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A Study on the Fine Eigenmodes in the Core Region of Coaxial Waveguide Induced by the Dielectric Cladding

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ABSTRACT

The fine eigenmodes in the core region of the coaxial waveguide induced by the dielectric cladding are investigated by the finite element method. The relative permittivity of the core region is significantly higher than that of the cladding area. By appropriately adjusting the dielectric constant and geometry of the cladding, electromagnetic waves can be focused on the core region. When the eigenmode formed by the waveguide resonates with the electromagnetic wave, it can propagate long distances without seriously losing energy. In this study, eigenmodes localized in a fine core region are found using the numerical iteration method of the finite element method. As a result, TEM (Transverse Electro-Magnetic) eigenmodes are shown in a simple schematic representation. These results will enable the implementation of more advanced waveguides by utilizing the ideal characteristics of the cladding layer.

Keyword: dielectric cladding, eigenmode, resonance, finite element method, iteration method, TEM (Transverse Electro-Magnetic).

INTRODUCTION

Previously, we have studied on the eigenmodes established in the photonic crystals of various types usingFEM (Finite Element Method) [1][2]. In these studies, air holes or dielectrics were arranged symmetrically according to the geometry of the photonic crystal waveguide. The main purpose of this research was to concentrating light onto the core waveguide of the photonic crystal. At the same time, the leakage of light energy induced into the waveguide line was minimized. The eigenmodes depicted in the schematic representation illustrate the potential of these photonic crystal waveguides for microscopic optical circuits. The possibility of achieving this goal increases as the eigenmodes generated in the waveguide become finer. Although the usability is different from the photonic crystal, fine eigenmodes can also be obtained from the core of a waveguide wrapped in a dielectric cladding. Recently, we have studied the fine eigenmodes in a cylindrical coaxial waveguide core wrapped in a dielectric coating [3]. In this study, fine eigenmodes of TM and TE have been obtained by using through FEM calculation. By adjusting the geometrical structure and electrical permittivity of the cladding, it was identified that it would be possible to establish finer eigenmode generated in the core. There would be a need to implement this possibility more concretely and progressively. If the thickness of the cladding is not so thin compared to the core and the dielectric constant is significantly different from the that region, it may be expected that the finer eigenmodes could be obtained.

Therefore, this study extends previous work and attempts to obtain finer and more detailed eigenmodes incylindrical coaxial waveguides. What different from the previous study is that when performing FEM calculations, the input parameters substituting into the program are adjusted to obtain the desired eigenmode with reducing try and error. The cylindrical coaxial waveguide is not much different from previous forms. One difference is that as the program progresses, the relative thickness and dielectric permittivity relation between the core and the cladding change little by little to obtain the final result. The cross-sectional area of the waveguide is decomposed into a mesh structure consisting of triangular elements for FEM calculation. The calculation of FEM is based on the vector Helmholtz governing equations and is achieved by obtaining the solution of the eigen matrix equations composed of the edges and nodes of the triangular elements [4]. The eigen equations are proportional to the number of triangular elements of the mesh. To increase the resolution of the spectrum, the density of triangular elements must be increased. Then, the eigen equations become larger and a computer with high processing capacity is needed. However, because the capacity of personal computers is limited, it is difficult to handle the inverse matrix of the large size eigen equation. To overcome this contradiction, FEM uses the Arnoldi algorithm to compress the matrix equation into the smaller one as mentioned in the previous manuscript. Afterwards, the Krylov-Schur iteration method is used to find several prominent eigenmodes with the highest reliability [5]. This method is used in this study to find the desired several eigenmodes. Eigenmodes consist of electric fields and potential pairs. These constitute the column matrix of the similarity transformation matrix usedin the iterative method. The mathematical derivation process for FEM has been mentioned in a previous manuscript [1][2]. Therefore, this process is not mentioned again in this manuscript. In other words, the theory of FEM is omitted in this manuscript. The description format of this manuscript deviates from the existing order and is described as follows. This manuscript describes the structure of waveguide for FEM calculation, the result and discussion of the simulation, and conclusion in order.

