

Design Parameters of Different Configuration of Optical Filters Made up of MgF_2 and Ta_2O_5

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ABSTRACT: In this paper, an improved design of a tunable optical filter device made up of alternating layers of MgF_2 and Ta_2O_5 is proposed. Different configurations of this narrow band pass (NBP) optical filter are used for whole visible spectral range (400nm-700nm). We report on the calculated values of the design parameters, such as pass band wavelength, 3-dB bandwidth and quality factor for different configurations of narrow band pass optical filter. The design parameters are also evaluated when varying the angle at which the optical wave is incident on the input layer of the filter.

KEYWORDS: tunable optical filters, pass band wavelength, 3-dB bandwidth, quality factor.

I. INTRODUCTION

Multichannel optical communication system was made possible by the realization of several optical components. An optical filter is one of the critical components used to increase the channel information capacity of the optical fiber. The fiber optics communication systems uses various types of interference filters such as multilayer thin films, wavelength selective filters, Fiber Bragg grating interference filters etc. [1] [2] [3] [4]. The priority task for the developers is to obtain maximal selectivity and maintainability of the filters using minimal number of thin-film layers in the structures. These filters determine the overall efficiency of the system. Recently, there has been a growing interest in the application of interference filters in the visible spectral range from 400nm to 700nm owing to their application in display and sensor devices which in turn are used in the field of life science, imaging, industrial, or defense industries. Multilayer interference structures of thin films with low and high refractive index materials and filters on the base of such structures are known for a long time. Design and realization of interference coatings are the principal stages in production of thin-film systems with given characteristics [5] [6]. The system of reflected and refracted waves appears at wave propagation processes in layer structure and forms multiple interference patterns. Modifying the structure of layered medium in terms of physical properties of layer materials, thickness of the layers and number of layers allows for controlling the characteristics of wave processes to a large extent. Interference filters can include some tens or even hundreds of dielectric layers. [7][8]. In this paper, we present different configurations of multilayer interference filter made up of alternating layers of MgF_2 and Ta_2O_5 and calculate the design parameters such as pass band wavelength, 3-dB bandwidth and quality factor by using Transfer matrix Method for the visible spectral range from 400nm to 700nm.

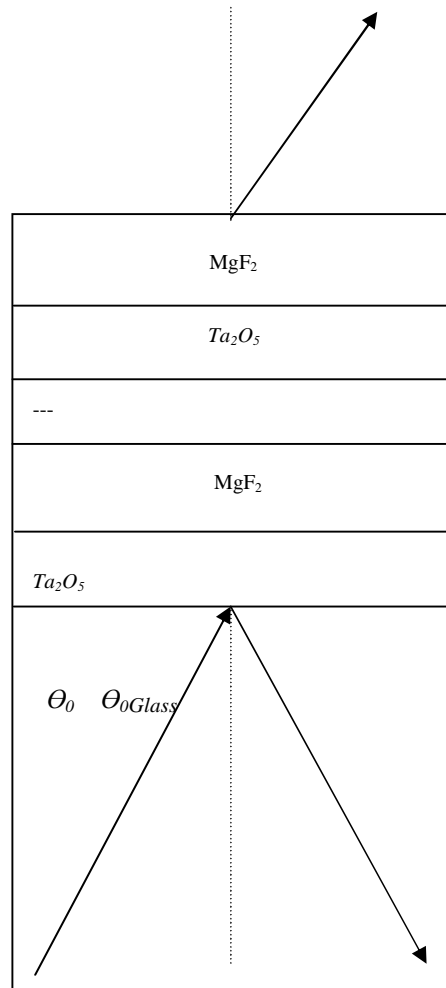
II. STRUCTURE AND PRINCIPLE

Generally, an interference narrow band pass (NBP) optical filter consists of alternating layers of H and L, film, alternating layers of H and L, ..., film, alternating layers of H and L. Here, H and L indicate high and low index layers respectively, with a common thickness of quarter wavelength. Also, the film consists of $2n'H'$ or $2n'L'$ where n is an integer and determines the length of the cavity. It consists of alternating MgF_2 and Ta_2O_5 layers deposited over glass substrate.

