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Omni Directional Reflection Characteristics of Photonic Crystal for Optical Communication

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***Abstract*— In photonic crystal it is possible to change the refection characteristics by various methods. In this paper initially one material is kept constant and the second material is varied to observe the reflection coefficient. Then the number of layers is varied to observe the reflection coefficient. The reflection coefficient is expected to be unity. Effect of change in the dimension on the property is observed. The reflection coefficient, stop band and center frequencies are calculated. Introduction to defect in the perfect periodicity results in change of behavior in the transmission of different wavelength. Response of the crystal for a single defect and double defect is observed and graph is analyzed. Under certain condition, one dimensional dielectric lattice displays total reflection of the incident light. The parameters are carefully chosen for better reflections which will find application in optical communication as switch, mirrors, sensors etc.**

Keywords— Photonic crystal, stop band; reflection coefficient; transmission coefficient.

INTRODUCTION

Photonic crystals are constructed by using alternating layers of high and low value of dielectric materials. Two materials with refractive index n1 with thickness a, n2 with thickness b ; d=a+b called lattice constant are used to form a photonic crystal.

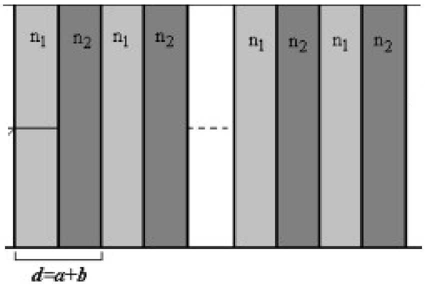

Fig 1: Photonic crystal structure with two different materials

When different frequencies enter photonic crystal depending on the dimension and dielectric constant it allows certain frequencies and blocks other frequencies. Allowed wavelengths that propagate through the crystal form a band called photonic band or pass band.Group of wavelengths that are blocked from propagating through the crystal form a photonic band gap (PBG) or stop band.

Light propagating in a high dielectric material is reflected at the interface of low dielectric material A periodic potential exists due to dielectric media. Multiple reflection and refraction occurs at each interface. For one dimensional photonic crystal, the variation is only in one direction. Each of the plane reflects only a very small fraction of incident plane wave. The total scattered wave consists of a linear superposition of all these partially reflected waves. The diffracted beams are found when all these reflected waves add up constructively. [8]Let Δ be lattice constant which is the period of index variation in space. The path difference for rays reflected from two adjacent planes is 2ΔsinΘ where Θ is the angle of incidence measured from the planes. Constructive interference occurs when the path difference is an integral number of wavelength λ/n in the medium, so that

$$2\Delta \sin\Theta = m(\lambda/n) \quad , \quad m=1,2,3\ldots..$$

Where n is the averaged index of refraction of the periodic medium and m is an integer. Beam diffraction occurs for certain values of Θ which obeys the Braggs law so that reflections from all planes add up in phase.

$$2k \sin\Theta = m(2\pi/\Delta) \quad ,$$

where k is the wave number of the light beam in the medium $k=2\pi n/\lambda$.The term $2\pi/\Delta$ is known as the grating wave number. The photonic band gap occurs at $\mathrm{Re}[k\Delta]=m\pi$. If W_0 is the centre of photonic band gap such that $k1a=k2b=\pi/2$

When the frequency of incident wave falls in the photonic band gap, the Bloch wave generated in the periodic medium is known as an evanescent wave which cannot propagate in the medium. The electric field amplitude decays exponentially. Thus the energy of the incident beam will be totally reflected and the medium acts as a high reflectance mirror for the incident wave. The reflection coefficient can be made 1 by proper designing of the photonic crystal. [10]

II LITERATURE SURVEY

The Omni directional reflection characteristics of one dimensional photonic crystal with the first material as Silicon Dioxide with refractive index 1.5 and the second material as Germanium with refractive index 4. The thickness is taken as 600nm and 400 nm respectively with the number of layers as 10.It is clear that the common range of unit reflectance is from 2247nm to 2438nm. So that total Omni directional Reflection Range has the band width of 191nm.[1].

