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# Dense and Narrow Reflection-Bands Structure Based on One Dimensional Photonic Crystal

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**Abstract:**
In this paper filters designed with normal incident of light that produced dense reflection bands with narrow band gap. Filters made of one dimensional Photonic crystal composed of three layers of Silicon Dioxide, Titanium Dioxide and Air. Thickness of layers specified to result in small total thickness of filter. Four filters got proposed with three layers that differ in layers arrangements and layer thickness. After specific repetition of periods showed nearly no effect on reflection bands when number of periods are increased at wavelength near 1550nm. Filters produced minimum quality factor of 7048 and reflection band gap near 0.22nm.Gap between two stop bands is nearly 0.45nm for all filters. All calculations are done with the help of Transfer Matrix Method in Mat-Lab.

**Keywords:** Total thickness, Transfer Matrix Method, Dense reflection bands, Narrow bands, Quality factor, Band gap, Photonic Crystals.

## I. INTRODUCTION:

Now days research on Photonic crystal is increasing for making optical communication more advance and compressing the size of each devices of communication system. New generation services with high speed internet growth cause a large traffic in communication. DWDM system can full fill need of more bandwidth for networks by its more number of channels with narrower channel spacing. Optical filter is a device for selectively transmitting or reflecting light in particular range of wavelengths while the other blocked. Band structure produced by photonic crystals have special regions where no optical waves are allowed to propagate (reflected back) are known as Photonic band gaps (PBG). These filters are also separating (De-multiplex) one optical channel from combined signals. So need to stop some channels lead the requirement of stop band filters. Its widespread uses are found in various areas of interest such as nanotechnology, astronomy and communication. Designing is the first step in making an effective channel filter in many applications. In this paper filters with 20 periods, each period compose of three layers. Paper considers normal incident of optics and effects on reflection bands only. Number of reflection bands got increased by selecting specific thickness of third layer (air) of each period. Three layers are Silicon dioxide, Titanium dioxide and Air. Third player selected as Air to have minimum total loss in photonic crystal. Paper is divided in two parts as per change in thickness of third layer (Air) in each period. Rest of two layers has constant thickness. First part where thickness of Air is large having two types of filter with period designed as ABC and ACB. Symbols A, B and C represent $SiO_2$, $TiO_2$ and Air respectively. Similarly, in second part where thickness of Air is small having two types of filter with period designed as ABC and ACB. All four filters producing dense and narrow reflection bands, so these features make it applicable for optical communication, optical wave guide, optical reflector, de-multiplexer etc. Range of wavelength where all filters can produce better result is 1300-1700(nm). Refractive indexes are 1.46, 2.4and 1 of $SiO_2$, $TiO_2$ and air respectively [3]. Paper depicted sample of result only for wavelength range of 1550nm to 1555nm producing 7 reflection bands. Band gap of reflection band comes out nearly 0.22nm. Gap between two stop bands is nearly 0.45nm. Quality factors are near 7048. All four filters are showing nearly no effect on reflection bands when number of periods are increasing after nearly N=20 (e.g. N=30, N=40 and N=50 etc.). Results are same for TE and TM mode when work on normal incident angle to filter and recorded all results. All calculations are done with the help of Transfer Matrix Method on Mat-Lab by simulations.

**Structure of filter:**

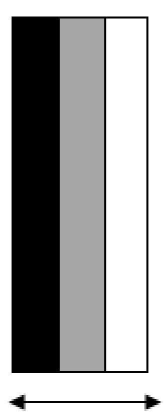

**Figure. 1 One period made of three layers**
Note: This period is repeated for 20 times in every filter in paper. This period is made of three materials with different thickness.

**Theory:**
$n_1$=refractive index of $SiO_2$

$n_2$=refractive index of $TiO_2$
$n_3$=refractive index of Air

**Thickness of layers are taken as follow**
$h_1$=thickness of $SiO_2$
$h_2$=thickness of $TiO_2$
$h_3$=thickness of Air
**Let denote these three layers with following symbols**
A. - layer with $n_1$ and $h_1$
B. - layer with $n_2$ and $h_2$
C. - layer with $n_3$ and $h_3$
**Dynamic Matrix for each layers are given by:**

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

m=1, 2, 3.
Where $n_m$ is refractive index of $m^{th}$ layer
And $\Theta_m$ is incident angle to $m^{th}$ layer

**And Dynamic Matrix for Air is given by:**

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

Where $n_0$ is refractive index of Air
And $\Theta_0$ is incident angle to layer
**And propagation Matrix for each layer is given by:**

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

m= 1, 2
Where each layer has its own wave vector
$k_m=2\pi n_m\cos\Theta_m/\lambda$

**Transfer matrix for each period made of three layers is given by:**
$M_p=D_1P_1D_1^{-1}D_2P_2D_2^{-1}D_3P_3D_3^{-1}$
**Total Transfer Matrix of total structure with period 20 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 and methods are taken from reference papers [1-21].

