PML 경계 조건을 사용한 자기광학적 평판 도파로 고유 모드의 수치해석

Numerical method for obtaining the eigenmode of magneto-optical planar waveguide with a PML boundary condition

권경일*, 황보승, 김철호
호남대학교 광전자공학과
kweon@honam.ac.kr

Non-reciprocal devices such as isolators and circulators are indispensable components in optical telecommunication systems. Although bulk optical devices are quite satisfactory in performance point of view, their large size and labor-intensive manufacturing process made it difficult to lower the device price and to realize integrated optical circuits incorporating non-reciprocal devices. On this reason, many researchers have studied waveguide-type non-reciprocal devices. Although experimental efforts have been concentrated on rib or channel waveguide configuration, proof-of-principle investigation have been centered on planar waveguide. The most successful configuration has been that of the magnetization direction perpendicular to the propagation direction where the fundamental TM mode experiences non-reciprocal phase shifts for the forward and backward propagation.

The theoretical analysis for this type of seemingly simple structure is not trivial because the familiar wave equation in terms of electric or magnetic fields are reduced to a general eigenvalue equation where the propagation constant (β) and its square (β^2) simultaneously appear. Therefore, conventional finite-difference approach to the wave equation results in a nonlinear equation that is not supported by standard numerical routines and even if it exists, the success in finding the solution cannot be guaranteed(1).

We have noticed that the Maxwell's equations for TM mode in presence of magneto-optical layer can be solved for one component of the electric field (E_x) and one component of the magnetic field (H_y). This coupled set of equations can be arranged to an eigenvalue problem that is linear in the propagation constant and hence, can be easily solved using canned numerical routines(2). However, promising designs for non-reciprocal devices are numerically challenging due to its minute index difference between the cover and the film. Combined with the awkward matrix structures resulting from the coupled set of equations, the solution of this non-Hermitian matrix is very unstable. For example, change to finer grid spacing or change of the waveguide position within the computational window may result in failure to find the correct guided modes. This numerical instability can be alleviated with the introduction of perfectly matched layer (PML) boundary at the edges of the computational window(3). If we assume the mode propagates along the z-axis and the waveguide plane is parallel to the y-z plane, then the coupled set of equations are given as

$$\begin{pmatrix} -\Phi\dfrac{\partial}{\partial x}\left(\dfrac{\varepsilon_{xz}}{\varepsilon_{zz}}\right) & k_o^2+\Phi\dfrac{\partial}{\partial x}\left(\dfrac{\Phi}{\varepsilon_{zz}}\right)\dfrac{\partial}{\partial x} \\ \varepsilon_{eff} & \dfrac{\varepsilon_{xz}}{\varepsilon_{zz}}\Phi\dfrac{\partial}{\partial x} \end{pmatrix}\begin{pmatrix} E_x \\ H_y \end{pmatrix}=\beta\begin{pmatrix} E_x \\ H_y \end{pmatrix}. \qquad (1)$$

where the notations follow the usual convention(1). The factor $\Phi \equiv \left(1-j\sigma_x/\omega\varepsilon_p\right)^{-1}$ is due to the PML boundary condition, and σ_x and ε_p are the anisotropic conductivity and the dielectric permittivity in the PML layer, respectively. The numerical solution of Eq. (1) agreed well with the analytical solution for a waveguide-type isolator designed to operate at 1.55 mm.

1. A. Erdmann, M. Shamonin, P. Hertel, and H. Dtsch, "Finite difference analysis of gyrotropic waveguides", Opt. Commun. 102, 25-30 (1993)

2. G. Kweon, S. Hwang-bo and C. Kim, "Eigenmode of Planar Magnetooptical Waveguide", *The 3rd International Conference on Advanced Materials and Devices*, DEV-P22, Jeju, Korea (Dec. 2003).

3. W. P. Huang, C. L. Xu, W. Liu, and K. Yokoyama, "The perfectly matched layer (PML) boundary condition for the beam propagation method", IEEE Photon. Technol. Lett. 8, 649-651 (1996)