A defect in the otherwise periodic photonic crystal can be introduced to alter the properties of it. The two materials chosen are Si and air representing $n_A=3.45$ and $n_B=1$ and $d_A=0.2a$, $d_B=0.8a$ respectively, where the parameter a is the lattice constant. The defect material is taken as Silicon and it's refractive index is varied between 2 to 4 at the given wavelength of 1550nm and the thickness is taken as 0.4a. The change in refractive index can be obtained through changes in pressure, temperature or concentration of impurities in Si.The stop band and pass band can be controlled by changing the dielectric constant and the dimensions of the defect layer.

When the refractive index is increased the stop band shifts to the lower value. This is used for making filters.
The photonic crystal can be made from graphite with low dielectric constant and tellurium with high dielectric constant. The value of refractive index of Graphite is taken as 2.87 and the refractive index of Tellenium is taken as 4.6 respectively. The thickness of each layer is calculated by quarter wave stack condition $d=\lambda_0/4n$, where $\lambda_0=800$ nm which is the central wavelength and n is the refractive index of layer. So the thickness of Graphite film is taken as 69.68 nm and that of Te is taken as 43.47 nm. The number of layers for computation is taken as N=20. Hence the totally reflected wavelength band which is common to the both polarizations and for the entire incident angles lie from 885 nm to 697 nm which gives a significant omnidirectional reflection band of 188 nm. This narrow omnidirectional reflection band in near infrared region of electromagnetic spectrum makes it suitable for making near IR cutoff filters which can be used in digital cameras and other imaging sensors.

The effect of number of layers is studied and it is found that as number of layers increases the band becomes wider for the same refractive index contrast and the reflection coefficient approaches unity. [3]
In this a photonic crystal with Si as high refractive index material and SiO2 as low refractive index material is considered. The refractive index of both the materials has been taken as wavelength and temperature dependent. So the allowed bands can be tuned by varying the temperature without changing geometry and angle of incidence. The refractive index of SiO2 layers are increase more per degree of temperature in comparison of Si layers. So refractive index contrast is decreased with temperature. The property of the proposed structure can be employed to tune the ODR bands. The refractive index of these two materials is temperature and wavelength dependent. Therefore the variation in the refractive index can be used to tune the allowed bands. The thickness of both layers is taken to be equal. This type of filter can be used in many optical devices such as temperature sensor, wavelength de-multiplexer etc. and in other optical systems. By choosing appropriate values of temperature, we can design a frequency selector or rejecter. Also, by cascading two, three or more filters we can design a perfect mirror or monochromatic.[4]
In the construction of photonic crystal three materials can be used with silicon Dioxide with dielectric constant 1.5,Tellurium with dielectric constant 4.6 and Germanium with dielectric constant 4.2 For the stack of AB layers, lattice period d is taken to be 400 nm and the thickness of A and B layers (a and b) are taken as $0.8d$ and $0.2d$ respectively. But for the stack of and C layers (a_1 and b_1) are taken as $0.7d_1$ and $0.3d_1$ respectively. By choosing appropriate values of the controlling parameters (refractive indices and lattice period) of the AC layers, it is possible to obtain the desired ranges of ODR region.[6]

III. . METHODOLOGY

The structure is made up of alternate layers of materials with high and low dielectric constants. The input signal contains all the frequencies. Depending on the thickness of the layers, dielectric constants, number of layers, the output signal will contain only the permitted frequencies. The remaining signal reflects back towards input.

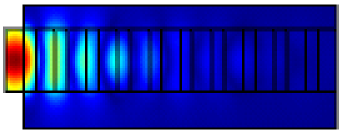

Fig 2: Reflected signal

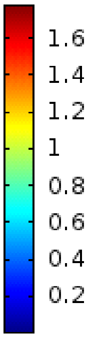

Fig 3: Amplitude Scale

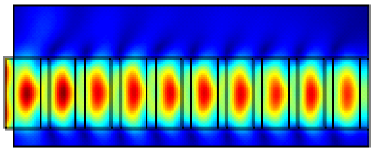

Fig 4: Transmitted signal

In stop band, the wave gets reflected. Fig 3 indicates the amplitude level. Red color indicates high amplitude and blue color indicates low amplitude. When the signal is outside the band gap, it gets transmitted as shown in fig 4.
Alternate layers of different dielectric materials are taken. The first material is kept constant as Silicon Dioxide (SiO_2) with refractive index 1.45 and the second material is changed. The different materials taken are Al_2O_3 with refractive index 1.76, ZnO with refractive index 1.92, SiC with refractive index 2.55, TiO2 with refractive index 2.65.The combined result of reflection coefficient is as shown in the figure.

