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# NEAR FIELD COMPUTATION IN 1D PHOTONIC CRYSTAL WAVEGUIDES FOR TE POLARIZATION

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Instead of conventional waveguides, photonic crystal waveguides are preferred due to better confinement of light within air core medium and zero radiation losses at the sharp bends. In this paper, we have designed one-dimensional (1D) photonic crystal waveguides for different parametrical values. It is observed that as the number of cladding stacks increased the oscillation of light waves is suppressed which is helpful to provide a better confinement of light in air guiding medium. It is also noted that in omnidirectional based waveguide, the guided mode can lie and well confined in the active region with zero propagation losses irrespective to the incident angle.

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*Keywords:* Optical Waveguides, Photonic Crystals, Omnidirectional Reflector, Polarization

## 1. Introduction

Earlier optical waveguides were the natural replacement over the metallic waveguides due its losses occurred at optical frequencies. In dielectric waveguides, the reflection is restricted to small incidence angles with respect to the waveguide surface and light is guided by total internal reflection at the boundary of the waveguide. But in optical waveguides, the radiation losses occurred at the bending cannot be ignored. In order to suppress these losses, the radius of curvature of waveguides needed to be large with respect to the wavelength. To achieve better confinement of light in a waveguide, it is desirable to move away from the common total internal reflection occurs in the conventional waveguides. In such circumstances, the discovery of photonic crystals [1-2] has put a new alteration on light guiding. Recently, the study of group velocity in photonic crystals has opened a door to realize new photonic devices [3]. One major advantage of photonic crystals is the possibility of designing electromagnetic modes. The ability to modify the dispersion diagram of a guided mode in a photonic crystal waveguide is very useful for practical applications. In photonic crystal waveguides, the transverse guiding is accomplished by distribution reflection within the cladding layers [4-5]. document In addition, the active layer can be made of lower refractive index than cladding layers due to which the transverse light propagation lies in the forbidden band of one-dimensional (1D) photonic crystals (clads). Presently, for the realization of optical integrated circuits the planer photonic crystal waveguides have became an essential building block due to its high transmission efficiency of light at sharp corners. Recently, much attention has been paid towards the study of omnidirectional reflectors [6-9]. If omnidirectional reflectors are used as a clad, better confinement of light can be expected. In addition there is no limitation of incidence angle of light as well. This mechanism is helpful for redirecting the scattered light in any direction completely within the guiding layer.

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In this paper, we have first designed the 1D photonic crystal waveguides for different parametrical values. To observe better field distribution in active region, we have designed omnidirectional reflector which is used as cladding layer for the waveguides. In section two, the mathematical approach has been presented; the results and discussion are summarized in section third. Finally, section fourth concludes the paper.

## 2. Design approach

To study the guiding mechanism of 1D photonic crystal waveguide we have assumed that the air guiding layer is sandwiched between two 1D photonic crystals. One-dimensional photonic crystals are composed of high and low refractive index layers respectively. The considered structure of one-dimensional photonic crystal waveguide is shown in **figure 1**.

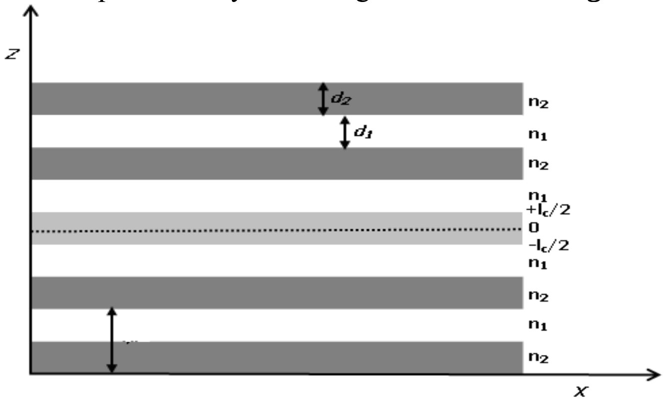



*Fig. 1. Schematic of 1D photonic crystal waveguide*

The cladding consists of two alternate layers of refractive index $n_1$ and $n_2$ and thickness $d_1$ and $d_2$. The refractive index and thickness of core region are $n_c$ and $l_c$ respectively. By employing transfer matrix method, the dispersion relation between the angular frequency 'ω' and the tangential component 'β' as well as Bloch wavevector 'K' is expressed as [3]

