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Dense and Narrow Stop-Bands Structure Based on One Dimensional Photonic Crystal Filter for Optical Communication

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Abstract:
In this paper Photonic filters produced narrow and multi reflection bands. Paper considered filter for normal incident of light and effect on reflection band only. We used two dielectric materials Gallium Phosphide and Gallium Antimonide for filters. Filters used with alternating layers of these two materials with different thickness for achieving narrow and dense reflection band. After some repetition of particular arranged sub-group (or period) had nearly no effect on the shape of stop-bands. This paper showed output of two filters for normal incidence of light with both TE and TM modes. Both filters differ in thickness but same in period and materials. Calculation done near wavelength 1550nm. Both filters produced minimum quality factor of 7830 and reflection band gap near 0.198nm.Gap between two stop bands is nearly 0.8nm for both filters. All calculations shown with help of Transfer Matrix Method Mat-Lab.

Keywords: Total –thickness, Transfer Matrix Method, Multi-reflection band, Narrow and dense band, Stop-band, Reflection band, Photonic crystals, Quality factor, band gap.

I. INTRODUCTION

One dimensional photonic crystal is most interesting area for new inventions. Photonic crystals are periodic array of dielectric layers with alternating refractive indices. Periods of these arrays is known as lattice constant. Special region in band structure produced by photonic crystal where no optical waves is allowed to propagate through them are known as Photonic band gaps. Photonic crystals are able to produce multiple optical channels at different central wavelengths and able to separate (De-multiplex) one optical channel from the combined signals. Sometimes need to stop some channel so we need stop band channel based filters. Earlier in Photonic crystal, multiple band-gaps are increased by increasing thickness of layers and introducing layer of other material (as defect layer). This creates problems during manufacturing process due to numbers of different materials used. This paper use same material for acting like main layer and defect layer also that producing desired narrow and multiple stop-bands. We increase more no. of stop-bands with keeping nearly same total-thickness of photonic crystal in comparison to other photonic crystals [1]. Two layers GaP and GaSb, both firstly used to categorize as main layers and again used as defect layers with different thicknesses. This model of photonic crystal produces narrow photonic bands and more-dense bands in specific range of wavelength near 1550nm with good quality factor. Two materials are Gallium Phosphide (GaP) and Gallium Antimonide (GaSb) with refractive index 3 and 4 respectively [1]. For both filters layer of GaP and GaSb are repeated for two times in each sub-group (or period) behaving like two main layers symbolized as A and B respectively. Again inserted as defect layer and symbolized as C and D respectively for understanding purpose. In 'First filter' defect layers are greater in thickness than main layers and in 'Second filter' defect layers are lesser in thickness than main layers. For both filter we have designed and repeated period of ABCD for 20 times for results. Its property of producing narrow and multi photonic reflection band is applicable in optical filter, optical de-multiplexer, optical fiber wave guide (WDM based) etc. Paper firstly shows result for 'First filter' with period ABCD for TE and TM both modes and then shows results for increased no. of period with negligible effect on shape of stop-bands with N=30, N=40 and N=50. Similarly again shows results for 'Second filter' with period ABCD. We have proposed work for normal incident angle of light and stop-bands only, for recording all the results in paper. This paper aimed to show work for having Quality factor (Q) =7830. These calculations are done with the help of Transfer Matrix Method in Mat-Lab by simulation.

Structure of filter (layers arrangement):

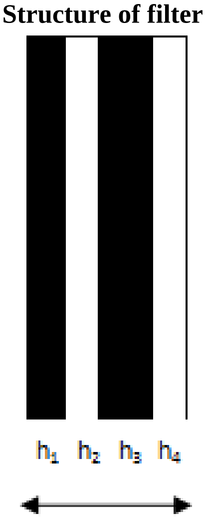

Figure.1. One sub-group or one period (ABCD)

Note: This period is repeated for 20 times in paper. This period is made of four layers of two materials with four different thicknesses.