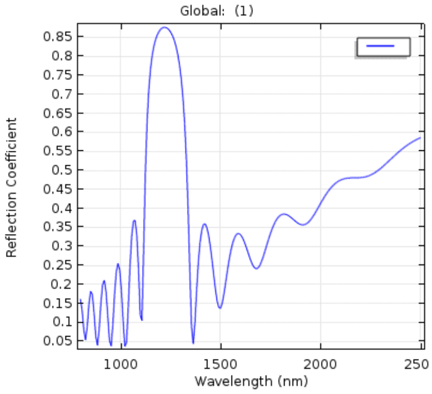

Fig 5: Reflection Coefficient for $SiO_2$and Al_2O_3

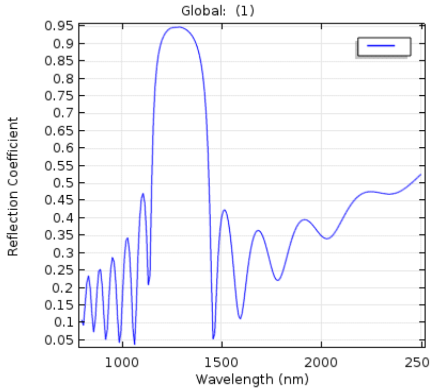

Fig 6: Reflection Coefficient for $SiO_2$and ZnO

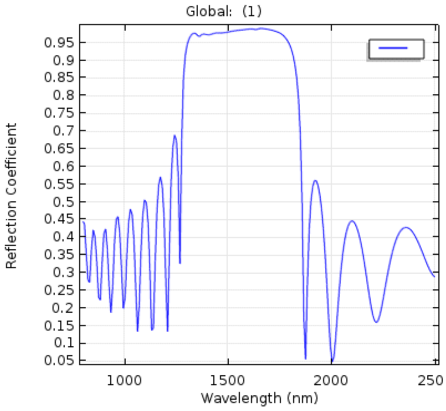

Fig 7: Reflection Coefficient for $SiO_2$and SiC

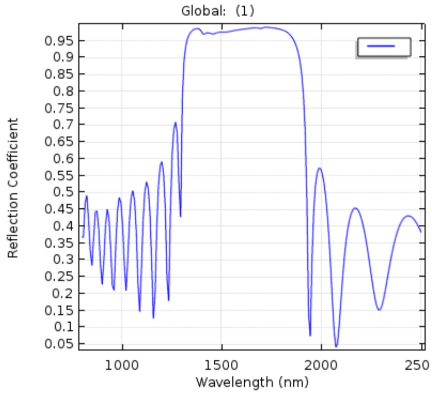

Fig 8: Reflection Coefficient for $SiO_2$and TiO_2

The center frequency which is selected is 1550 nm which is optimum for optical communication. So the structure can be used as switch or reflector in optical communication. The following table gives the center frequency obtained from the graph for different combinations and the corresponding bandwidth. It is observed that the combination of Silicon Dioxide(SiO_2) with refractive index 1.45 and the second material as Silicon Carbide with refractive index 2.55 gives the best result with centre frequency 1525 nm and bandwidth of 550nm.So for further analysis this combination can be taken as the reference.

TABLE 1

Material used	Center frequency	Bandwidth
$SiO_2$and Al_2O_3	1275nm	150nm
$SiO_2$and ZnO	1300nm	200nm
$SiO_2$and SiC	1525nm	550nm
$SiO_2$and TiO_2	1625nm	550nm