$$K(\beta,\omega)=\left(\frac{1}{\Lambda}\right)\cos^{-1}\left[\frac{1}{2}(A+D)\right] \tag{1}$$

where in case of transverse electric polarization, *A* and *D* is defined as

$$A=e^{-ik_1a}\left[\cos(k_2d_2)-\frac{1}{2}i\left(\frac{k_2}{k_1}+\frac{k_1}{k_2}\right)\sin(k_2d_2)\right] \tag{2}$$

$$D=e^{ik_1a}\left[\cos(k_2d_2)+\frac{1}{2}i\left(\frac{k_2}{k_1}+\frac{k_1}{k_2}\right)\sin(k_2d_2)\right] \tag{3}$$

The solutions of Bloch wave vector 'K' gives forbidden and pass bands. After the solution of '*K*' we have obtained the omnidirectional reflection bands by substituting it in equation (4). The expression for reflectivity is expressed as

$$|r_N|^2=\frac{|C|^2}{|C|^2+\left(\dfrac{\sinh \operatorname{Im}(K)\Lambda}{\sinh N\operatorname{Im}(K)\Lambda}\right)^2} \tag{4}$$

It is important to note that the second term in the denominator exponentially tends to zero for large '$N$' (number of bilayers or stacks).

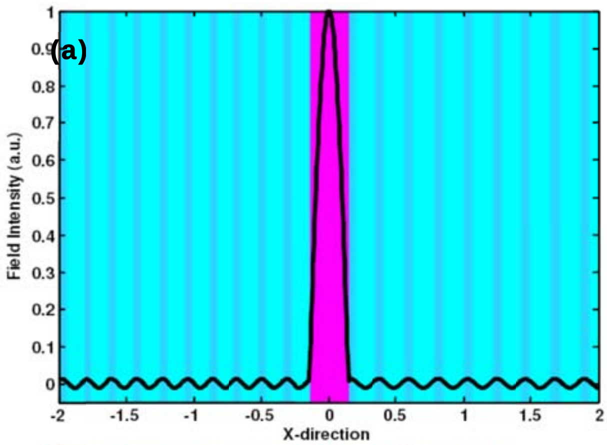
By ignoring the intermediate mathematical steps, the equation of electric field distribution in 1D photonic crystal waveguide for TE polarization is expressed as

$$E_{TE}(x)=\begin{cases} C_1^{TE}\cos(k_c x), x \le \frac{l_c}{2} \\ C_2^{TE}\left(-\frac{k_2}{k_1}\right)^n \sin\left[k_1\left(x-\frac{l_c}{2}-n\Lambda\right)\right], n\Lambda \le \left(x-\frac{l_c}{2}\right) \le (n\Lambda+a) \\ C_2^{TE}\left(-\frac{k_2}{k_1}\right)^n \cos\left[k_1\left(x-\frac{l_c}{2}-n\Lambda-a\right)\right], n\Lambda+a \le \left(x-\frac{l_c}{2}\right) \le (n+1)\Lambda \end{cases} \tag{5}$$

Here, $lc$ and $\Lambda$ are the thickness of active layer and lattice constant. However, other coefficients defined in equation (5) can be found in ref. [10].