Theory:
n_1= refractive index of first material (GaP)
n_2=refractive index of second material (GaSb)

We have used these two materials for four times with different thickness in each period.
$n_1=n_3$
$n_2=n_4$

Thickness of layers in each period are taken as follow
h_1= thickness of first layer
h_2=thickness of second layer
h_3=thickness of third layer
h_4=thickness of fourth layer

Let denote these four layers with following symbols
A- Layer with n_1 and h_1 (main layer)
B- Layer with n_2 and h_2 (main layer)
C- Layer with n_3 and h_3 (defect layer)
D- Layer with n_4 and h_4 (defect layer)
Dynamic Matrix for each individual layers are given by:

$$D_m=\begin{Bmatrix} \begin{bmatrix} 1 & 1 \\ n_m cos\Theta_m & -n_m cos\Theta_m \end{bmatrix} for\ TE\ mode \\ \begin{bmatrix} cos\Theta_m & cos\Theta_m \\ n_m & -n_m \end{bmatrix} for\ TM\ mode \end{Bmatrix}$$

m=1, 2, 3, 4

Where n_m is refractive index of m^{th} layer
And Θ_m is incident angle to m^{th} layer

And Dynamic Matrix for Air is

$$D_0=\begin{Bmatrix} \begin{bmatrix} 1 & 1 \\ n_0 cos\Theta_0 & -n_0 cos\Theta_0 \end{bmatrix} for\ TE\ mode \\ \begin{bmatrix} cos\Theta_0 & cos\Theta_0 \\ n_0 & -n_0 \end{bmatrix} for\ TM\ mode \end{Bmatrix}$$

Where n_0 is refractive index of Air
And Θ_0 is incident angle to layer

And propagation matrix for each layer is given by

$$P_m=\begin{bmatrix} e^{(ik_m h_m)} & 0 \\ 0 & e^{(-ik_m h_m)} \end{bmatrix}$$

Where each layer has its own Wave Vector
$k_m = 2\pi n_m cos\Theta_m/\lambda$

Transfer matrix for each sub-group (for period 'ABCD') is equal to:
$M_p=D_1 P_1 D_1^{-1} D_2 P_2 D_2^{-1} D_3 P_3 D_3^{-1} D_4 P_4 D_4^{-1}$

Total Transfer Matrix of total structure with 20 periods is given by:
$$M=D_0^{-1} M_p^{20} D_0=\begin{bmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{bmatrix}$$

Where D_0 is dynamic matrix of air that surrounds total structure

Reflection coefficient is given by:
$r=\frac{M_{21}}{M_{11}}$

Reflectance is given by:
$R=|r|^2$
And, Transmission coefficient is given by:
$t=\frac{1}{M_{11}}$
Transmittance is given by:
$T=|t|^2$
Expressions are related and taken from every reference papers [1-18].

III. CALCULATION WITH RESULTS:

Following 'Two filters' are proposed:
I. First filter:
Thickness of Filter's layer are critically given in nm for more accuracy as h_1=100000, h_2=75000, h_3=100129.703 and h_4=75097.2772, but value can be approximated. Refractive index are n_1=3(GaP), n_2=4(GaSb), n_3=3(GaP) and n_4=4(GaSb). Period is ABCD.
The Quality factor of filter given by**:**
$Q=\lambda_0/\Delta\lambda$

Following table shows **Quality Factor (Q)** of Reflection Bands of filter (period **ABCD)** with **TE mode**

Table no. 1			
Band no.	λ_0(nm)	$\Delta\lambda$(nm)	Quality factor (Q)
1	1550.4	0.198	7830.3
2	1551.4	0.198	7835.4
3	1552.4	0.198	7840.4
4	1553.4	0.198	7845.5
5	1554.4	0.198	7850.5
6	1555.4	0.198	7855.6
First filter with Period-ABCD TE mode N=20			

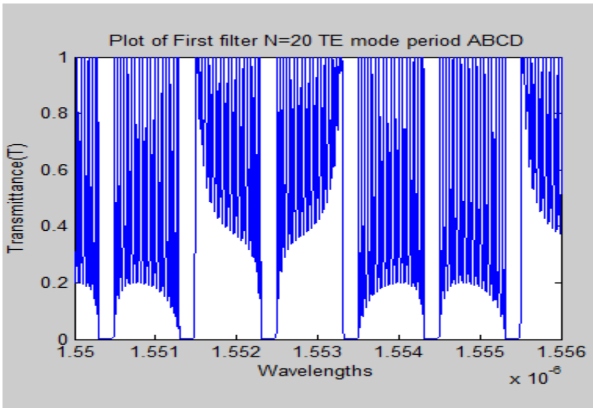

Figure.2. Reflection band structure of 1-D Photonic filter (with Period ABCD) TE mode N=20.

