Hybrid analytical / numerical coupled-mode modeling of guided wave devices

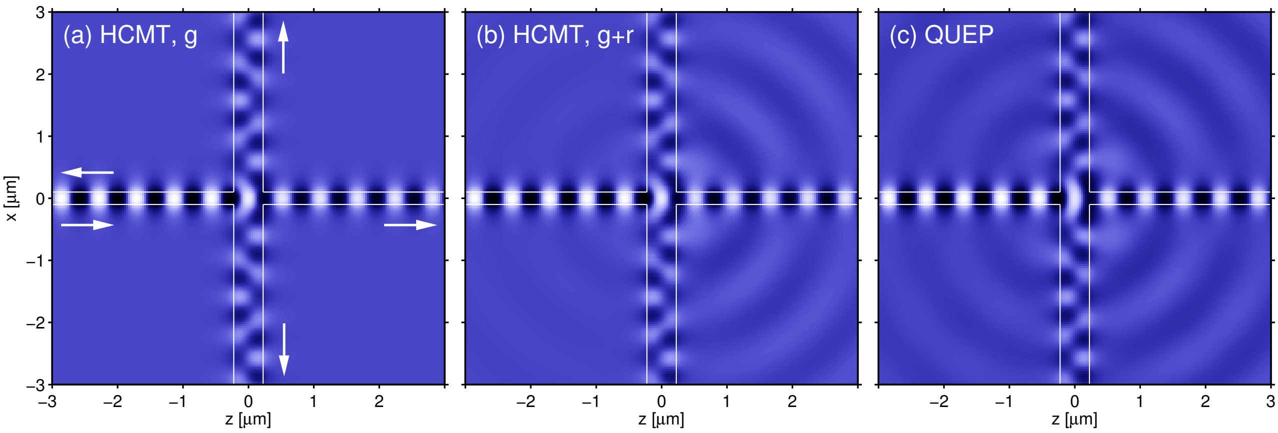
Manfred Hammer
MESA$^+$ Institute for Nanotechnology, University of Twente, Enschede, The Netherlands
m.hammer@math.utwente.nl

A general coupled-mode-theory version for integrated optical scattering/Helmholtz problems is proposed. Modes of optical channels and templates for radiated fields are combined with coefficient functions along arbitrary coordinates. Approximate solutions are obtained by 1-D FEM discretization of these amplitudes.

Summary

Frequently, the light propagation through integrated optical structures is discussed in terms of interactions of a few well defined basis fields, typically the guided modes that are supported by the (local) optical channels of the device. Up to some remainder that represents radiated fields, it is then usually straightforward to write a reasonable ansatz for the optical field by superimposing the directional basis fields with coefficient functions that vary along the respective propagation coordinates, where position and orientation of these axes can be arbitrary. What remains is to determine the amplitudes, i.e. to compute the strength of the interactions. Here we propose to use numerical procedures: the amplitude functions are discretized by linear (1-D) finite elements. Then a variational (Galerkin) procedure is applied that permits to establish a dense, but small-size system of linear equations for the element coefficients, which is solved numerically. We show that it is also possible — with limitations — to incorporate radiation losses by suitable field templates, e.g. by properly placed Gaussian beams.

What concerns the field ansatz, the proposed approach may be regarded as a generalized ("hybrid", analytical/numerical) variant of coupled mode theory (HCMT), but one where the familiar viewpoint of mode amplitude evolutions along a common axis of propagation has to be abandoned. Alternatively, this may be viewed as a numerical finite element technique with highly specialized, structure-adapted elements. A series of examples, including the waveguide crossing below, allows to assess the performance. The HCMT results are benchmarked versus a Helmholtz solver based on rigorous quadridirectional eigenmode expansion (QUEP). While so far only 2-D simulations have been carried out, the given formulation should permit a straightforward extension to 3-D.



2-D simulations of a perpendicular crossing of high contrast waveguides (refractive indices $1.45 : 3.40$, core thicknesses $0.2\,\mu$m (horizontal channel) and $0.45\,\mu$m (vertical waveguide, bimodal)), illuminated from the left by the fundamental mode of the horizontal channel. The plots show snapshots of the electric field E_y for TE polarized light at a vacuum wavelength of $1.55\,\mu$m. (a, b) HCMT simulations, basis fields: the guided modes supported by the horizontal and vertical cores, waves traveling in positive and negative directions along both axes (a). In (b), additionally four Gaussian beams (half-waist-width $0.5\,\mu$m, origins at the inner corners, outgoing at 45° angles) represent radiated fields. (c) QUEP simulation with 120×120 modal expansion terms on a $12\,\mu$m $\times$ $12\,\mu$m computational window, reference.