**Calculation with results:**
**Following 'Four filters' are proposed:**
**1. First part:**

**a. First filter:**
Filter with period 'ABC' have following specifications of layers: Refractive indexes are $n_1$=1.46, $n_2$=2.4, $n_3$=1.
Thicknesses are critically given in nm for more accuracy as $h_1$=410958.9041, $h_2$=250000, $h_3$=600388.3497, but value can be approximated.

**Output table is given below:**

| Table no. 1 | | | |
|---|---|---|---|
| Band no. | $\lambda_0$(nm) | $\Delta\lambda$(nm) | Quality factor(Q) |
| 1 | 1550.72 | 0.22 | 7048.7 |
| 2 | 1551.39 | 0.22 | 7051.8 |
| 3 | 1552.06 | 0.22 | 7054.8 |
| 4 | 1552.73 | 0.22 | 7057.9 |
| 5 | 1553.40 | 0.22 | 7060.9 |
| 6 | 1554.07 | 0.22 | 7064 |
| 7 | 1554.74 | 0.22 | 7067 |
| First filter period ABC TE mode N=20 | | | |

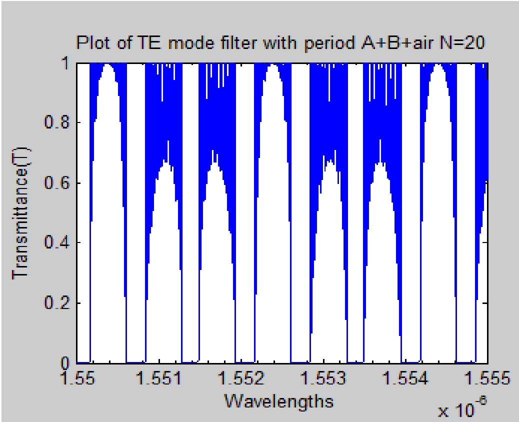

**Figure.2. Plot of reflection bands of filter with period 'ABC' for TE mode with N=20**

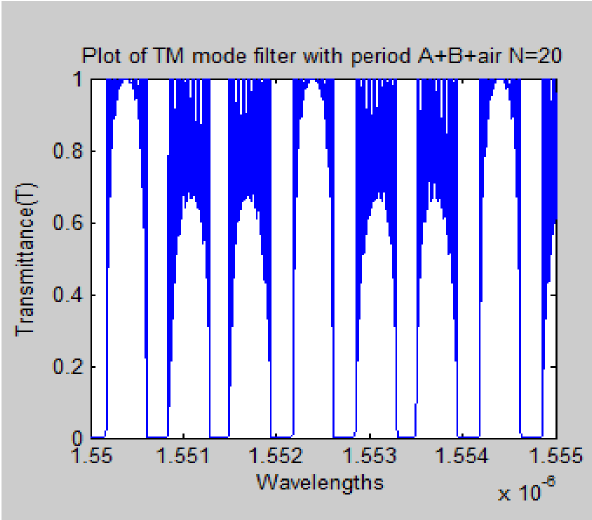

**Figure.3. Plot of reflection bands of filter with period 'ABC' for TM mode with N=20**

Both TE and TM modes are producing same reflection bands for normal incident. Total 7 bands are there in range of 1550nm to 1555nm of wavelengths. Each band having nearly 0.22nm reflection bands gap. Gap between two stop bands is nearly 0.45nm. Minimum Quality factor is near 7048. In following figures as no. of periods increase with N=30, N=40 and N=50

