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Calculation of eigenfunctions for optical waveguides using a new numerical approach

Takayuki Yamanaka, Shunji Seki and Kiyoyuki Yokoyama
NTT Opto-electronics Laboratories
3-1 Morinosato Wakamiya, Atsugi, Kanagawa 243-01, Japan

Abstract : An efficient numerical approach has been applied to analyze optical field distributions for optical waveguides. This approach does not require accurate eigenvalues to obtain eigenfunctions, and in contrast to the Householder method, results are accurate enough for optical waveguide design.

Introduction : Propagation mode analysis of dielectric waveguides is very important in designing a suitable device structure. The Householder method, which is the prevailing approach, has been applied to the symmetric matrix ($N \times N$: for N discretized mesh points). Here, the matrix is diagonalized to solve the eigenvalues, *i.e.*, propagation constants. Then the corresponding eigenvectors, *i.e.*, field distributions, are obtained using the eigenvalues. However, in attempts to solve problems related to large-scale systems (complicated device structure), this conventional diagonalization method overburdens computational resources--a large amount of CPU time and memory storage.

Numerical Method : The equation below describes the present problem.

$$\frac{\partial^2 E(x,y)}{\partial t^2} = \frac{c^2}{n^2(x,y)}\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} - \beta^2\right)E(x,y)$$

Here $E(x,y)$ and $n^2(x,y)$ are the scalar value of optical field and refractive index, respectively. c is the light speed in vacuum. β is the propagation constant corresponding to the eigenvalue of each optical field. The numerical technique employed here was originally applied to the study of phonon localization in disordered systems[1]. This method is based on the idea that the eigenfrequency of this system satisfies the resonance condition when applying the periodic external force. Note that it does not require accurate β values to obtain $E(x,y)$'s. This is very advantageous for taking this problem. In our experience, CPU time by the Householder method is proportional to $N^{2.4}$. This means that with this method we easily reach the maximum node limitation. On the other hand, our method can be applied to very large-scale systems which cannot be handled by conventional diagonalization methods[2]. Therefore, our method is an attractive candidate for further study.

Calculated Results : The transverse mode distribution for the optical waveguide shown in Fig. 1 is calculated using our method. For this *buried heterostructure* the optical field is strongly confined to the core region. The calculated bird's-eye view of light intensity distributions, which is the square of the obtained optical field distributions, are shown in Fig. 2. These calculated results are then compared with those attained by the Householder method. Figure 3 shows the light intensity distributions for the 0-th and the 1-st order modes along x- and y-axes at the midpoint of the active region. The figure shows very good agreement between the two approaches.
In conclusion, the authors have calculated optical field distributions with sufficient accuracy using a novel numerical method. This approach is promising for further application to the optical device simulations.

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[1] M. Williams and H. Maris, Phys. Rev. **B31**, 4508 (1985)
[2] K. Yakubo and T. Nakayama, Phys. Rev. **B40**, 517 (1989)

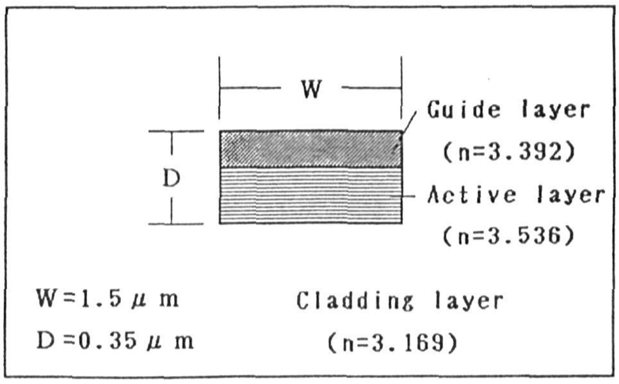

Fig. 1 Schematic cross-section of *buried heterostructure* optical waveguide.