THE STRUCTURE OF WAVEGUIDE

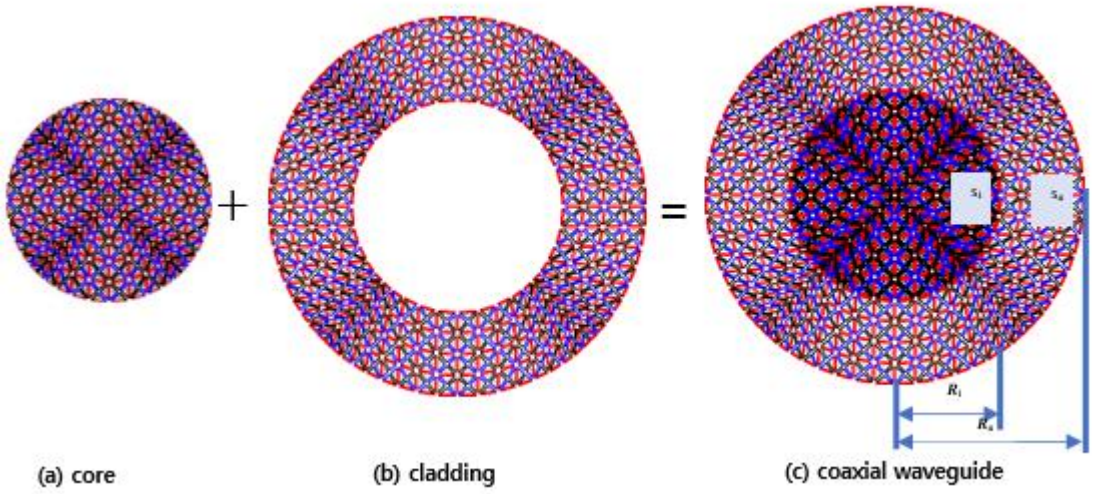


Figure 1: Schematic representation of cross section of awaveguide depicted as a mesh of triangular units Ref. [3].

As mentioned in the previous study, the eigenmode strongly depend on the thickness of the cladding layerand its dielectric permittivity. Accordingly, it was first obtained the eigenmodes by varying the thickness of the cladding layer in the coaxial waveguide. The relative dielectric constant between the core and cladding is fixed to be $\varepsilon_i : \varepsilon_O = 11 : 1$. This remarkable dielectric constant ratio is intended to relatively concentrating electromagnetic waves in the core area according to Snell's law. Figure 1 is a schematic representation of the coaxial waveguide used in this study. In this figure, the core and cladding areas of the dielectric coaxial waveguide are separated to facilitate understanding of the structure. By several try and error, it was identified that among waveguides, the structure of Figure 1 reveal most fine resolution of the eigenmode spectra. Similar to previous studies, the small and irregular potential distribution in the cladding region forms a complex spectrum even with a major peak in the core region. Nevertheless, compared to the spectra of other structures, the eigenmodes obtained from Figure 1 are the best resolution. Therefore, this study establishes a mesh of triangular element based on Figure 1 and applies FEM on it. The spectrum shown in the next section is the result of struggle to find the most ideal thickness of the cladding. In this study, the thickness of the cladding layer is set to be $d = R_O - R_i = 0.5 - 0.35(arb.units)$.

Generally, in FEM calculations, TM (Transverse Magnetic) and TE (Transverse Electric) modes are distinguished by boundary conditions set on the waveguide surface. As mentioned in the previous study, the eigenmodes are expressed only as an electric field, because in FEM calculations, the magnetic field is obtained through the same process as in the electric field. When obtaining the TE mode, the calculation is performed by canceling the components of the edges and nodes corresponding to the surface of the waveguide from the eigenequation. Then, the eigen equations are reduced by their number, allowing only the tangential component of the electric field and excluding the perpendicular component. However, in this study, the eigenmode is determined by the interface between the core and the cladding rather than the surface. These TM and TE characteristics are mixed in one eigenmode spectrum to represent the TEM (Transverse Electro-Magnetic) mode.