## 3. Results and discussion

We have designed 1D photonic crystal symmetric waveguide for TE polarization case. To understand the field distribution within the air core region we have varied various designing parameters such as core thickness, refractive index, number of bilayers of clad and wavelength. Fig. 2(a) and Fig. 2(b) shows the near field distribution in air core photonic crystal waveguides. As shown in figure 2(a), the field distribution is well confined within the core medium however; either the sides of core region the oscillation of light can be observed. Figure 2(b) shows the same electric field profile but for increased number of bilayers. The reduced wave oscillation either the sides of core region can be observed as the number of bilayers increased from 10 to 15. The parametrical values used for figure 2(a) and figure 2(b) are $n_1$=2.3, $n_2$=2.0, $n_c$=1, a=b=2μm, $l_c$=0.291μm, N=10 and $n_1$=2.3, $n_2$=2.0, $n_c$=1, a=b=2μm, $l_c$=0.291μm, N=15 respectively.



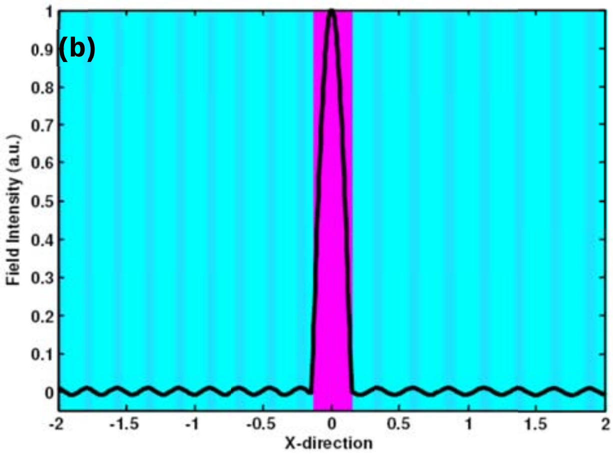



*Fig 2. Electric field Intensity versus propagation direction figure (a) $n_1$=2.3, $n_2$=2.0, $n_c$=1, a=b=2μm, $l_c$=0.291μm, N=10 and figure (b) $n_1$=2.3, $n_2$=2.0, $n_c$=1, a=b=2μm, $l_c$=0.291μm, N=15.*

If the oscillation of light either the side of active region is reduced then maximum incident light will be confine within core region. Therefore we have plotted **figure 3(a)** and **figure 3(b)** at changed parametrical values. To plot **figure 3(a)** and **figure 3(b),** the used parametrical values are $n_1$=2.3, $n_2$=1.5, $n_c$=1, a=b=2μm, $l_c$=0.291μm, N=6 and $n_1$=2.5, $n_2$=1.4, $n_c$=1, a=b=2 μm, $l_c$=0.35μm, N=5 respectively. An efficient reduction is oscillation of light waves can be clearly observed in **figure 3(a)**. However, it is almost suppressed in **figure 3(b)**. Hence, for better confinement of light in core region the optimal values of structural and optical parameters are required.