for TE mode showing nearly no effect on structure of reflection bands

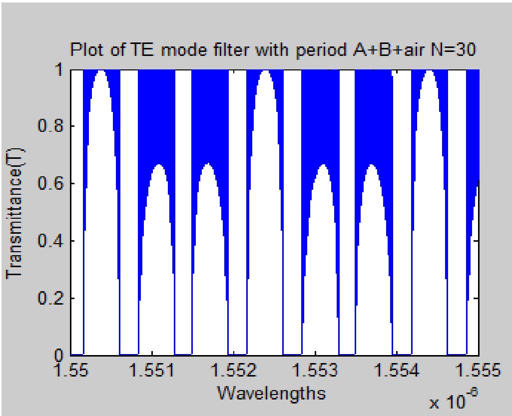


**Figure.4. Plot of reflection bands of filter with period 'ABC' for TE mode with N=30**

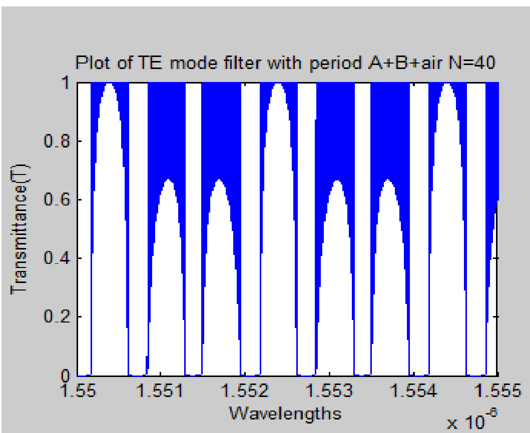


**Figure.5. Plot of reflection bands of filter with period 'ABC' for TE mode with N=40**

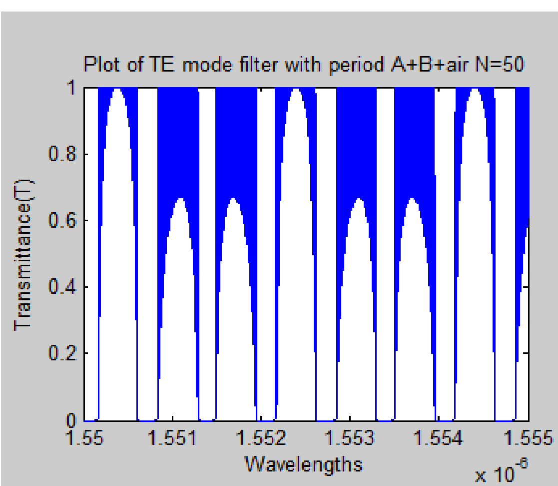


**Figure.6. Plot of reflection bands of filter with period 'ABC' for TE mode with N=50**

**b. Second filter:**

**Filter with period 'ACB' have following specifications of layers as:**

Refractive indexes are $n_1$=1.46, $n_2$=2.4 and $n_3$=1. Thicknesses are critically given in nm for more accuracy as $h_1$=410958.9041, $h_2$=250000 and $h_3$=600388.3497, but value can be approximated.

**Output table is given below:**

Table no. 2

| Band no. | $\lambda_0$(nm) | $\Delta\lambda$(nm) | Quality factor(Q) |
|---|---|---|---|
| 1 | 1550.72 | 0.22 | 7048.7 |
| 2 | 1551.39 | 0.22 | 7051.8 |
| 3 | 1552.06 | 0.22 | 7054.8 |
| 4 | 1552.73 | 0.22 | 7057.9 |
| 5 | 1553.40 | 0.22 | 7060.9 |
| 6 | 1554.07 | 0.22 | 7064 |
| 7 | 1554.74 | 0.22 | 7067 |