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According to electro-magnetic theory for the multilayer film we have,

$$\begin{bmatrix} \frac{1}{\sqrt{\mu_0/\epsilon_0}} \times E_0 \\ H_0 \end{bmatrix} \left\{ \prod_{i=1}^k \begin{bmatrix} \cos \delta_i & j \frac{\sin \delta_i}{\eta_i} \\ j \eta_i \sin \delta_i & \cos \delta_i \end{bmatrix} \right\} \times \begin{bmatrix} \frac{1}{\sqrt{\mu_0/\epsilon_0}} \times E_{k+1} \\ H_{k+1} \end{bmatrix} \quad (1)$$

The film's transmission matrix is shown as follows:

$$\begin{bmatrix} B \\ C \end{bmatrix} = \left\{ \begin{bmatrix} \cos \delta_i & j \frac{\sin \delta_i}{\eta_i} \\ j \eta_i \sin \delta_i & \cos \delta_i \end{bmatrix} \right\} \begin{bmatrix} 1 \\ \eta_{k+1} \end{bmatrix} \quad (2)$$

Where,

$$\theta = \sin^{-1} \left(\frac{\sin \theta}{\eta_i} \right)$$

$$\delta_i = \frac{2\pi}{\lambda} n_i d_i \cos \theta_i$$

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$$\eta_i = \frac{n_i}{\cos \theta_i} \text{ (for P Light)} \tag{3}$$

$$n_i = n_i \cos \theta_i \text{ (for S Light)} \tag{4}$$

$$Y = B / C , \tag{5}$$

$$r^p (r^s) = \frac{\eta_0 - Y}{\eta_0 + Y} \tag{6}$$

$$R^p (R^s) = \left(\frac{\eta_0 B - C}{\eta_0 B + C} \right) \left(\frac{\eta_0 B - C}{\eta_0 B + C} \right) \tag{7}$$

$$R = \frac{R^p + R^s}{2} \tag{8}$$

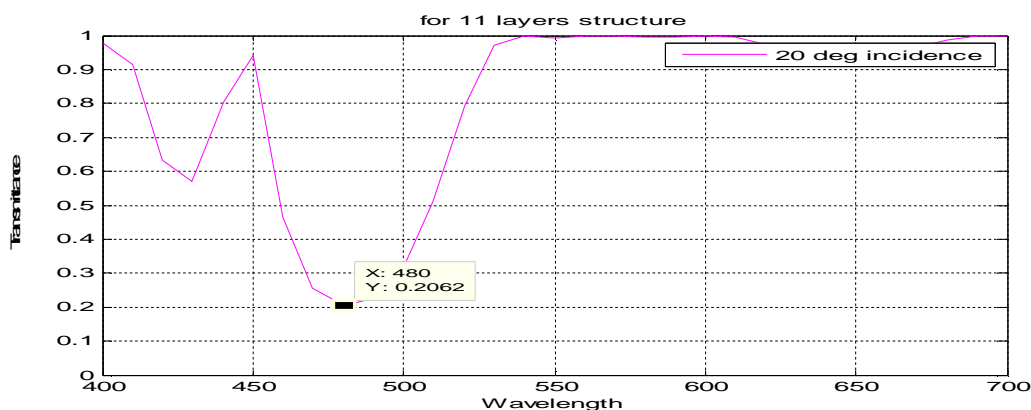
$$T = 1 - R \tag{9}$$

Thus transmission is calculated by using equation (9).

III. DESIGN PARAMETERS OF DIFFERENT CONFIGURATION

The transmittance of layered structure is calculated according to thin film equations using MATLAB 2012 software. We have concentrated mainly on obtaining the precise design parameters rather than the computation time required. The design parameters which control the transmission characteristics are the value of pass wavelength, 3-dB bandwidth or Full Width at Half Maximum (FWHM) and quality factor. The 3-dB bandwidth or Full Width at Half Maximum (FWHM,) in the case of the pattern in transmitted light, is the width between the points on either side of a maximum where the intensity has fallen to half its maximum value. It is a measure of the sharpness of the fringes. Another parameter that determines the performance of the device is the quality factor of the filter, which is given by the ratio of the pass band wavelength to the 3-dB bandwidth. The quality factor is a measure of selectivity.

Figure 1 shows spectral Response of NBP filter configuration with 11 layers and 1 cavity according to cavity length(n) for a filter configuration ‘substrate/ LHLHL(2nH)LHLHL/ cover’ and a pass wavelength of 480 nm.



