Solution of Optical Waveguide Full-Vector Eigenmodes Using Different Numerical Formulations

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An optical waveguide is a longitudinally uniform structure for guiding light signals to achieve transmission along a single direction, such as the round optical fiber in optical communication systems and the more rectangular-shaped-like wavguide in an integrated optic chip. Most often the light propagates along the core region that has a refractive index larger than that of the surrounding region such that the total intenal reflection can take place to effect the guiding. The electromagnetic field propagating along the waveguide is composed of guided modes, each of which is characterized by electric and magnetic field components being functions of the transverse coordinates with a corresponding propagation constant describing the phase velocity. These guided modes, or the eigenmodes of the structure, can be derived from Maxwells equations with the material syetem being the two-dimensional permitivity and permeability distributions in the transverse cross-section. To formulate a numerical scheme to solve the eigenmodes of a general waveguide, first a computational domain in the waveguide cross-section is designed, and then a matrix eigenvalue equation can be derived based on a numerical approximation. The finite difference and finite element methods have been most popularly employed. The multidomain pseudospectral approach will also be shown in this presentation. The solved eigenvalues will lead to the propagation constants of the guided modes to be determined and the eigenvectors give the mode fields.

A general derivation will offer the mode solution of full-vector characteristics. For many traditional optical waveguide problems, scalar modes or just semi-vector modes obtained from simplified numerical derivations would be enough in practical analysis and design applications. However, the rapid technological advancement in the past decade has led to the invention of new waveguides and the reconsideration of some special waveguide structures, which require full-vector solutions due to their more complicated structures. For example, the photonic crystal fibers involving many air holes in the structure, the subwavelength-sized photonic wire waveguides with much high contrast in their refractive-index profiles, and tiny plasmonic waveguides involving dielectric-metal interfaces and surface plasmonic effects all need full-vector considerations and demand efficient and accurate numerical schemes to offer reliable propagation-constant solutions. Moreover, some of these waveguides are leaky ones, that is, the mode field would not be perfectly confined and the mode power leaks away gradually during propagation with the propagation constant becoming a complex value. To include such more complex effect in the analysis, some aborbing boundary conditions, such as the perfectly matched layers (PMLs), need to be designed surrounding the computational domain.

To obtain high-accuracy solutions in electromagnetics problems such as solving the waveguide modes, proper fulfillment of field continuity conditions at dielectric interfaces is essential. Very high-accuracy results in mode analysis can be demanded in some waveguide design, e.g., that involving birefringence properties. The dependence of numerical accuracy upon how the continuity conditions are treated will be discussed, e.g., the stair-case, the index averaging, and the proper boundary-condition matching schemes in the finite difference formulation will be compared. And a new multidomain pseudospectral formulation will be demonstrated to be able to offer very high accuracy.