Second filter period ACB TE mode N=20

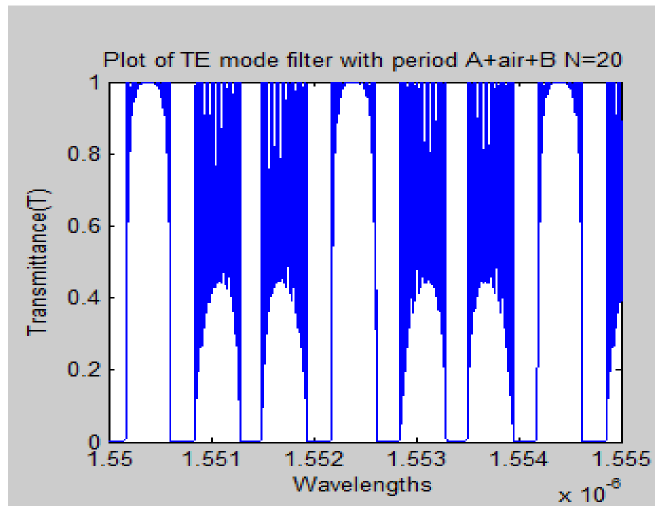


**Figure.7. Plot of reflection bands of filter with period 'ACB' for TE mode with N=20**

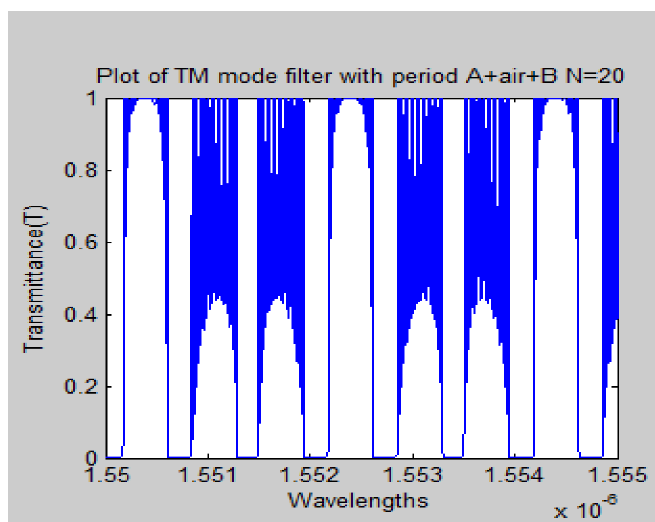


**Figure.8. Plot of reflection bands of filter with period 'ACB' for TM mode with N=20**

Both TE and TM modes are producing same reflection bands for normal incident. Total 7 bands are there in range of 1550nm to 1555nm of wavelengths. Each band having nearly 0.22nm reflection bands gap. Gap between two stop bands is nearly 0.45nm. Minimum quality factor is near 7048. In following figures as no. of periods increase with N=30, N=40 and N=50

for TE mode showing nearly no effect on structure of reflection bands.

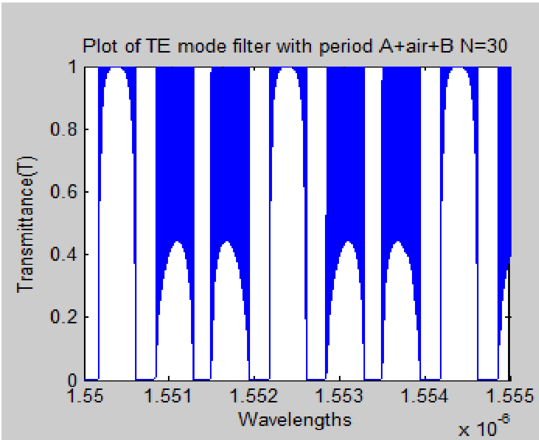


**Figure.9. Plot of reflection bands of filter with period 'ACB' for TE mode with N=30**

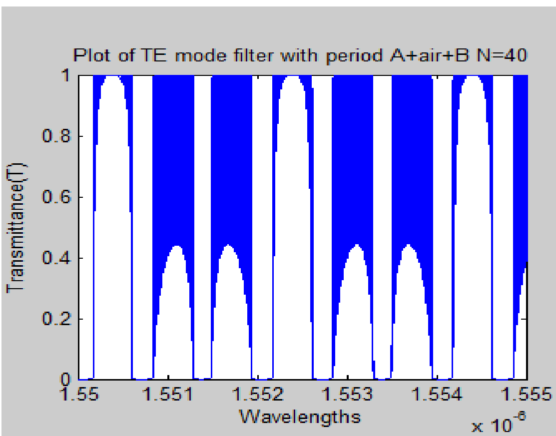


**Figure.10. Plot of reflection bands of filter with period 'ACB' for TE mode with N=40**

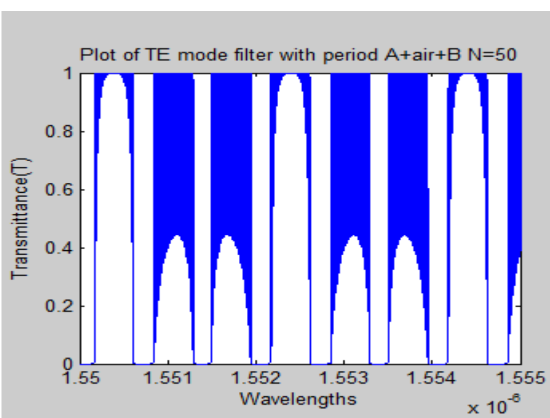


**Figure.11. Plot of reflection bands of filter with period 'ACB' for TE mode with N=50**

**2. Second part:**

**a) Third filter:**

**Filter with period 'ABC' have following specifications of layers as:**

Refractive indexes are $n_1$=1.46, $n_2$=2.4 and $n_3$=1. Thicknesses are critically given in nm for more accuracy as $h_1$=410958.9041, $h_2$=250000 and $h_3$=599612.1528, but value can be approximated.