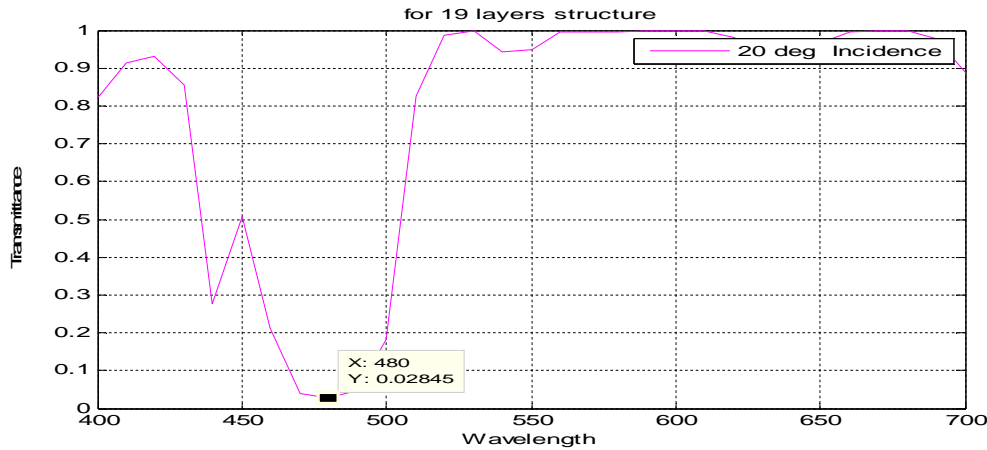
Fig(1) Spectral Response of BPF configuration with 11 layers

Figure 2 shows spectral Response of NBP filter configuration with 19 layers and 1 cavity according to cavity length(n) for a filter configuration ‘substrate/ LHLHLHLHL (2nH) LHLHLHLHL / cover’ and a pass wavelength of 480 nm.

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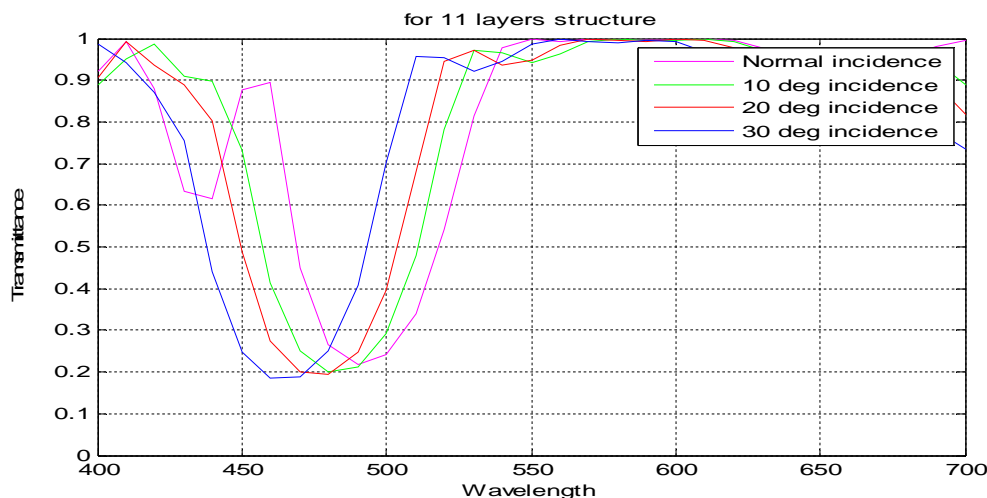
Fig(2) Spectral Response of BPF configuration with 19 layers

The numerical values of the design parameters, i.e. 3-dB bandwidth and quality factor, are obtained from figure (1) and figure (2) are given in Table (1). It is observed that, as the number of layers increase, the cut-off characteristic sharpness increases and there is a sharp decrease in the value of 3-dB bandwidth. This makes the filter efficient with a better quality factor.

For 20 degree incidence	11 layers structure	19 layers structure
FWHM or 3-dB bandwidth	60 nm	40 nm
Q-factor	9.1	13.7

Table (1) Design Parameters of 11 layers and 19 layers structure.

