Quadridirectional eigenmode expansion scheme for 2-D modeling of wave propagation in integrated optics

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Superpositions of two perpendicularly oriented bidirectional eigenmode propagation (BEP) fields, composed of basis modes that satisfy Dirichlet boundary conditions, can establish rigorous semianalytical solutions for problems of 2-D fixed-frequency wave propagation on unbounded, cross-shaped domains.

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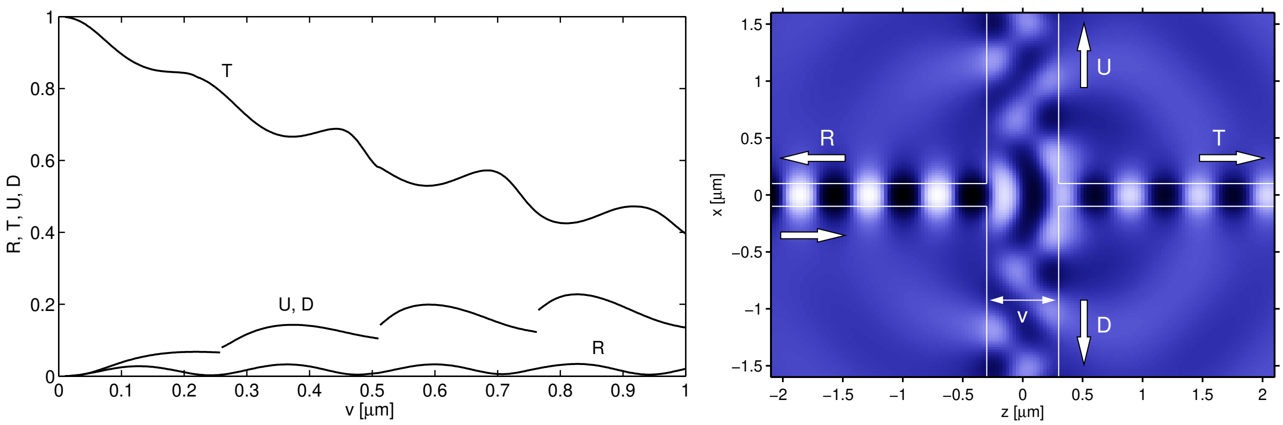
Intended for devices that consist of sequences of piecewise homogeneous waveguide segments, bidirectional eigenmode propagation (BEP) methods are established as standard tools for 2-D simulations in integrated optics. While the BEP techniques can adequately capture effects like wide angle propagation and backscattering, a common starting point is that one identifies one major axis of light propagation, along which also the interesting input and output waves evolve. The electromagnetic field is expanded into the sets of local eigenmodes, defined by suitable boundary conditions at the ends of a lateral computational window.

While this procedure appears to be adequate for a variety of guided wave problems, in particular for the presently discussed high contrast structures like photonic crystals or microresonator devices the viewpoint of a dominant axis of propagation seems unnatural. In a simulation of e.g. a waveguide crossing as in the figure below, one would expect the propagation along the two coordinate axes to be treated completely identically, with direct access to the four waveguide ports. The presentation will show how this can indeed be realized on a semianalytical level, if one combines two BEP expansions, where for one the horizontal axis is the dominant one, while the other is set up along the vertical axis. Dirichlet boundary conditions (hence real mode profiles and effective mode permittivities) are sufficient to establish solutions of the relevant Helmholtz wave equation on a rectangular computational domain, formed by the overlap of the lateral windows of the two BEP sets, with fully transparent boundaries (exception: the corner points). Modeling simultaneous influx and outflux over all four boundaries is straightforward; the computational effort remains moderate. Since modes propagating in the positive and negative directions along the horizontal and vertical axes play a role, this approach could be called a "quadridirectional eigenmode propagation" (QUEP) method.



QUEP simulations of waveguide crossings; 100×100 expansion terms on a $6\,\mu m \times 6\,\mu m$ computational window. A horizontal guide (thickness $0.2\,\mu m$, refractive indices 1.45 and 3.40) is intersected by a vertical core of variable width v. TE polarized light with wavelength $1.55\,\mu m$ is inserted via the fundamental mode of the horizontal waveguide. Left: Dependence of the relative guided power fractions R, T, U, D (see annotations) on v. Right: Snapshot of the single optical electric field component E_y, for $v = 0.6\,\mu m$.