**Output table is given below:**

Table no. 3

| Band no. | $\lambda_0$(nm) | $\Delta\lambda$(nm) | Quality factor(Q) |
|---|---|---|---|
| 1 | 1550.72 | 0.22 | 7048.7 |
| 2 | 1551.39 | 0.22 | 7051.8 |
| 3 | 1552.06 | 0.22 | 7054.8 |
| 4 | 1552.73 | 0.22 | 7057.9 |
| 5 | 1553.40 | 0.22 | 7060.9 |
| 6 | 1554.07 | 0.22 | 7064 |
| 7 | 1554.74 | 0.22 | 7067 |

Third filter period ABC TE mode N=20

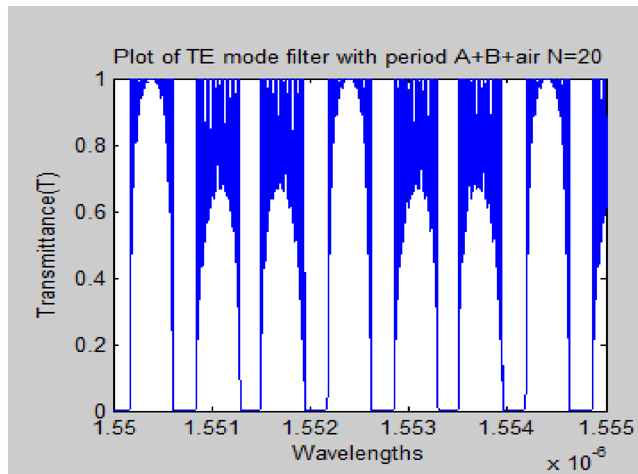


**Figure.12. Plot of reflection bands of filter with period 'ABC' for TE mode with N=20**

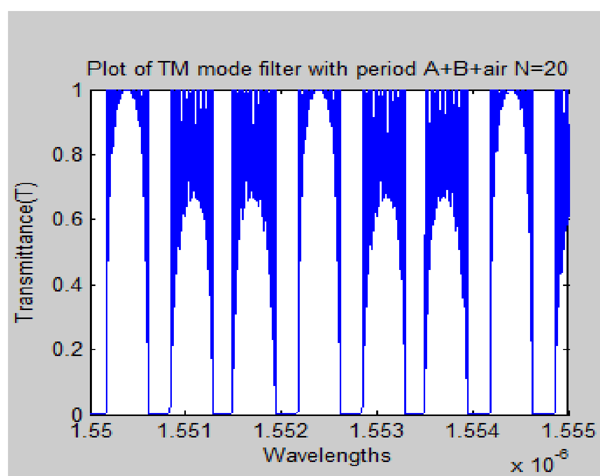


**Figure.13. Plot of reflection bands of filter with period 'ABC' for TM mode with N=20**

Both TE and TM modes are producing same reflection bands for normal incident. Total 7 bands are there in range of 1550nm to 1555nm of wavelengths. Each band having nearly 0.22nm reflection bands gap. Gap between two stop bands is nearly 0.45nm. Minimum quality factor is near 7048. In following figures as no. of periods increase with N=30, N=40 and N=50

TE mode showing nearly no effect on structure of reflection bands.

