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LETTER

Analysis of Dielectric Hollow Slab Waveguides Using the Finite-Difference Beam-Propagation Method

Junji YAMAUCHI†, Takashi ANDO† *and* Hisamatsu NAKANO†, *Members*

SUMMARY The finite-difference beam-propagation method is applied to the analysis of hollow slab waveguides (HSWs). The attenuation constants for the TE_0 and TE_1 modes are evaluated and compared with those obtained by the perturbation theory. The propagating field and differential power loss in the transition from a straight HSW to a bent HSW are revealed and discussed.

key words: *beam-propagation method, dielectric hollow waveguide*

1. Introduction

The finite-difference beam-propagation method (FD-BPM) has been successfully used for the analysis of various optical waveguides [1]-[4]. The FD-BPM has advantages over the conventional FFT-BPM in that waveguides with large refractive-index difference can be efficiently treated, and that a transparent boundary condition [5] can be incorporated. These facts encourage us to analyze leaky wave structures such as a dielectric hollow waveguide [6] by the FD-BPM. Therefore, we investigated the possibility of analyzing a dielectric hollow slab waveguide (HSW) by the FD-BPM [7]. Subsequently, Abe and Miyagi [8] succeeded in analyzing a long HSW with complex refractive indices in the cladding, by evaluating the second order derivative with respect to the propagation direction.

In this Letter, we analyze HSWs with real refractive indices by the FD-BPM and compare the steady-state results with those obtained by the perturbation theory [6]. The propagating field and differential power loss [9] in the transition from a straight HSW to a bent HSW are revealed and discussed.

2. Discussion

We consider an HSW with a core width of W. The refractive indices of the core and cladding are taken to be $N_{CO}=1.0$ and $N_{CL}=1.5$, respectively. A wavelength of $\lambda=10.6\ \mu$m is used throughout this analysis. The sampling grid in the FD-BPM calculations has 512 points in the transverse direction. The spacing between transverse sampling points is $\Delta x=0.25\ \mu$m and that for longitudinal sampling points is $\Delta z=0.1\ \mu$m. The transparent boundary condition [5] is imposed at the

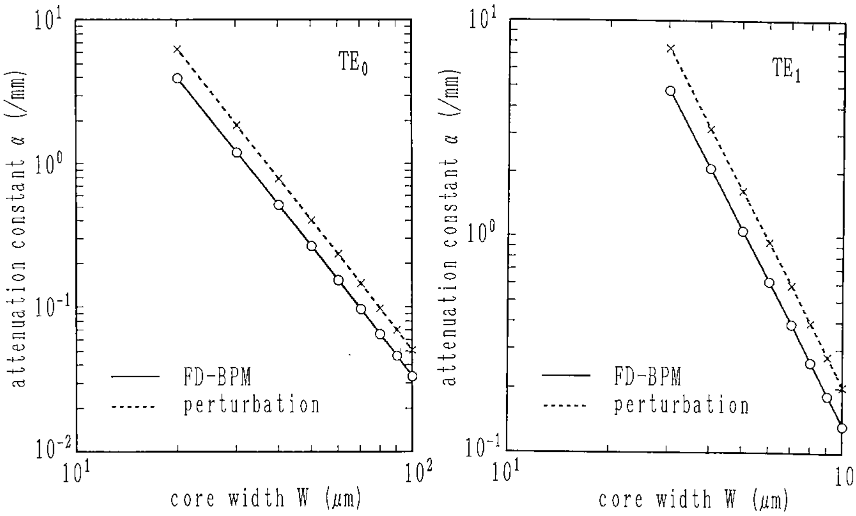

Fig. 1 Attenuation constant of straight HSW.

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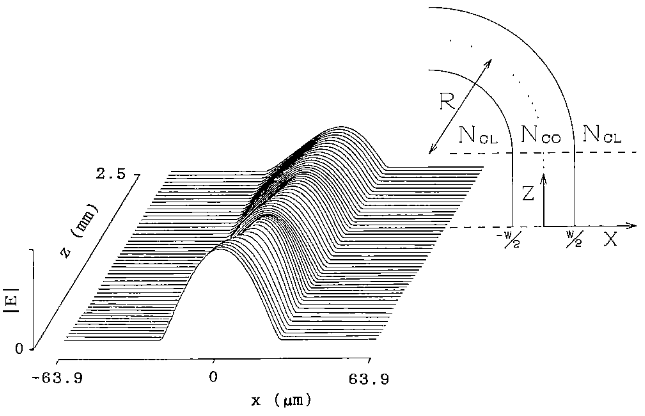

Fig. 2 Propagating field in the transition from straight HSW to bent HSW.

edge of the computational window. We choose the field obtained by the perturbation theory as the incident field.

Figure 1 shows the attenuation constant α of the straight HSW as a function of core width W. The attenuation constant α is evaluated for the TE_0 and TE_1 modes using the differential power loss (DPL) [9]. The DPL is calculated by evaluating the difference in the integrated optical power in the computational area between two adjacent axial propagation steps. It is seen that α decreases as the core width is increased. For comparison, the data obtained by the perturbation theory are also presented. Good correlation is found to exist between both results, although the FD-BPM results show slightly smaller values than those obtained by the perturbation theory. The slight difference is probably due to the fact that the perturbation theory assumes the tightly confined field in the core.