THE RESULTS AND DISCUSSION

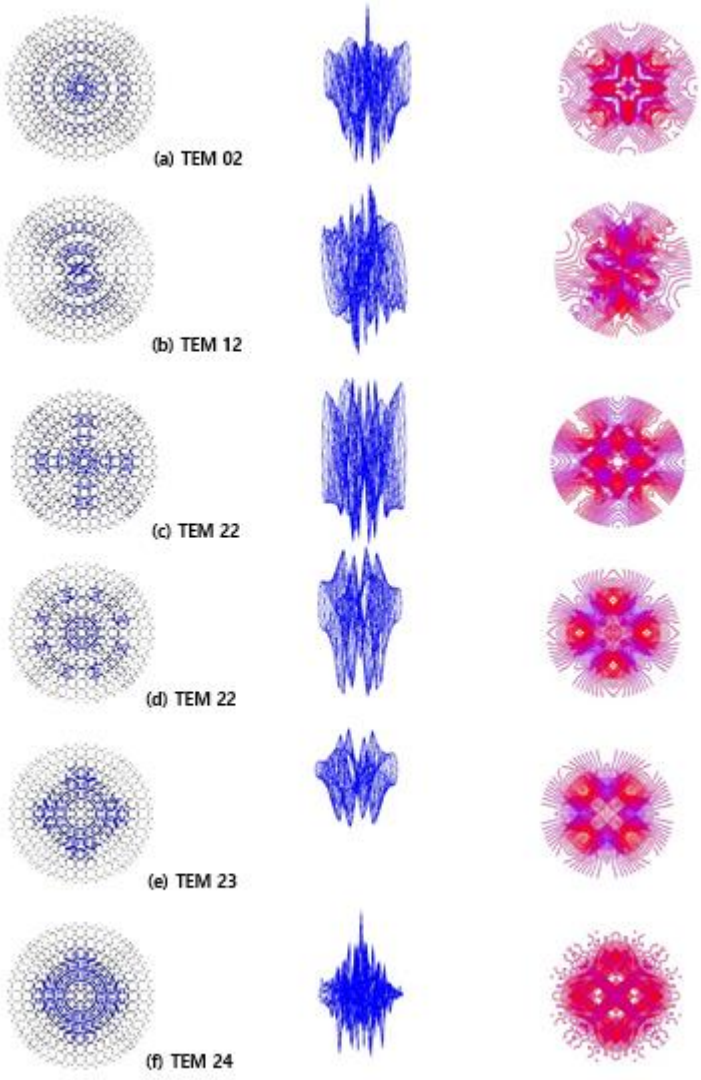


Figure 2: Schematic representation of TEM mode-1.

Figure 2 schematically represents some of the TEM modes obtained through FEM calculations. Small and complex potential peaks in the cladding area are present, but are not of a concern level. In this figure, the electric potential is represented as a three-dimensional solid representation and as an equipotential contour in a cross section of the waveguide. As can be seen from the expression of the potential, there are small and complex components in the spectrum, making it difficult to determine their eigenmodes. These components appear concentrated in the cladding and interface. It is guessed that these components are due to the heterogeneous material properties of the core and cladding. Equipotential contours are used as complementary to determine the eigenmodes for each spectrum along with the electric field. The spectrum for the electric potential as a whole describes the eigenmodes well along with the electric field. As expected, the spatial distribution of the electric field is concentrated in the core region. The dielectric cladding with a low dielectric constant suppressed the expansion of the

eigenmode beyond the interface. These spectra have such a clear resolution of the electric field that the eigenmodes can be distinguished even in a small area. These eigenmodes form concentric circles from the center and extend to the interface between the core and the cladding. They show that the eigenmodes of tangential components are more developed than that of in the radial direction. Reflecting these characteristics of each spectrum, the eigenmodes are determined as shown in Figure 2. In particular, in the case of low-order spectra (a) and (b), an eigenmode is formed concentrated at the center of the core. In the application field, attention will be focused on these eigenmodes so that they can be applied to fields with high utility.

