Project outline, academic year 2021 20.10.2021

Modes of complex planar multilayer slab waveguides: COMSOL-simulations

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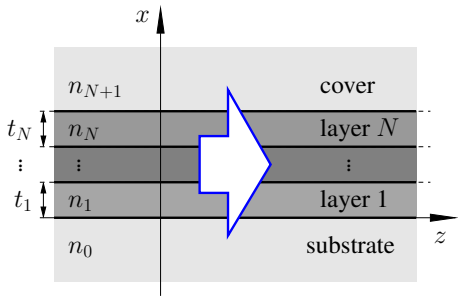
Embedding: Theoretical Electrical Engineering (TET)

1-D modal analysis of optical multilayer slab waveguides can be counted among the standard tasks in theoretical photonics / in integrated optics design. Specialized analytical solvers exist, mostly for identifying guided modes of lossless dielectric systems [1]. Things become a little more complicated if one considers layer systems with loss or gain, i.e. with complex refractive index and permittivity, and guided as well as leaky modes. We shall see in this project in how far that task can be addressed with the solvers of the COMSOL-Multiphysics Suite [2, 3]. The figure shows a schematic of the multilayer geometry that is to be investigated.



Optical multilayer structure with N interior layers between half-infinite substrate and cover regions. The interior layers are of thicknesses t_j with potentially complex refractive indices n_j; substrate and cover are characterized by refractive indices n_0 and n_{N+1}, respectively. Cartesian coordinates x, y, z are oriented such that x is perpendicular to the interfaces. We are interested in wave propagation along the z axis; the structure and all optical fields are assumed to be constant along y.

Tentative program, negotiable and to be adapted according to the progress of the work:

- Make yourself familiar with the theoretical background of the problem in question. Keywords: source-free Maxwell equations in the frequency domain, nonmagnetic, isotropic, and piecewise-homogeneous media, 2-D TE / TM fields, ansatz for guided and leaky modes, mode profile, propagation constant, effective mode index, boundary conditions, complex refractive index and permittivity.
- Carry out a respective literature search, with particular attention to results that might serve as benchmarks for the analytical and numerical solvers.
- Establish 1-D or 2-D frequency-domain models in COMSOL for
  - guided modes of standard lossless dielectric multilayer waveguides, compare with the analytical solver [1],
  - guided modes of dielectric waveguides with small loss or gain, compare with the analytical solver [4],
  - leaky modes of a multilayer structure, where the leakage is caused by a high refractive index in an outer region (such as e.g. a silicon thin-film core on a silica buffer layer on a silicon substrate), compare with the analytical solver [4],
  - plasmonic modes of a single metal / dielectric interface ($N = 0$), compare with the analytical solver [4],
  - other potentially interesting structures.
- Generate converged, reliable solutions that can serve for comparison with other solvers, or as benchmarks for semi-analytical solutions of the problem.
- Report on all findings.

If you think that you might like a theoretical task in between Applied Physics, Applied Mathematics, and Electrical Engineering, then don't hesitate to contact us!

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[1] M. Hammer, *1-D mode solver for dielectric multilayer slab waveguides*, siio.eu (accessed 03.2021)
[2] *COMSOL-Multiphysics Modeling Software*, comsol.com (accessed 03.2021)
[3] *Dielectric Slab Waveguide*, COMSOL Application Gallery, comsol.com, Application ID 14709 (accessed 03.2021)
[4] M. Hammer, *1-D mode solver for complex optical multilayer step-index slab waveguides*, siio.eu (accessed 10.2021)