Figure 3 shows spectral response of NBP filter configuration with 11 layers and 1 cavity for a filter configuration 'substrate/ LHLHL (2nH) LHLHL/ cover' and a pass wavelength of 480 nm



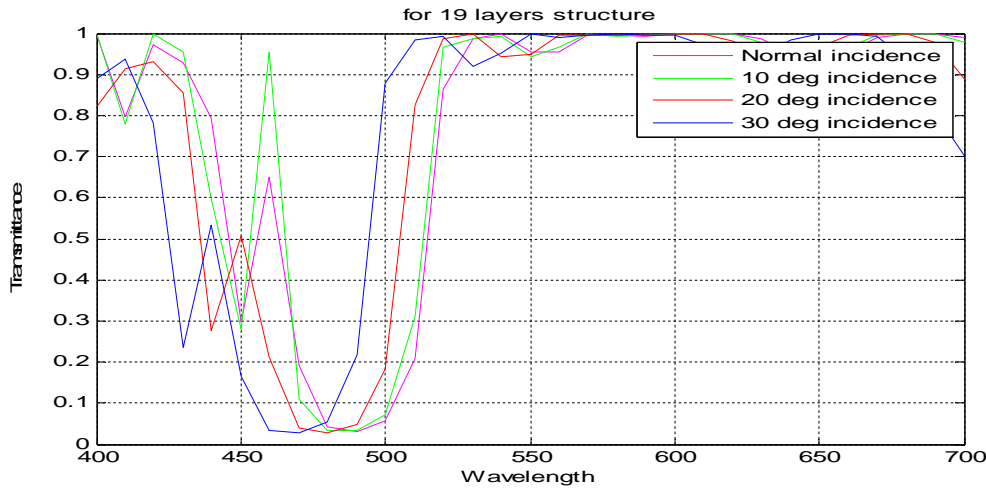
Fig(3) Spectral Response of 11 layers BPF at different angles of incidence

Figure 4 shows spectral Response of NBP filter configuration with 19 layers and 1 cavity for a filter configuration 'substrate/ LHLHLHLHL (2nH) LHLHLHLHL / cover' and a pass wavelength of 480nm.

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Fig(4) Spectral Response of 19 layers BPF at different angles of incidence

It is observed that in case of both the structures, as angle of incidence increases, pass wavelength shifts to lower values, which indicates that this type of configuration can be used as tunable filter for wavelength 400-700 nm. Table 2 gives the corresponding values of the wavelength of minimum loss due to reflection.

It is observed from figures (3) and (4) that, at a tilt of 20 degree incidence, the minimum loss due to reflection occurs at the pass wavelength for which the filter is designed i.e. 480 nm. As the angle of incidence decrease, the passband shifts to higher wavelengths such as 485nm at a tilt of 10 degree and 490 nm at normal incidence. As the angle of incidence increases, the passband shifts to shorter wavelengths such as 470 nm at a tilt of 30 degree. Thus, the filter can be made tunable.

Angle of incidence	Wavelength(nm)
0	490
10	485
20	480
30	470

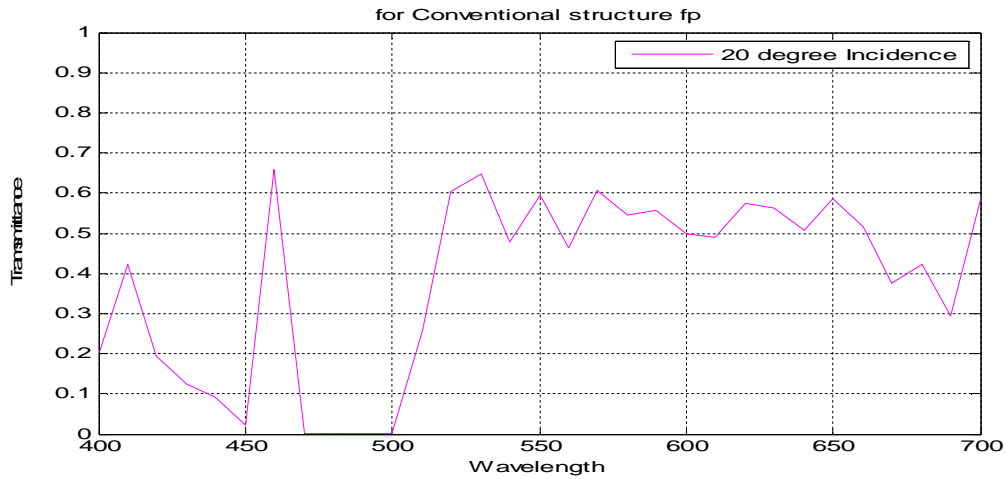
Table (2) Shift of Wavelength at lower values as incident angle increases for 11 layers and 19 layer structures