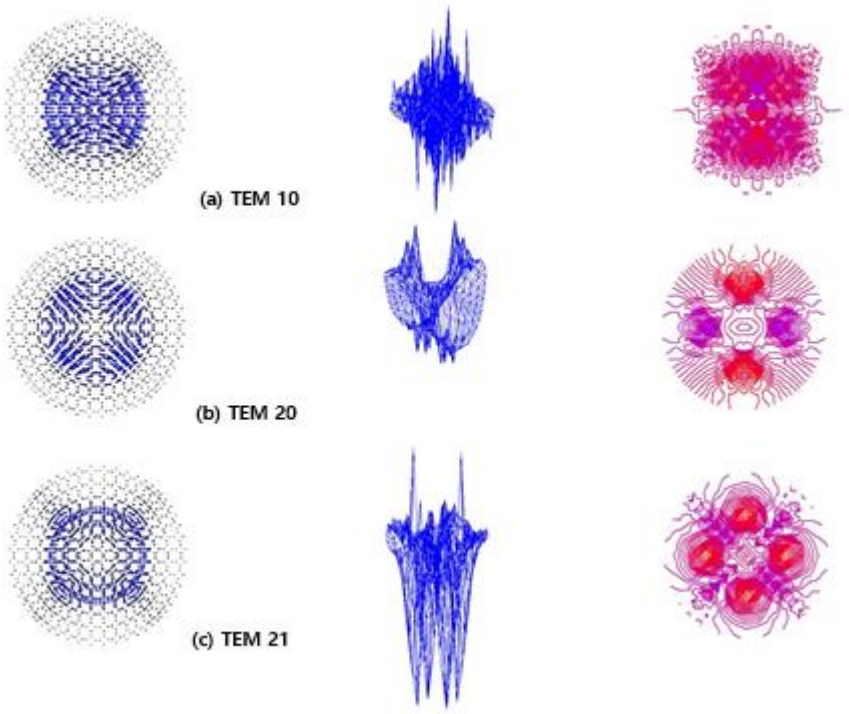


Figure 3: Schematic representation of TEM mode-2.

Figure 3 schematically represents another TEM modes obtained through FEM calculations. These spectra are TEM eigenmodes similar to TM modes. They form in small areas of the core and exhibit a clear spatial distribution of electric fields. Here too, small and complex potential peaks between the cladding and the interface are included, and these cannot be excluded from all spectra. All potentials nevertheless contribute, together with the overall electric field, to impose eigenmodes on their respective spectra. These spectra are a fine reproduction of those seen in reference [6] from a small region of the core. Compared to them in reference [6], the eigenmodes for the spectrum shown in Figure 3 can be easily imposed. The eigenmodes corresponding to each spectrum are inserted in Figure 3.

