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Determination of Single Mode Condition in Dielectric Rib Waveguides with Large Cross Section by Finite Element Analysis

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The single mode condition in large cross section rib waveguides is of great interest because almost every kind of active and passive integrated optoelectronic device or sensor, is designed to sustain only the fundamental mode of propagation for better matching with optical fibers.

In this paper we present a criterion to determine the single mode condition for a large cross section rib waveguides, by comparison between the numerical solutions found with Neumann boundary conditions and Dirichlet boundaries conditions applied when solving the eigenvalues problem.

INTRODUCTION

The main issue when solving the Helmholtz equation with numerical techniques is that the numerical solver may find solutions that are not physical nor related to the geometries of the problem, but "inspired" by the boundaries conditions. Such solutions are usually caused by the unavoidable need to limit the inspection domain to save computational resources. Sometimes it can be difficult to distinguish between physical solution and these "spurious" solutions. Therefore, if we want to investigate the single-mode condition in rib waveguides, we have choose a robust criterium to understand weather a numerical solution is either a guided mode or it is leaking away from our guiding structure.

The rib waveguide guides modes are supposed to be well confined nearby the rib region and insensible of the lateral boundaries, so we suppose the non physical solutions having larger spatial extension and, for these reason, they are more sensible to lateral boundary conditions. Therefore, by changing the rib section geometrical dimensions, we expect a higher difference between the eigenvalue of first mode solution found with Dirichlet boundaries conditions the one found with Neumann boundaries conditions, when these solutions become not physical (i.e. the mode is not longer guided).

SINGLE MODE CONDITION: FEM ANALYSIS

Along this line of argument, we have developed a numerical code based on FEMLAB and MATLAB which, keeping fixed the rib height H, studies the difference ($|n_{eff10D} - n_{eff10N}|$) between the first higher order mode effective refractive index found with Dirichlet boundaries conditions (n_{eff10D}) and first mode effective refractive index found with Neumann boundaries conditions (n_{eff10N}), by changing etching value (i.e. changing the etching complement r, see Fig.1) for each width-height ratio value, w/H, chosen between 0.5 and 1.75. This has been done in order to compare our results with recently published literature data [1-3].

The typical outcome of this analysis is the plot reported in the Fig. 2 where we observe, for $r<r^*$, the quantity $|n_{eff10D} - n_{eff10N}|$ being essentially negligible, while for $r>r^*$, the difference $|n_{eff10D} - n_{eff10N}|$ increases as expected. The r* value is what we expect to be the boundary between a single mode waveguide and a multimode one. In Fig. 3 we show the comparison between our results, Soref [1] and Pogossian [2] results.

The analysis, originally performed for TE polarization, can be extended to the TM case and to different cross sections in order to evaluate if field polarization or waveguide geometries affect the single mode condition as they become comparable to the wavelength of the propagating field.

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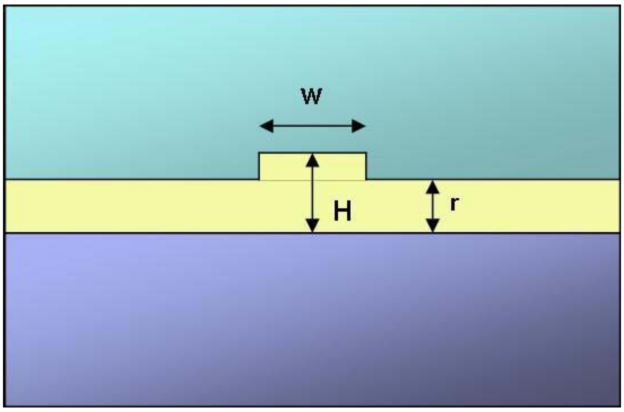

Fig. 1. Rib waveguide section. H is the rib height; w the rib width and r the etching complement.

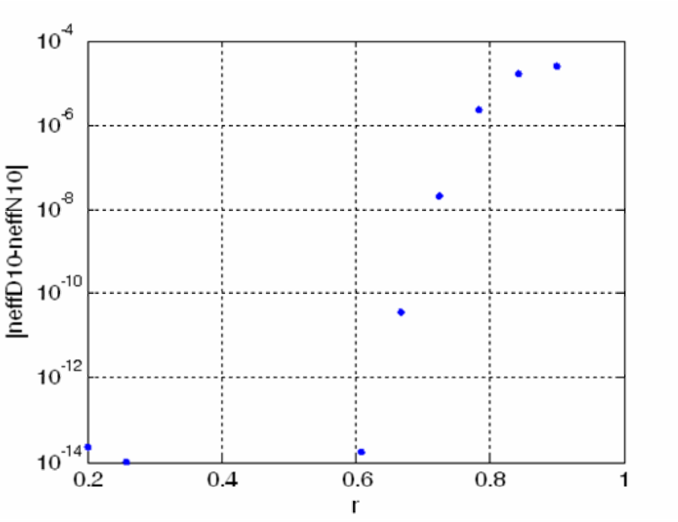

Fig. 2. Difference between first mode solution found with Dirichlet boundaries conditions and first mode solution found with Neumann boundaries conditions. Typically, when this solutions become not physical (i.e. the mode is not longer guided) the difference explodes, so we can observe a particular value of r, r* , so that for r<r*, the quantity |neff10D- neff10N| being essentially negligible, while for r>r*, the difference |neff10D- neff10N| increases. The r* value is what we expect to be the boundary between a single mode waveguide and a multimode one.

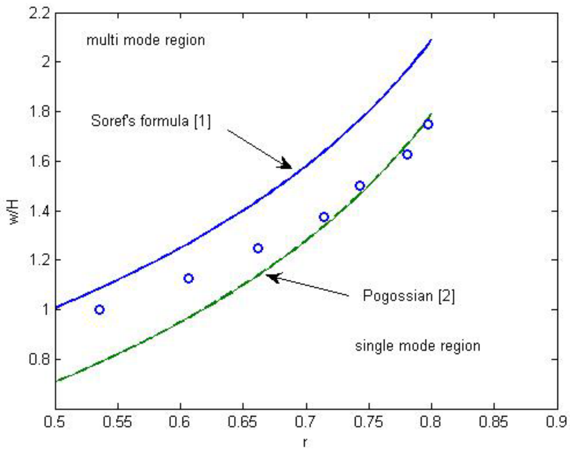

Fig. 3. Comparison between our FEM analysis results (circle), Soref's formula [1] and Pogossian et al. results [2]. Above the curves we define the multi mode region, while below the single mode region.