Figure (5) shows the spectral response of filter configuration under conventional design method [8] with a configuration of (1H 1L 1H 1L 1H 1L)3 2H (1L 1H 1L 1H 1L 1H)3 1L (1H 1L 1H 1L 1H 1L)3 2H (1L 1H 1L 1H 1L 1H)3 1L (1H 1L 1H 1L 1H 1L)3 2H (1L 1H 1L 1H 1L 1H)3 .26569H 1.30674L. It is observed that the pass band is comparatively larger ranging from minimum wavelength of 470 nm to maximum wavelength of 500 nm. This filter behaves as a broadband filter.

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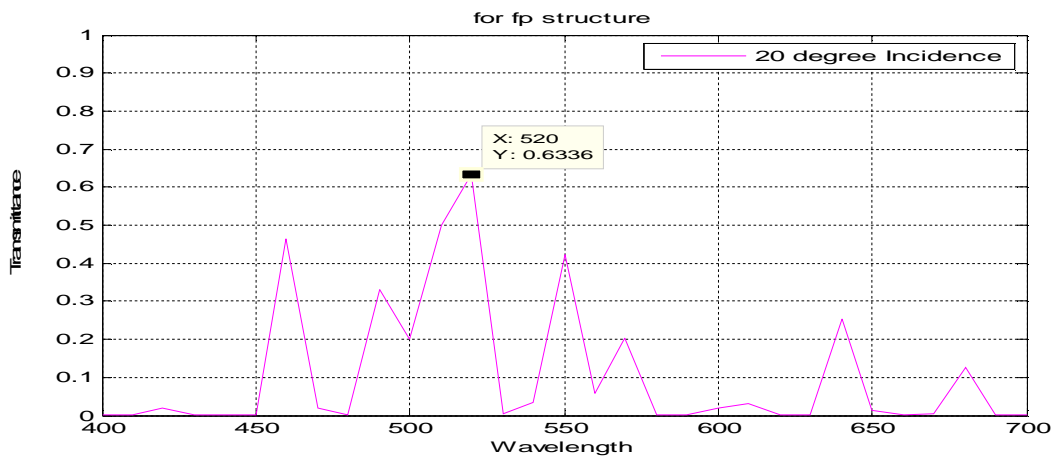
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Fig(5) Spectral Response of conventional method design

In contrast, the spectral response of Fencepost method design of filter (.2H 1.8L)9 .2H 2.75L .2H (1.8L .2H)9 1.74L (.2H 1.8L)9 .2H 2.75L .2H (1.8L .2H)9 1.74L (.2H 1.8L)9 .2H 2.75L .2H (1.8L .2H)9 1.8L shown in figure (6) has the minimum loss due to reflection at various dispersed values of pass wavelength .



Fig(6) Spectral Response of Fencepost method design

IV. CONCLUSION

Mathematical expressions have been given for the improved design of a tunable optical filter device made up of alternating layers of MgF₂ and Ta₂O₅ for whole visible spectral range (400nm-700nm). The optical interference effect on the transmission characteristics of the filter is demonstrated in terms of parameters such as FWHM or 3-dB bandwidth and Quality factor are calculated. We have carried out a comparative study of the spectral response of the optical filter for different number of layers, conventional design and fencepost design. Also, a variation in the wavelength of minimum loss due to reflection is observed for different angle of incidence. Increasing angle of incidence from normal to 30 degree shows shift of wavelength at lower values. Thus, by varying the angle of incidence, the filter can be made tunable. Extensive research and development efforts are underway to realize such tunable filters in the visible region experimentally, since such a device may serve as one of the basic building blocks in display and sensor devices which in turn are used in the field of life science, imaging, industrial, or defense industries. Furthermore, graded index structure of the materials can be analyzed to obtain enhanced filter characteristics.

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