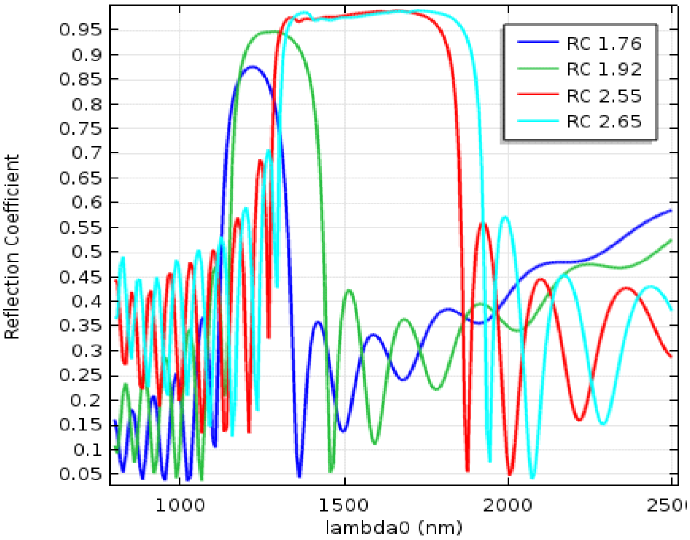

Fig 9: Reflection Coefficient for different material

The number of layers is varied to find the effect on Reflection Coefficient. As the number of layers is increased the reflection coefficient approaches to unity. Figure 2 gives number of layers and the corresponding reflection coefficient .Thus it is always preferred to have more number of layers limited by the manufacturing feasibility.

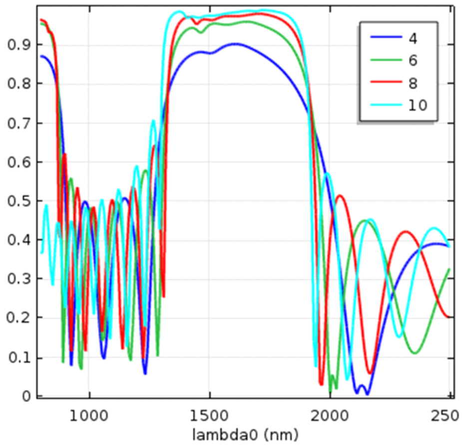

Fig 10: Reflection Coefficient for different layers

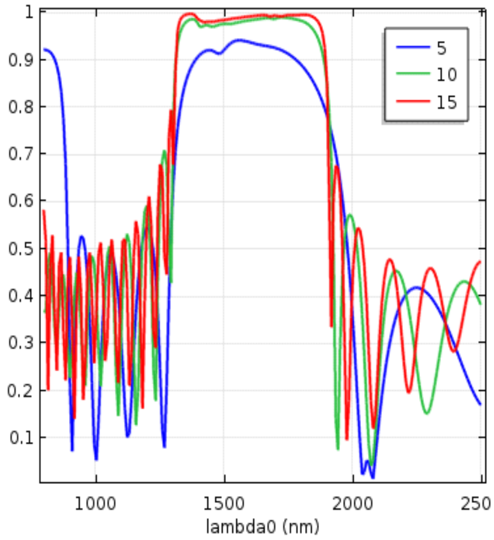

Fig 11: Reflection Coefficient for different layers

TABLE 2

Number of layers	Reflection coefficient
4	0.90
5	0.92
6	0.95
8	0.97
10	0.98
15	0.99

Next, it is checked to see if there is any variation with dimension ratio. When the dimension ratio of each layer is varied there is slight shift in the stop band. Any combination can be taken as long as the reflection coefficient is near to unity.

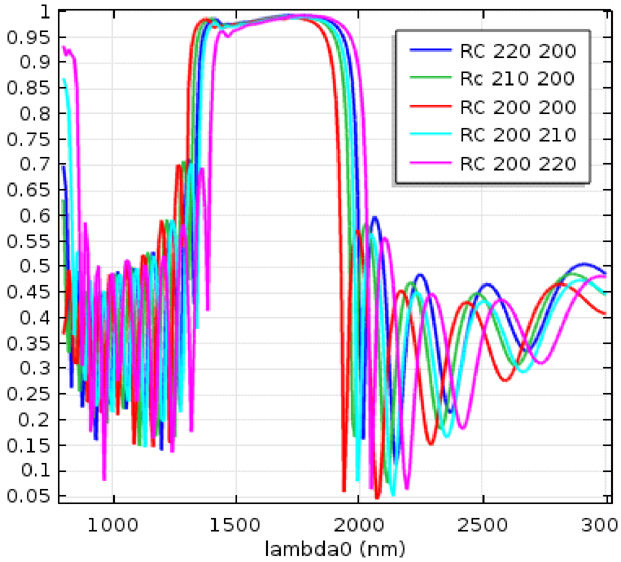

Fig 12: Reflection coefficient for different dimension ratio

TABLE 3

Dimension ratio	Center frequency	bandwidth
220-200	1675	650
210-200	1625	550
200-200	1600	600
200-210	1625	750
200-220	1725	650

When the periodicity of the structure is altered, that creates a defect in the system. When a defect is introduced is introduced in the periodic symmetry the response is slightly varied. When the defect is put in the beginning the sidebands are much reduced.

