Polarization-Insensitive Linear Waveguiding with Annular Photonic Crystals

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***Abstract*-Simultaneous propagation of transverse-electric and transverse-magnetic modes through a linear waveguide defined in an annular photonic crystal in two dimensions is demonstrated. Overlapping of the two linearly-independent guided modes is achieved by the utilization of Simplex algorithm for the optimal design parameters.**

I. INTRODUCTION

Guiding an unpolarized wave in a photonic device is essential in many respects, ranging from communications to photonics computing. One appropriate host for linear waveguides is a photonic crystal, which is more commonly found and more easily fabricated in two-dimensional geometries. Two-dimensional linear photonic crystals are shown to guide light waves with negligible loss even at sharp corners [1]. However, the most important problem with two-dimensional photonic crystal waveguides is that a particular guide can host either the transverse-electric (TE) or transverse-magnetic (TM) mode, depending on the design geometry.

One solution for polarization-independent waveguiding is designing two-dimensional linear guides in three-dimensional photonic crystal structures, where each linearly-independent mode is guided effectively in adjacent half layers [2]. On the other hand, a truly two-dimensional polarization-independent wave guide making use of self collimation is demonstrated [3]. However, this requires a certain incidence angle (45^0) and a definite frequency.

Annular photonic crystals are two-dimensional structures that offer the largest overlapping of TE and TM band gaps, thus possessing a so-called full band gap in two dimensions [4]. Therefore, an annular photonic crystal can be utilized to host a linear wave guide which is able to guide TE and TM modes simultaneously in two dimensions, leading to polarization-independent waveguiding. The focus of this study is the design of such a linear waveguide.

II. WAVEGUIDE GEOMETRY AND COMPUTATIONAL METHODS

The annular photonic crystal hosting the guide is composed of annular dielectric rods in air to form a square lattice. Relative dielectric constant, ε_1, of the material is taken as 13, which is close to that of GaAs in the infrared. Inner (r_{in}) and outer (r_{out}) radii of the rods are adjusted to achieve the maximum overlapping of the TE and TM band gaps, Fig. 1. The band structures are then computed by the Plane Wave Expansion Method (PWE) [5]. The optimal values are $r_{in}=0.251a$ and $r_{out}=0.396a$, where a is the lattice constant, Fig. 1. The gap ratio of the "full band gap" for these values is around 8%.

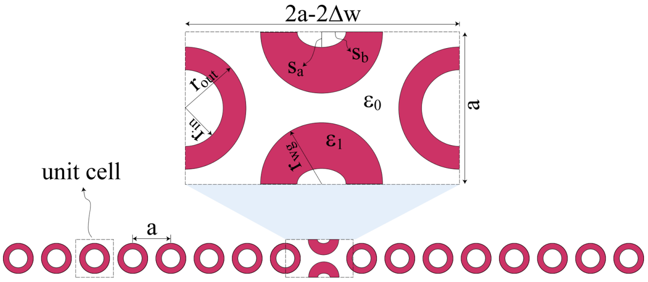

Fig. 1-The supercell and design parameters employed in the search of overlapping guided TE and TM modes.

The guide consists of dielectric rods with different outer radii (r_{wg}) than the photonic crystal. The core of each waveguide element is hollow in the form of an ellipse, whose semi major axes are s_a and s_b, respectively. The waveguide width is modified by $2\Delta w$, where its original value was $2a$, Fig. 1. Physical values for the parameters are adjusted such that center of the full band gap is at 1.3 μm. The supercell presented in Fig. 1 is employed in the normalized band structure calculations of the guided modes [1]. Supercell size is chosen so that modes in adjacent supercells do not interact. Mode profiles for the TE and TM guided modes are also computed.

The four parameters r_{wg}, s_a, s_b and Δw are varied by means of Simplex to minimize the sum of squares for the differences in the normalized angular frequencies of the TE and TM modes.

III. RESULTS

Fig. 2a presents the normalized band structure for the guided even modes in the case of hollow waveguide, i.e. the guide obtained by just removing one row of the crystal. Here, k_x is the wave number along the guide direction and $\omega a/2\pi c$ is the normalized angular frequency. The TE and TM bulk bands and the full band gap are shaded in different colors. It is seen that the guided modes cross at only one normalized wave number and do not traverse the whole range. On the contrary, the optimal values for the four above-mentioned parameters yield full coverage of the k-range and optimal overlapping of the TE and TM guided modes with a sum of squares value around 2×10^{-5}. The parameter set yielding optimal overlapping is found out to be $\{r_{wg}, s_a, s_b, \Delta w\} = \{0.392a, 0.0899a, 0.156a, 0.0558a\}$ where the maximum discrepancy between the modes is around 3nm,

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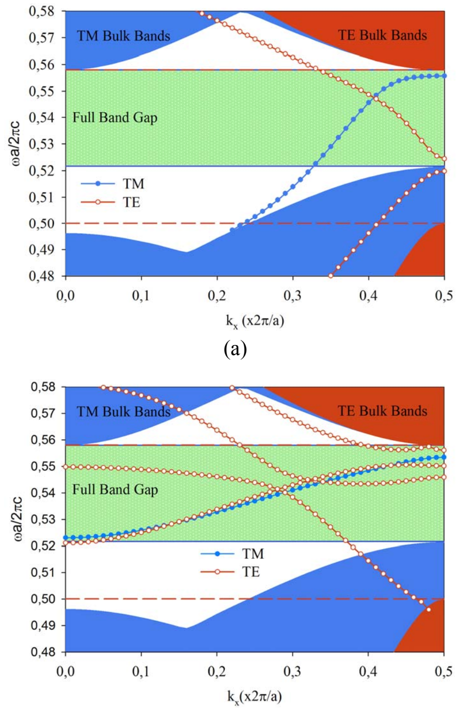

(a)

(b)

Fig. 2-Normalized band structure along the propagation direction in the linear waveguide for (a) hollow geometry and (b) optimized parameters.

which is of the order of the band width of an infrared laser. The TE and TM modes are both even and the confinement of the modes is succeeded within the guide layer and the immediate rows surrounding it, Fig. 3.

Finite-Difference Time-Domain (FDTD) simulations of the guiding of TE and TM modes for the optimal parameters are in progress. Preliminary results show that both modes are guided with small loss at the target wavelength of 1.3μm.

Implementation of the search algorithm to accomplish the overlapping of the two linearly-independent modes on other lattices and the inverse geometry, in which annular air holes are drilled into a dielectric, is also under way.

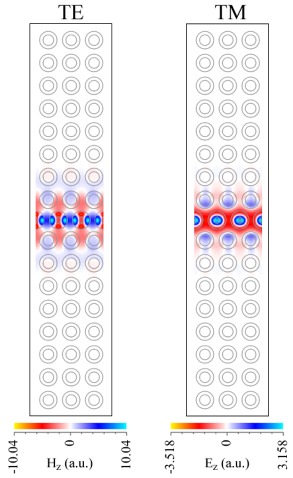

Fig. 3-Profiles of the guided TE and TM modes for optimized parameters.

IV. CONCLUSION

With the choice of suitable design parameters, a truly two-dimensional linear waveguide in an annular photonic crystal is demonstrated to guide TE and TM modes simultaneously with a small loss. The modal profiles reveal that both polarizations are confined in the guide layer within the order of the free space wavelength of the incoming light.

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