Figure shows result for TE mode with normal incident angle and have 6 reflection bands with their specifications shown in table no. 1 and fig. no. 2. Wavelength range is 1550nm to 1556nm. Band gaps are equal to 0.198nm and Quality factor (Q) equals nearly 7830. Gap between two stop bands is nearly 0.8nm. This pattern is as usual till 1565nm wavelength. Similarly, for TM mode (period ABCD) is shown below in fig 3.

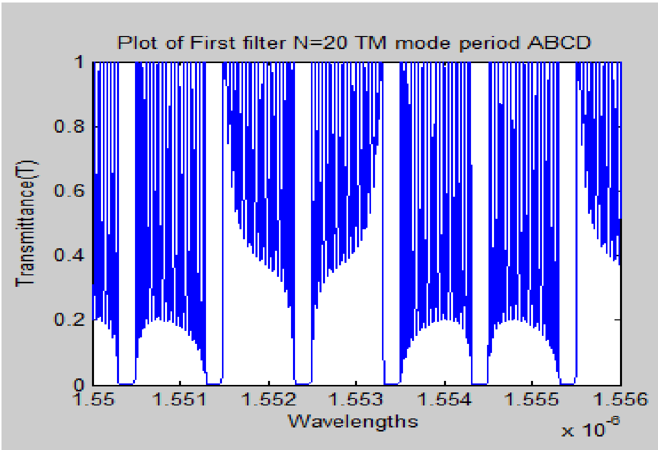

Figure.3. Reflection band structure of 1-D Photonic filter (with Period ABCD) TM mode N=20

For normal incidence results are same for TE mode and TM mode.
Now results for different no. of periods are given below as N=30, N=40 and N=50, showing nearly no effect on structure of reflection bands. All of following plots are providing same periodicity of reflection and same reflection band gaps.

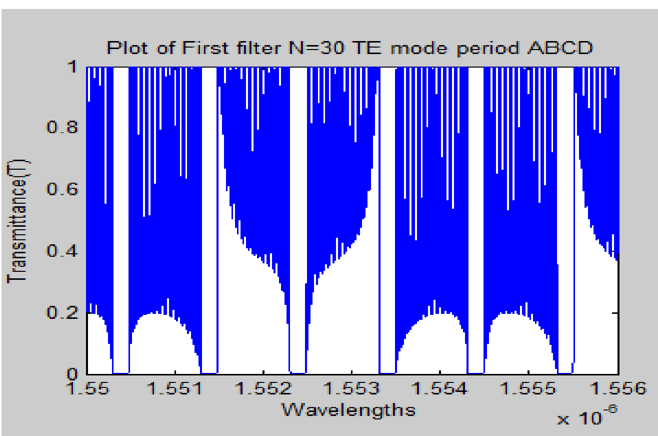

Figure.4. Reflection band structure of 1-D Photonic filter (period ABCD) TE mode N=30

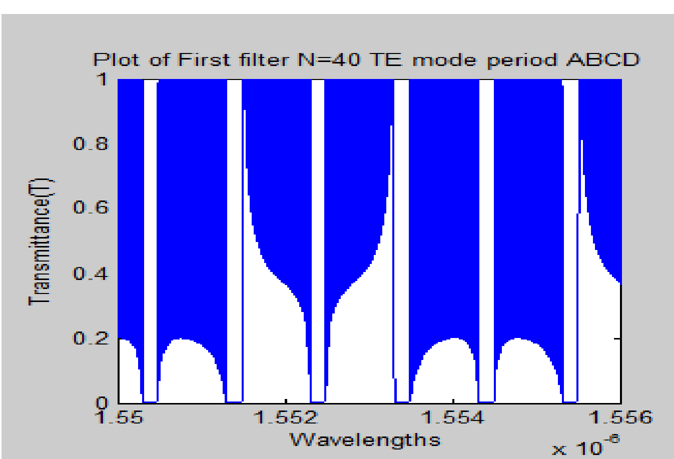

Figure.5. Reflection band structure of 1-D photonic filter (period ABCD) TE mode N=40