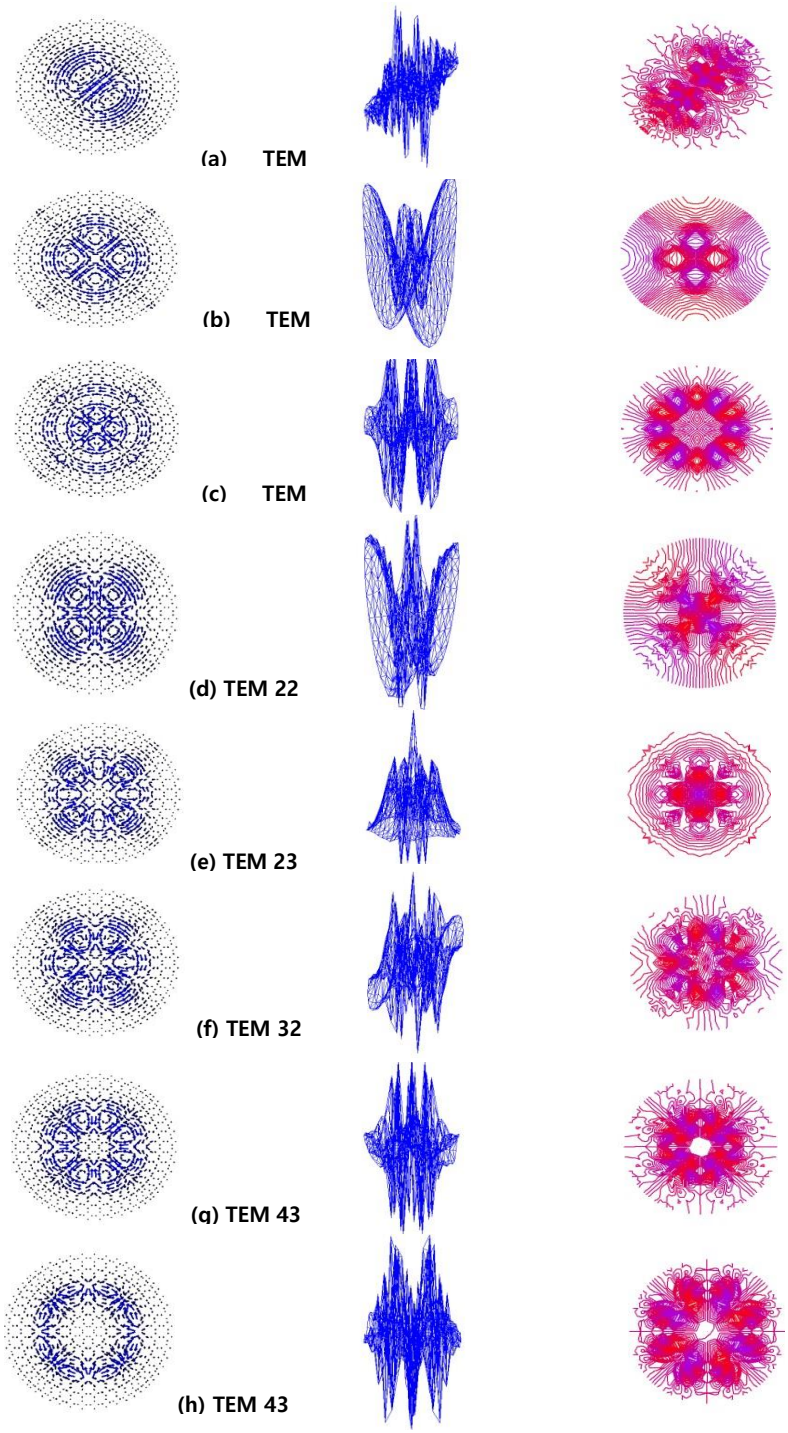


Figure 4: Schematic representation TEM mode-3.

Another type of spectrum appearing in the core region is shown in Figure 4. The characteristics that appear at the center of the core extend to the interface and determine the eigenmode properties of the spectrum. The higher the order of the spectrum, the more complex the spectrum becomes. But in this study, even if the spectrum exists in a small area of the core, the resolution is not so bed. No matter how complex the eigenmode is formed inside the core, it is

difficult to extend beyond the interface, and its component exists only weakly in the cladding area. Electromagnetic waves limited by the interface are concentrated in the core and form an eigenmode that reflects the characteristics of the structure. The spectra shown in Figure4 reveal TEM eigenmodes similar to the TE mode. In the spectra, it is identified that the eigenmodes develop sequentially as the order increases. Figure 4(a) shows a spectrum similar to that in Figure 2(b). However, when comparing the spectra in Figure 2(b) and Figure 4(1) in detail, it is reasonable to impose each eigenmode as TEM 12 and TEM 11, respectively. If this eigenmode resonates with electromagnetic waves injected from the outside, its energy can be propagated over long distances. It can be asserted that the eigenmodes organized in each figure exhibit similar functions. The above results can be said to meet the main purpose of focusing the eigenmodes only on the core and forming the finer characteristics in detail by wrapping the core with the dielectric cladding.

CONCLUSION

The main purpose of this study was to identify finer and detailed eigenmodes formed in the core of a coaxial waveguide. As a result of FEM calculations, TEM modes concentrated in the core region were obtained, and eigenmodes were assigned to them and shown in the schematic representation. From these results, it wasfound that the eigenmodes generated in the core of the coaxial waveguide are greatly dependent on the dielectric cladding. Furthermore, it was discovered that the desired eigenmode can be obtained by controlling the dielectric cladding and that this may be practically utilized in application fields.

Reference

[1] Yeong Min Kim, A STUDY ON THE EIGENMODES OF PCF VARYING THE POSITION OF THE DIELECTRIC HOLE SBYFEM, Global Journal of Engineering Science and Researches, July 2016, 3(7).

[2] Yeong Min Kim, A Study on the Contribution of a Buffer Coated with a Perfect Conductor to Constructing Eigenmodes in Square HAPCF, Journal of Electrical and Electronic Engineering, March 2019, 7(1), pp 36-41.

[3] Yeong Min Kim, A Study on the Eigen Properties of the Coaxial Waveguide of Cylindrical Form, Transactions on Engineering and Computing Sciences, Oct., 25, 2023, 11(5).

[4] C. J. Reddy, Manohar D. Deshpande, C. R. Cockrell, and Fred B. Beck, NASA Technical Paper, 1994, 3485.

[5] V. Hernandez, J. E. Roman, A. Tomas, V. Vidal, Krylov-Schur Methods in SLEPc, June, 2007, Available at Available at http://www.grycap.upv.es/slepc.

[6] Yeong Min Kim, Jong Soo Lim, A Study on the Eigen-properties on Varied Structural 2-Dim. Waveguidesby Krylov-Schur Iteration Method, Journal of the IEIE, February 2014, 51(2).