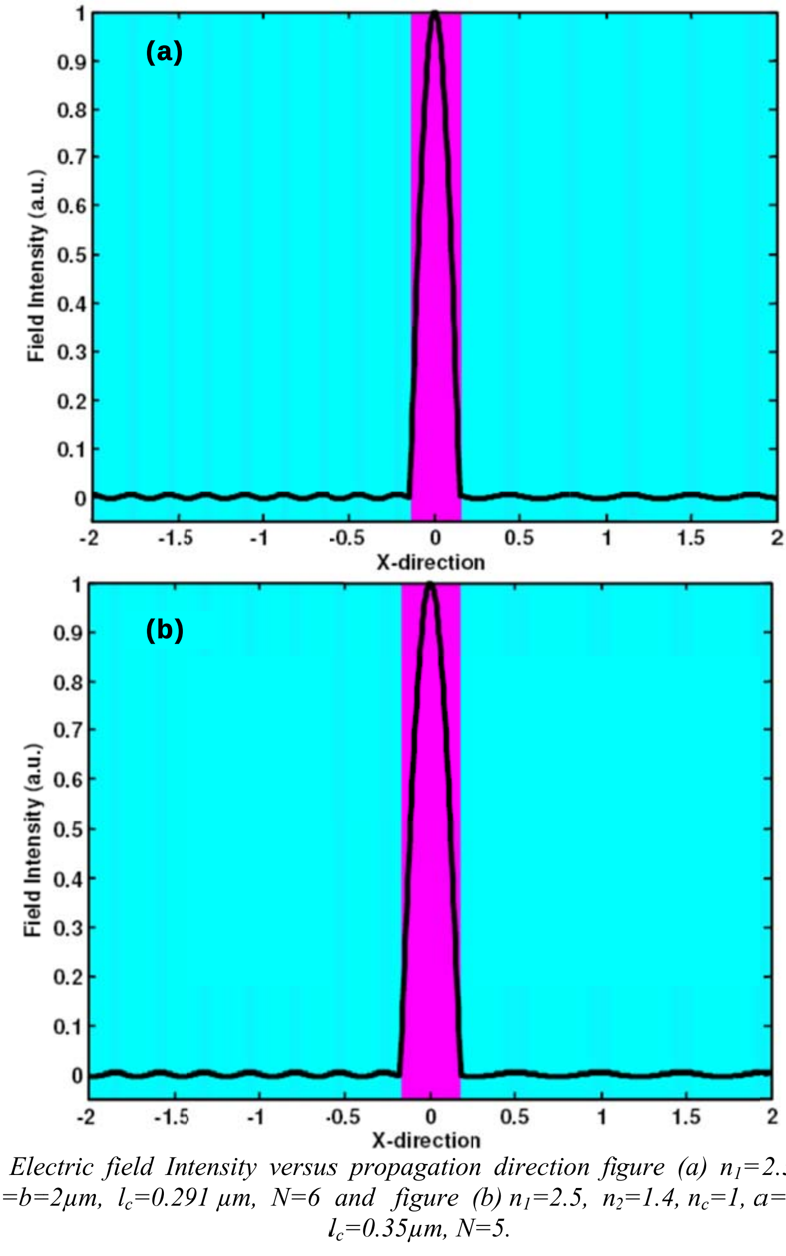



*Fig. 3. Electric field Intensity versus propagation direction figure (a) $n_1$=2.3, $n_2$=1.5, $n_c$=1, a=b=2μm, $l_c$=0.291 μm, N=6 and figure (b) $n_1$=2.5, $n_2$=1.4, $n_c$=1, a=b=2 μm, $l_c$=0.35μm, N=5.*

The use of omnidirectional reflectors as a clad is beneficial in order to get better confinement and zero losses at the corners/bends. This mechanism is helpful for redirecting the scattered light in any direction completely within the guiding layer. Hence, we have obtained the omnidirectional reflection bands of one-dimensional photonic crystal for transverse electric (TE) wave which is depicted in **figure 4**. The omnidirectional photonic bandgap for both TE and TM polarizations are defined by the lower bandedge at the normal incidence ($\theta=0^0$) and the upper bandedge at the perpendicular incidence ($\theta=90^0$). The normalized frequency ranges of omnidirectional reflection bands for TE wave are 0.31-0.39 and 0.72-0.73 (in the units of $\omega d/c$). In **figure 4**, the white region, dark gray region and light gray strips are corresponding to the pass, forbidden and omni bands respectively. Once the range of omnidirectional reflection bands are known efficient guiding of light can be done in the waveguide.

