COMPUTER SIMULATION OF LIGHT PROPAGATION IN PHOTONIC WAVEGUIDE STRUCTURES

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Abstract

An interactive program for simulating light propagation through photonic waveguide structures was developed. From the viewpoint of CAD, two parts of this program are interesting: the channel waveguide editor, and the 3D graphic interpretation of the results. The program is written in MS FORTRAN 5.1 and runs under DOS on standard PC's. Graphs are drawn in separate windows. It communicates with the user through the mediation of a single command line and keyboard controlled menus. In this contribution, a rough description of the program is given.

Introduction

Methods simulating light propagation through photonic waveguide structures are called beam propagation methods (BPM). Methods based on the fast Fourier transform (FFT-BPM) [1] and on the finite difference scheme (FD-BPM) [2] are mostly used. They are either two dimensional (2D) with one propagation axis (mostly the z axis) and an axis perpendicular to it or three dimensional (3D) with one propagation axis and a plane perpendicular to it. At the propagation axis an initial condition is considered (an input light beam) and at the axes perpendicular to it zero or transparent boundary conditions at the edges of the computational window are taken into account.

In any algorithm which is based on the BPM, the following step is used: A set of values of a discretized electromagnetic field at the plane $z = z_0 + \Delta z$ is evaluated using initial values given at $z = z_0$. The new set of values plays the role of the initial values in the next step. Thus, the values of the field are consecutively calculated at $z = k \,.\, \Delta z$, where $k = 0, 1, \ldots, M$. The accuracy of the algorithm should rise with decreasing Δz

The program description and it's use

The program is based on the 2D-FFT-BPM and was developed for simulating optical processes in diffused $Ti : LiNbO_3$ channel waveguides. User, working with the program, can follow these steps:

1. The user designes a channel waveguide in the channel waveguide editor (described below).
2. The user defines the input beam (the initial condition) using a gaussian distribution (it correspods to a laser beam) or an eigenmode of the channel waveguide.
3. The user passes the input beam through the waveguide using the beam propagation algorithm.
4. The user draws the results in a 3D graph (described below).

At any z, overlap integrals of the field with eigenmodes of channel waveguides can be calculated which enables to determine the radiation loss and the phase shift of the propagating wave.

The key sequence through which a user controls running of the program can be predefined in a file. This option is advantageous when long calculations are to be done.

The channel waveguide editor

A waveguide is a dielectric medium and is characterized by it's dielectric permittivity $\varepsilon(x, y, z)$. A channel is a long narrow region within a waveguide structure and is characterized by it's width, depth and the dielectric permittivity distribution $\varepsilon(x, y, z)$. The permittivity of the channel ε is greater then the permittivity of the surrounding substrate ε_0.

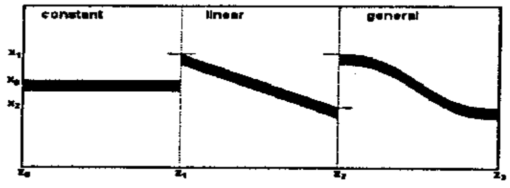

Fig. 1
A sample of three different shape types.

The editor allows the user to design a 2D channel waveguide: each channel is defined by the shapes of it's side borders. The shape is given by a polynom of the fifth order. Practically, three kinds of shapes are used (see fig. 1):

1. A constant shape -

$$x(z) = x_0 .$$

2. A linear shape -

$$x(z) = x_1 + k(z - z_1),$$

where $k = \frac{(x_2 - x_1)}{(z_2 - z_1)}$.

3. A general shape -
$x(z)$ is given by the values of the zeroth, the first and the second derivatives of the polynom at $z = z_2$ and $z = z_3$. The coeficients of the polynom are thus uniquely determined.

Both the constant and the linear shape are special cases of the general shape. Therefore only the general shape is taken into account in the program. However, the parameters of the shape are read from a file, where some of them can be predefined (e.g. in the case of the constant shape both the first and the second derivatives are zeroes). Thus, only one simple consecutive file-directed algorithm gives different results according to the choosen control file. A new shape type (e.g. a quadratic polynom) can be created without rebuilding the program.

Still, the algorithm is restricted to the polynoms of the fifth order. Could it be expanded to all (or to the most of) algebraic functions?

A channel consist of the "left shape" $x_l(z)$ and the "right shape" $x_r(z)$. The inequality $x_l(z) \le x_r(z)$ should hold for every z, where the channel is defined.

Any channel waveguide in the editor is divided in segments $z_0 < z_1 < ... < z_p$. A finite number of channels can be designed within each segment. The data defining the channel waveguide can be stored in a single file in the ASCII format.

The 3D graphic interpretation

As the calculation is finished, the results can be drawn in the form of a three-dimensional graph. The front-back axis is the propagation axis (z axis), the horizontal (left-right) axis is perpendicular to the z axis, and the light intensity is represented in the down-up direction (see Fig. 2).

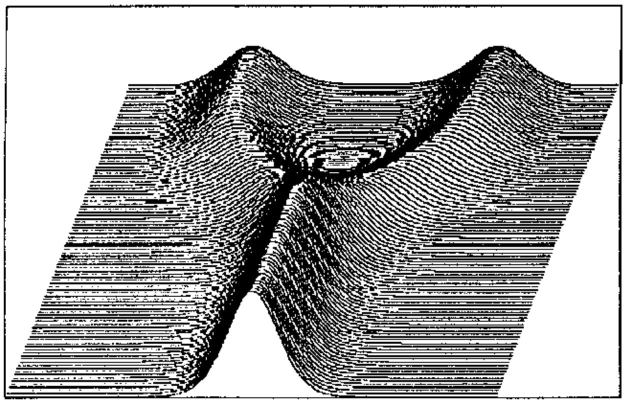

Fig. 2
An example of a graph.

The data is drawn in the same sequence as it was calculated. The area limited by the lines already drawn is protected against overlaping with new lines. Thus, the "back lines" remain invisible.

Standard commercial graphic programs usually require input data in an ASCII-file which results in very large files (greater than 1MB). That's why a special graphic system with packed data backup system was developed. This way was inefficient from the programmer's point of view but significantly enhanced the interactive feature of the program.

References

[1] M.D.Feit, J.A.Fleck Jr.: Computation of mode properties in optical fiber waveguides by the propagating beam method. Appl.Opt. 19, 1980, pp.1154-1164.
[2] W.P.Huang, C.L.Xu, S.K.Chaudhuri: The finite difference vectorial beam propagation method. Electron.Lett. 37, 1991, pp.2119-2121.