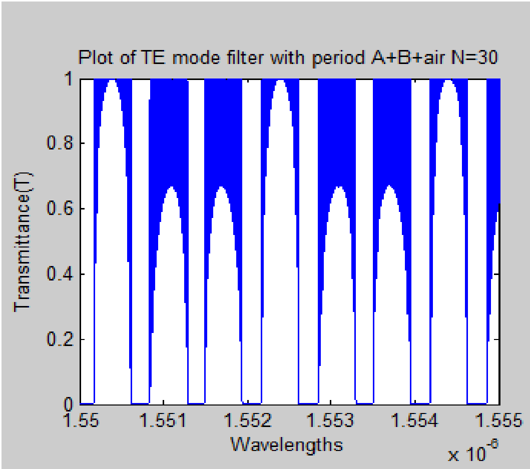


**Figure.14. Plot of reflection bands of filter with period 'ABC' for TE mode with N=30**

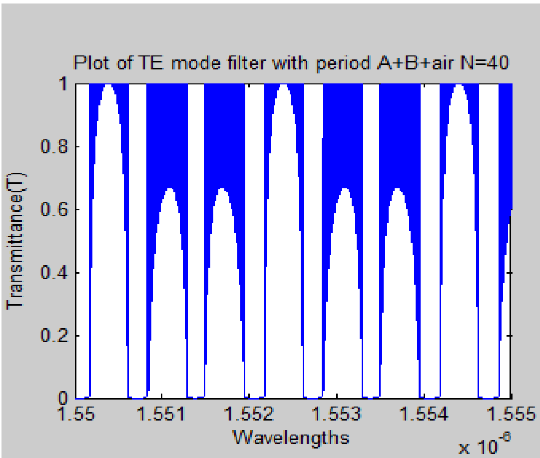


**Figure.15. Plot of reflection bands of filter with period 'ABC' for TE mode with N=40**

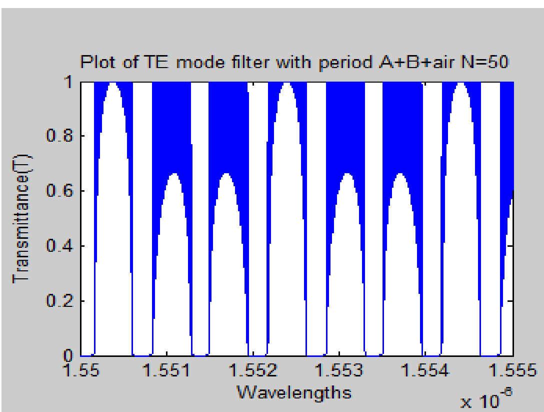


**Figure.16. Plot of reflection bands of filter with period 'ABC' for TE mode with N=50**

**c. Fourth filter:**

Filter with period 'ACB' have following specifications of layers as:

Refractive indexes of layers are $n_1$=1.46, $n_2$=2.4 and $n_3$=1. Thicknesses are critically given in nm for more accuracy as $h_1$=410958.9041, $h_2$=250000 and $h_3$=599612.1528, but value can be approximated.

**Output table is given below as:**

Table no. 4

| Band no. | $\lambda_0$(nm) | $\Delta\lambda$(nm) | Quality factor(Q) |
|---|---|---|---|
| 1 | 1550.72 | 0.22 | 7048.7 |
| 2 | 1551.39 | 0.22 | 7051.8 |
| 3 | 1552.06 | 0.22 | 7054.8 |
| 4 | 1552.73 | 0.22 | 7057.9 |
| 5 | 1553.40 | 0.22 | 7060.9 |
| 6 | 1554.07 | 0.22 | 7064 |
| 7 | 1554.74 | 0.22 | 7067 |

