohibit a coupling between TM slab modes in the central rib segment and outwards propagating TE slab modes in the lateral segments. The TM mode of the channel becomes symmetry protected [2]. We illustrate the properties of the plus waveguides by a series of numerical examples (Comsol, JCMwave), and evaluate tolerances regarding typical fabrication errors.



Fundamental TM modes of a rib (a–c) and plus waveguide (d–f), electric mode profile components E_x, E_y, E_z; Parameters: refractive indices $1.45 : 3.45 : 1.45$, vacuum wavelength $1.55\,\mu$m, total film thickness 220 nm, etching depth 50 nm (rib) and $2 \times 25\,\mu$m (plus), rib width $0.5\,\mu$m. Effective indices and attenuation constants are $N_{\text{eff}} = 1.8604$, $\alpha/k = 0.0056$ (rib) and $N_{\text{eff}} = 1.8616$, $\alpha = 0$ (plus). [2]

References

[1] T. G. Nguyen, A. Boes, A. Mitchell. *IEEE J. of Sel. Topics in Quantum Electronics*, 26(2):1–13, 2020.

[2] N. Üstün, H. Farheen, M. Hammer, J. Förstner. Symmetry-protected TM modes in optical rib-like waveguides with shallow etching, 2024. (manuscript submitted for publication).