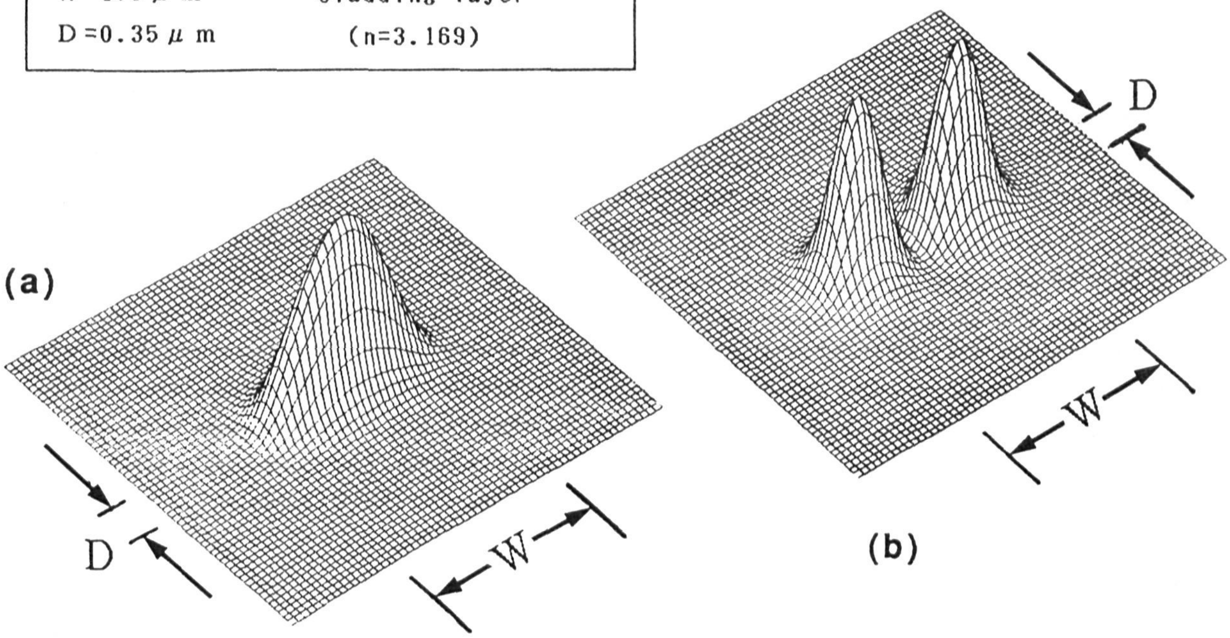

Fig. 2 Light intensity distributions for (a) 0-th and (b) 1-st transverse mode. W and D are width and thickness of core region in Fig. 1.

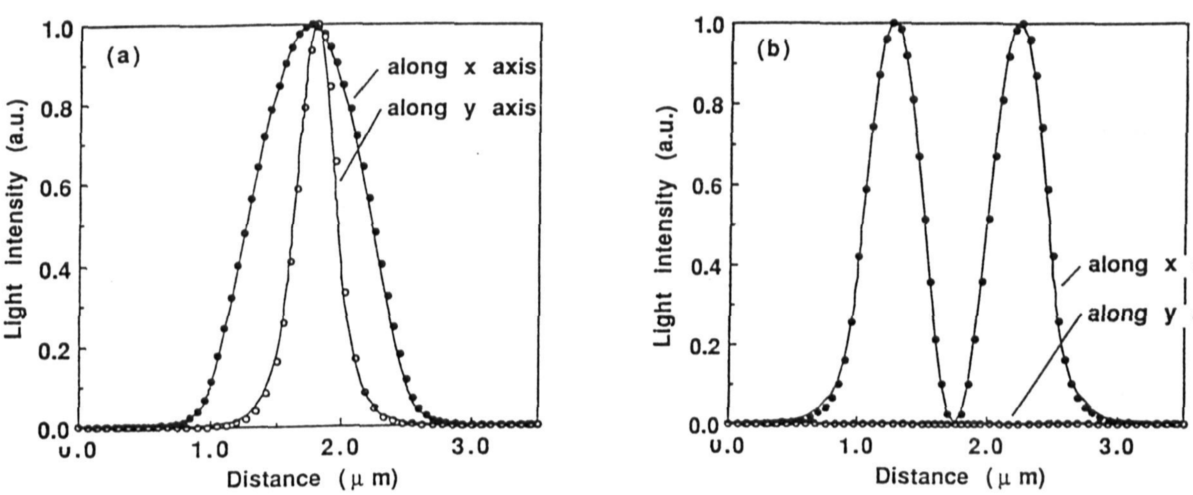

Fig. 3 Light intensity distributions by the two methods; open and closed circles represent results by the present work. Solid lines are those by the Householder method. (a) for 0-th mode, and (b) for 1-st mode.