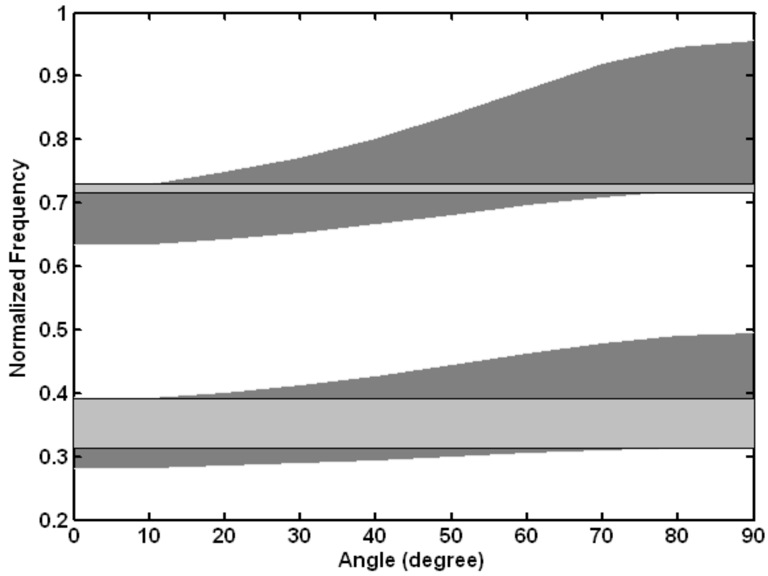



*Fig. 4. Projected band diagram of 1D photonic crystal showing omnidirectional bands for TE polarization.*

If we used our designed omnidirectional reflectors for a waveguide then guided mode can lie and well confined in the active region with zero propagation losses. Therefore, we have plotted **figure 5** in which the near field intensity of fundamental mode is depicted. Here, the omnidirectional reflectors designed for 25 bilayers of alternate layers of $n_1=1.3$ and $n_2=2.4$ is used as clad at $1.55\mu m$ wavelength.

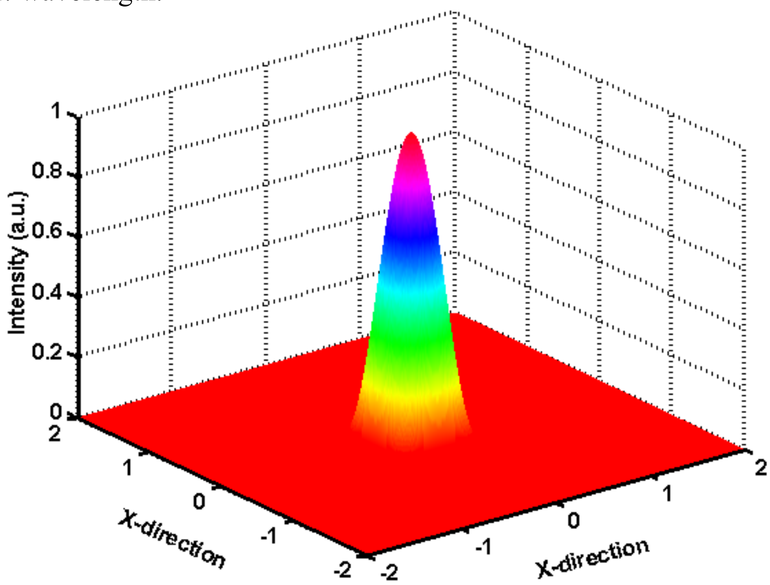



*Fig. 5. Electric field Intensity in 1D photonic crystal waveguide for TE polarization.*

It is observed that the electric field is well guided in the guiding region where the refractive index of guiding layer is lower than the refractive indices of the cladding layers. It is also observable that the field strength decays rapidly on both side of the air guiding layer. The assumed thicknesses of upper and lower cladding layers are $a = b = 2\mu\text{m}$ however, the thickness of air guiding medium is $l_c = 0.5\mu\text{m}$ . In simple words, the wider omni band means wider frequency (wavelength of light) selection is permissible to forbid hundred percent of light after striking upon the omnidirectional reflectors. If we used these reflectors as a cladding 100 % light will be strongly reflected after made incident and enforced to forward in the guiding medium to give better confinement.

## 4. Conclusions

By employing transfer matrix method the designing of 1D photonic crystal waveguides have been carried out. Initially, we have designed and analyzed the near field in the active air region for different parametrical values. It is observed that the confinement of near field is better at optimized parametrical values. In addition, the oscillation of light waves either the sides of core region is suppressed for optimal values of structural and optical parameters. The suppression of oscillation of waves is useful to confine maximum part of incident light. Further, we have obtained the omni bands for TE polarization which provides 100% the reflection of light irrespective to the angle of incidence. In omnidirectional reflector based waveguide it is found that field is well confined within the air guiding medium where the refractive index of guiding layer is lower than the refractive indices of the cladding layers.

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