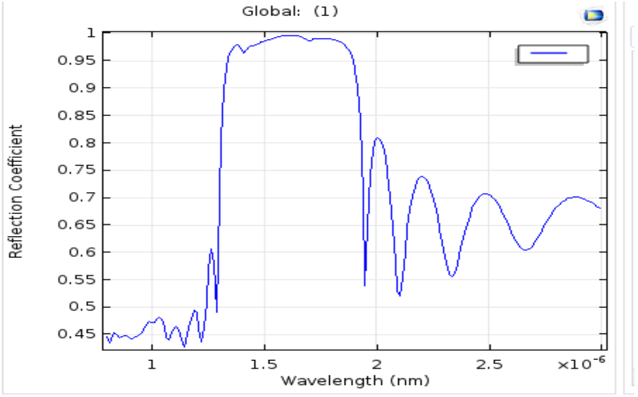

Fig 13: Reflection coefficient for defect at the beginning.

When the defect is put at the end, the response is as shown in the figure and when double defect is the response is as shown in figure8

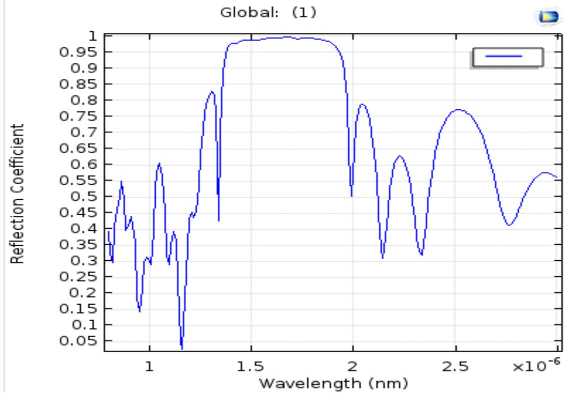

Fig 14: Reflection coefficient for single defect

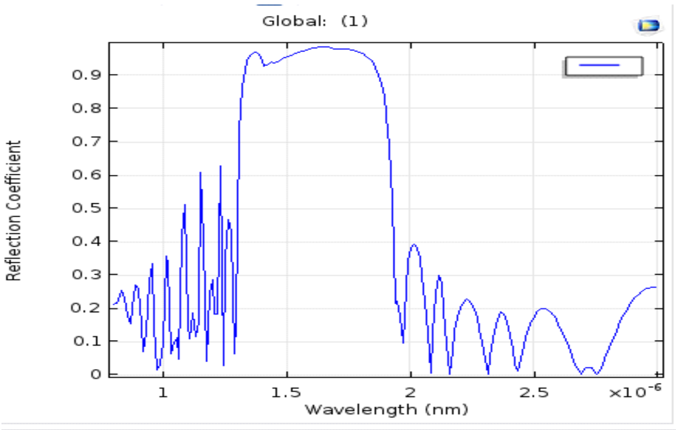

Fig 15: Reflection coefficient for double defect

IV.CONCLUSION

In the structure of photonic crystal, initially one material is kept constant as Silicon Dioxide and the second material is changed to Al_2O_3 ,ZnO,SiC and TiO_2 to observe the reflection coefficient. As observed from Table 1, the combination of Silicon Dioxide and Silicon Carbide gives best reflection with center frequency 1525nm and bandwidth of 550nm. The number of layers in the crystal is varied and it is observed that the reflection coefficient reaches to unity as the number of layers is increased. From Table 2 it is seen that when 15 layers are used the reflection reaches to 99%. Next, it is checked to see if there is any variation with dimension ratio. When the dimension ratio of each layer is varied there is slight shift in the stop band. Any combination can be taken as long as the reflection coefficient is near to unity. Center frequency is near to the designed value 1550nm when the dimension ratio is equal. When periodicity is changed, a defect gets introduced. When the defect is at the beginning, the sidebands are reduced. When two defects are introduced, the bandwidth is slightly reduced. Thus we can design photonic crystals for reflecting any wavelength by properly designing the materials, the number of layers and the thickness of each layer.

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