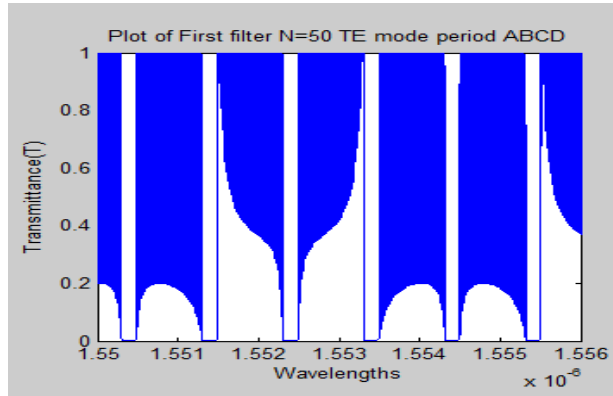

Figure.6. Reflection band structure of 1-D photonic filter (period ABCD) TE mode N=50.

III. SECOND FILTER:

Thickness of Filter's layer are critically given in nm for more accuracy as h_1=100000, h_2=75000, h_3=99870.633 and h_4=74902.975, but value can be approximated.
Refractive index are n_1=3(GaP), n_2=4(GaSb), n_3=3(GaP) and n_4=4(GaSb). Period is ABCD.
In second filter defect layers thickness are smaller than main layer, so its total filter thickness is less than first filter but nearly providing same output and due to this will be more applicable than First filter. Following table shows Quality factor (Q) of Stop Bands of Second filter (period ABCD) TE mode with N=20.

Table no. 2

Band no.	λ_0(nm)	$\Delta\lambda$(nm)	Quality factor(Q)
1	1550.4	0.198	7830.3
2	1551.4	0.198	7835.4
3	1552.4	0.198	7840.4
4	1553.4	0.198	7845.5
5	1554.4	0.198	7850.5
6	1555.4	0.198	7855.6

Second filter with Period-ABCD TE mode N=20

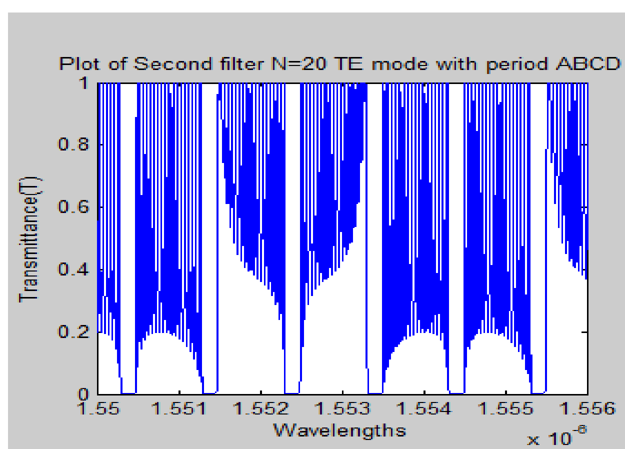

Figure.7. Reflection band structure of 1-D photonic filter (period ABCD) TE mode N=20

For normal incident to filter results in 6 reflection bands with their specifications shown in table no. 2 and fig. no.7.

Wavelength range is 1550nm to 1556nm. Reflection band gap is equal to 0.198nm and Quality factor (Q) is equal to nearly 7830.Gap between two stop bands is nearly 0.8nm. This pattern is as usual till 1565nm wavelength. Similarly, for TM mode filter with period ABCD is given below in fig. no.8.

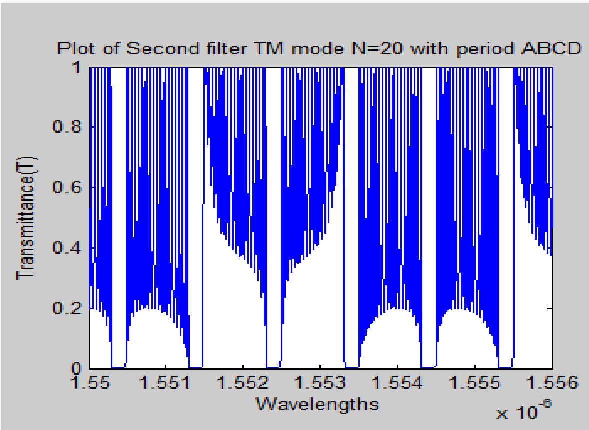

Figure.8. Reflection band structure of 1-D photonic filter (period ABCD) TM mode N=20

For normal incident results are same for TE and TM mode.
Now results for different no. of period as N=30, N=40 and N=50, showing nearly no effect on structure of reflection band of filter. All of following plots are providing same periodicity of reflection bands and same reflection band gaps (Δλ).