Fourth filter period ACB TE mode N=20

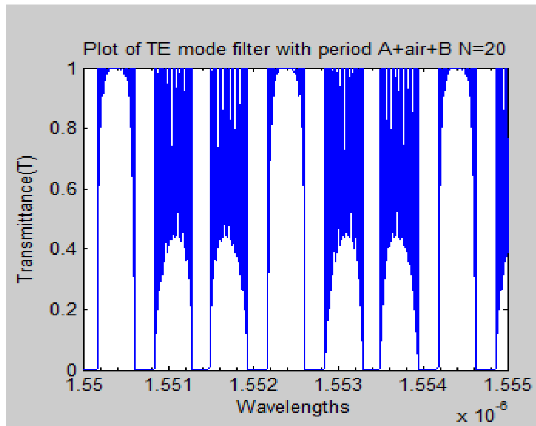


**Figure.17. Plot of reflection bands of filter with period 'ACB' for TE mode with N=20**

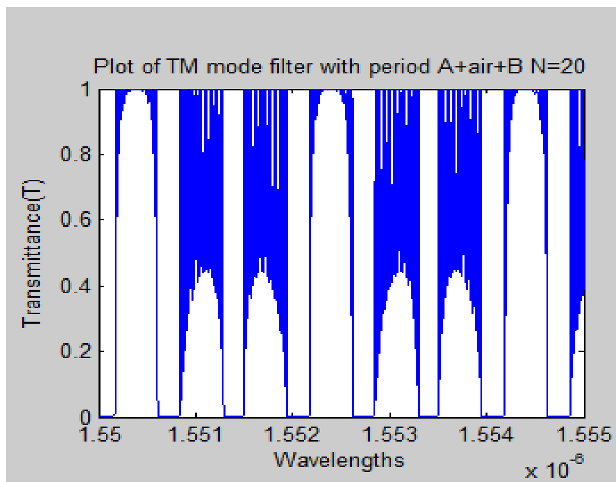


**Figure.18. Plot of reflection bands of filter with period 'ACB' for TM mode with N=20**

Both TE and TM modes are producing same reflection bands for normal incident. Total 7 bands are there in range of 1550nm to 1555nm of wavelengths. Each band having nearly 0.22nm reflection bands gap. Gap between two stop bands is nearly 0.45nm. Minimum quality factor is near 7048.In following figures as no. of periods increase with N=30, N=40 and N=50 for TE mode showing nearly no effect on structure of reflection bands.

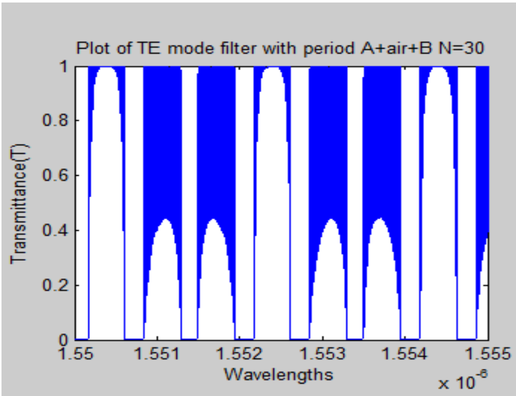


**Figure.19. Plot of reflection bands of filter with period 'ACB' for TE mode with N=30**

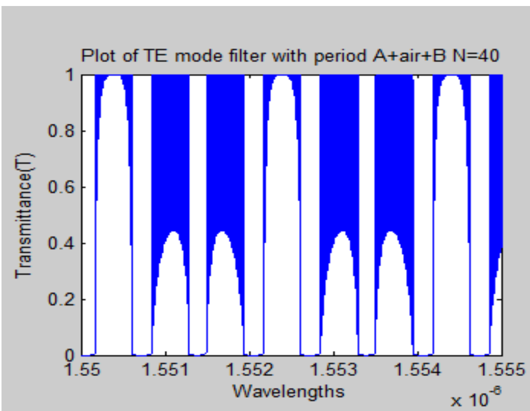


**Figure.20. Plot of reflection bands of filter with period 'ACB' for TE mode with N=40**

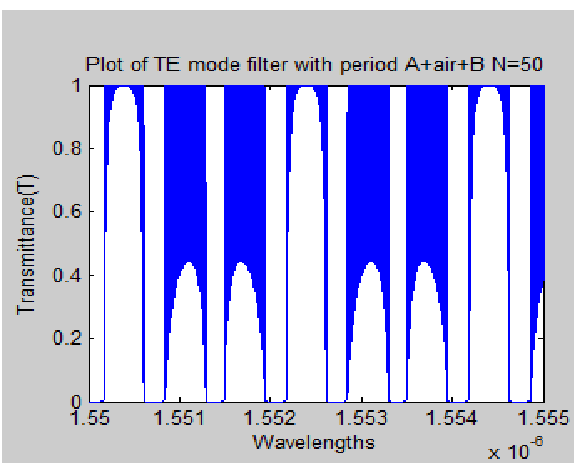


**Figure.21. Plot of reflection bands of filter with period 'ACB' for TE mode with N=50**

## II. CONCLUSION:

In this paper we designed four filters each with period of three layers as Silicon dioxide, Titanium dioxide and Air. Paper considered normal incident of light and effect on reflection bands only. Due to consideration of layer of air total loss in filter reduced. Each of layers considered with a specific thickness so that we got success in minimizing total thickness of filter. Outputs of all four filters are producing dense and narrow reflection bands. This made more applicable in optical communication system, where DWDM schemes are running. These filters are also got application optical waveguide, optical reflector, optical de-multiplexer etc. All filters are producing quality factor near 7048 and reflection band gap is near 0.22nm. Gap between two stop bands is nearly 0.45nm for all filters. There are 7 bands in ranges of 1550nm to1555nm.

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