Propagation Characteristics for Dielectric Waveguide Composed of Dielectric Circular Cylinder with Air-hole Cylinder Array

Ryosuke Ozaki, Tsuneki Yamasaki
College of Science and Technology, Nihon University, 1-8-14 Surugadai, Kanda, Chiyoda-ku, Tokyo, Japan

Abstract - In this paper, we analyzed the guiding problem for dielectric waveguides composed of dielectric circular cylinder array with air hole cylinder array by the case of shifting the adjacent dielectric of defect regions, and investigated the complex propagation constants at the first stop band region and energy distribution at the guiding mode by using the combination of improved Fourier series expansion method and multilayer method.

Index Terms — waveguide, propagation, guiding problem, dielectric circular cylinders

1. Introduction

Photonic crystals [1-2] with periodicity into arbitrary direction are very interesting fields in design or fabrication of optics and electronics devices. In general, the photonic crystals are well known as optical nanostructures with periodic of electric permittivity properties. Furthermore, to control the electromagnetic waves or light in the photonic crystal structures formed by circular cylinder array, it is possible to produce the frequency domain which electromagnetic mode cannot exist. Its region is known as photonic band gaps or stop band region [2]. Therefore, it is extremely important to examine its region such as photonic band gap region.

In recent papers [3-4], we have analyzed the guiding problem for dielectric waveguide with defect region in one period composed of dielectric circular cylinder and air-hole cylinders array, and examined the influence for both radius of cylinder and circular cylinder of the middle layer by propagation characteristics analysis for TE mode.

In this paper, we analyzed the guiding problem for dielectric waveguides composed of dielectric circular cylinder array with air hole cylinder array by the case of shifting the adjacent dielectric of defect regions, and investigated the complex propagation constants at the first stop band region and energy distribution at the guiding mode by using the combination of improved Fourier series expansion method and multilayer method.

2. Method of analysis

Let us consider the dielectric waveguide composed of dielectric circular cylinder and air-hole circular cylinder array as shown in Fig.1. The structure of Fig.1 has periodic length \( p \) along the \( z \)-direction, and is uniform in the \( y \)-direction. The regions \( S_1 \) and \( S_3 \) are defined by dielectric constants \( \varepsilon_0 \) and permeability \( \mu_0 \). In the region \( S_2 \), the width of each layer and all region are defined by \( d \), \( D(=ld) \), respectively. The middle layer region has only dielectric circular cylinder with cross section area \( b \times c \) and permittivity profile \( \varepsilon_0(\zeta) \). And also, dielectric constants are assumed to be \( \varepsilon_0 \) at background medium of the first layer and dielectric circular cylinder in the second layer. The time factor of the electromagnetic fields is \( \exp(-i\omega t) \) and will be omitted in the field expression. In the following formulation or analysis, we consider only TE dominant mode.

The electromagnetic fields of all regions to satisfy the Maxwell equations are expressed as follows: [3-4]

\[
E_x^{(i)} = e^{i\omega t} \sum_{n=-N}^{N} r_n e^{ikx_1 + 2\pi x_1/p} A_n \epsilon_{1}(n+1/2, 1.0) f_n(z),
\]

\[
E_y^{(i)} = \sum_{n=-N}^{N} \left[ A_n \epsilon_{1}(n+1/2, 1.0) + B_n \epsilon_{2}(n+1/2, 1.0) \right] f_n(z),
\]

where \( A_n \) and \( B_n \) are complex coefficients, \( \epsilon_{1}(n+1/2, 1.0) \) and \( \epsilon_{2}(n+1/2, 1.0) \) are the permittivity profiles at the middle layer, and \( f_n(z) \) is the energy distribution function.
\[ E_y^{(3)}(z) = e^{2\pi i z / \lambda} \sum_{n=-N}^{N} t_n e^{-2\pi i n \alpha \pi / \lambda}, \quad (3) \]
\[ f_s^{(l)}(z) = e^{2\pi i z / \lambda} \sum_{n=-N}^{N} u_n^{(l)} e^{-2\pi i n \alpha \pi / \lambda}, \quad (1 \leq l \leq M) \]
\[ H_{n}^{(l)} := \frac{1}{i \alpha} \frac{\partial E_{s}^{(l)}}{\partial z}, \quad H_{z}^{(l)} := \frac{1}{i \alpha} \frac{\partial E_{y}^{(l)}}{\partial x}, \quad (5) \]

where,
\[ k^{(m)} = \sqrt{k_0^2 - (\gamma + 2n\pi / \lambda)^2}, \quad d_0 := d / M, \quad k_0 = 2\pi / \lambda, \]
\[ k^{(x)} \text{ and } \gamma(= \beta + i\alpha) \text{ is propagation constants in the } x \text{ and } z\text{-directions, respectively.} \]

The results of type I, II, and III are shown as black solid line. The structure of dielectric waveguide as shown in Fig.2.

4. Conclusion

In this paper, we analyzed the guiding problem for dielectric waveguides composed of dielectric circular cylinder array with air hole cylinder array by the case of shifting the adjacent dielectric of defect regions, and investigated the complex propagation constants at the first stop band region and energy distribution at the guiding mode.

References