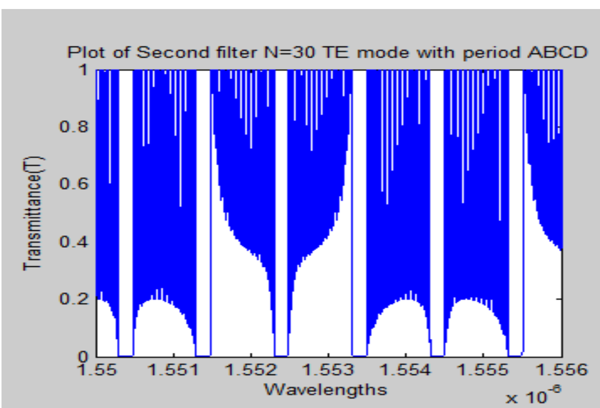

Figure.9. Reflection band structure of 1-D Photonic Filter (with period ABCD) TE mode N=30

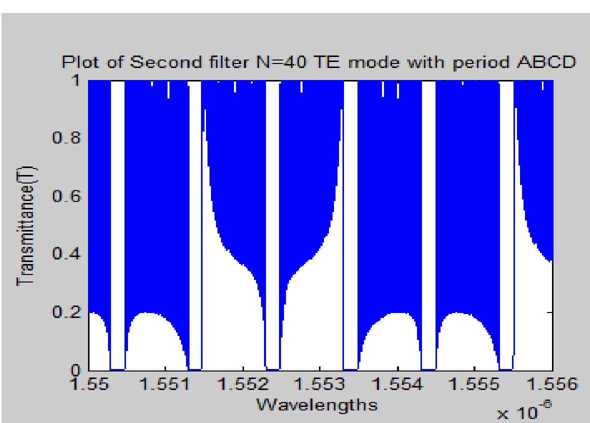

Figure.10. Refection band structure of 1-D Photonic Filter (with period ABCD) TE mode N=40.

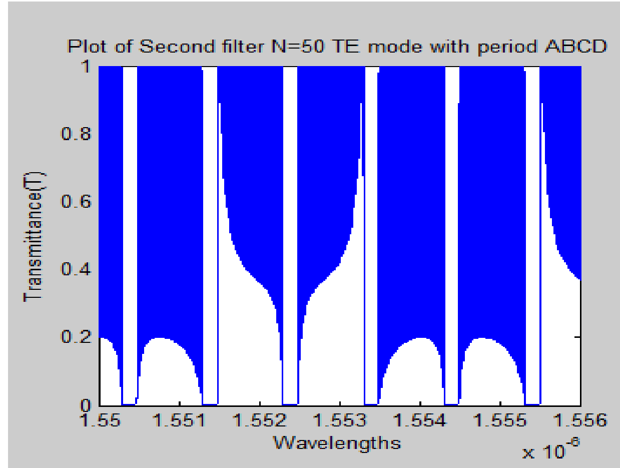

Figure.11. Reflection band structure of 1-D Photonic Filter (with period ABCD) TE mode N=50.

IV. CONCLUSION

In this paper we designed two filters as photonic crystal with each period of four layers. Where two were acting as main layer and other two with varied thickness were acting as defect layer. Two filters were proposed where first filter was having defect layer with greater thickness than main layer's thickness and vice-versa for Second filter. Both filters were producing dense and periodic reflection bands with reflection band gap equals to nearly 0.198nm, gap between two stop bands is nearly 0.8nm and quality factor equal to nearly 7830. Both filters were designed with specifications by which they produced all above properties that made them more applicable with keeping nearly constant total thickness of filter than compare to other filter [1]. There was nearly no effect of increasing no. of periods greater than nearly N=20 on reflection bands. For normal incident there was no effect on filter's output for TE and TM modes. These filters can be used where photonic narrow stop-band with reduced filter thickness are required like photonic filter for WDM in communication system, with laser, waveguides, de-multiplexers etc.

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