Now, we study the transient behavior of the propagating field and DPL caused by the connection of a straight HSW to a uniformly bent HSW. The HSW to be considered has the straight section of a 100 μm-length connected to the curved section with a bending radius of $R=3$ mm, as shown in the inset of Fig. 2. The refractive-index distribution of the bent section is transformed to that of the equivalent straight HSW [9]. The HSW with a core width of $W=50$ μm is typically investigated. The fundamental TE_0 mode of the straight HSW is used as the incident field.

Figure 2 shows the propagating field, which is plotted at an interval of 50 μm. It is revealed that the field exhibits an oscillatory change, as it propagates. The oscillatory behavior can be explained by the interference between the fundamental mode and higher modes generated at the junction between the straight and bent HSWs. The oscillatory behavior tends to converge as the propagation distance is increased, since the attenuation constants of higher modes are larger than that of the TE_0 mode. The behavior of the propagating field is closely related to the change in the DPL shown in Fig. 3. The DPL also tends to converge as the propagation distance is increased.

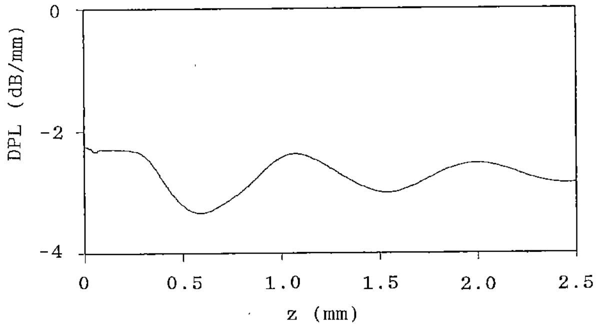

Fig. 3 Differential power loss (DPL).

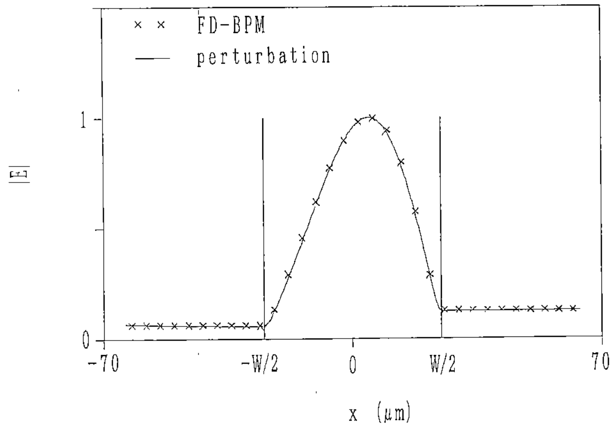

Fig. 4 Steady-state field in bent HSW.

It is interesting to compare the steady-state field observed at large propagation distances with that calculated by the perturbation theory. Figure 4 shows a comparison between the field distributions. Each field is normalized to unity at the center of the core. We can again find good agreement between the FD-BPM result and the analytical result. As expected, the field is deformed toward the outer side of the bend.

3. Conclusions

The finite-difference beam-propagation method (FD-BPM) is applied to the analysis of a dielectric hollow slab waveguide (HSW). The attenuation constants of the straight HSWs for the TE_0 and TE_1 modes are evaluated and compared with those obtained by the perturbation theory. The propagating field and differential power loss in the transition from the straight HSW to the bent HSW are revealed. The steady-state field observed at large propagation distances agrees well with that calculated by the perturbation theory. It is concluded that the FD-BPM with the transparent boundary condition can be used for the analysis of the HSW with large refractive-index difference.

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References

[1] Chung, Y. and Dagli, N., "An assessment of finite difference beam propagation method," *IEEE J. Quantum Electron.*, vol. 26, no. 8, pp. 1335–1339, 1990.

[2] Accornero, R., Artiglia, M., Coppa, G., Di Vita, P., Lapenta, G., Potenza, M. and Ravetto, P., "Finite difference methods for the analysis of integrated optical waveguides," *Electron. Lett.*, vol. 26, no. 23, pp. 1959-1960, 1990.

[3] Scarmozzino, R. and Osgood, Jr, R. M., "Comparison of finite-difference and Fourier-transform solutions of the parabolic wave equation with emphasis on integrated-optics applications," *J. Opt. Soc. Am. A*, vol. 8, no. 5, pp. 724–731, 1991.

[4] Yamauchi, J., Ikegaya, M., Ando, T. and Nakano, H., "Finite-difference beam-propagation method for circularly symmetric fields," *IEICE Trans. Electron.*, vol. E75-C, no. 9, pp. 1093–1095, 1992.

[5] Hadley, G. R., "Transparent boundary condition for beam propagation," *Opt. Lett.*, vol. 16, no. 9, pp. 624–626, 1991.

[6] Miyagi, M., "Bending losses in hollow and dielectric tube leaky waveguides," *Appl. Opt.*, vol. 20, no. 7, pp. 1221-1229, 1981.

[7] Yamauchi, J., Ando, T., Ikegaya, M., Saito, Y. and Nakano, H., "Analysis of hollow dielectric slab waveguides using the finite-difference beam-propagation method," 1992 *IEICE Nat. Conv. Rec.*, C-224.

[8] Abe, S. and Miyagi, M., "Attenuation in bent multimode slab hollow waveguides: Analysis using the improved finite difference beam propagation method," *IEICE Technical Report*, OQE92-153, 1993.

[9] Saijonmaa, J. and Yevick, D., "Beam-propagation analysis of loss in bent optical waveguides and fibers," *J. Opt. Soc. Am.*, vol. 73, no. 12, pp. 1785-1791, 1983.