International Journal of Photonics.
ISSN 0974-2212 Volume 5, Number 1 (2013), pp. 13-19

http://www.irphouse.com

Design and Analysis Narrowband Filters

Gaillan H. Abdullah*, ElhamJasim Mohammad, and Anaam Musa HadeeAbud****

**Ministray of Science & Technology Materials Chemistry & Physics Directorate*
***Al-Mustansiriyah University, Collage of Sciences, Physics Department*
E-mail: elham.jasim@yahoo.com

Abstract

In this paper three designs band-pass filter with different number of layers are presented. These designs are concerned with a theoretical study on optoelectronics physics to design and analyze band-pass filter. These designs consist of two materials TiO_2/SiO_2 as high/low index. The wavelength range from (600-850)nm and the design wavelength (700)nm. The results show that the effects of angle of incident on the characteristics curve transmission vs. wavelength for each design. The resulting design approach to push pulse durations further into the single-cycle regime.

Index Terms: Narrow band-pass filter, Fabry-Perot interferometer, Half width, Transmission.

Theory of Narrow Bandpass Filters

The basic design of narrow band-pass filter is constructed on the Fabry-Perot Interferometer. It belongs to the class of interferometers known as multiple-beam Interferometers because a large number of beams is involved in the interferometer.

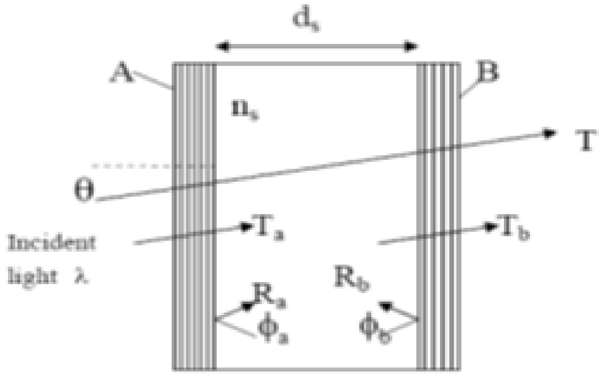

Figure 1: Structure of a Fabry-Perot interferometer [1].

Figure 1 shows the structure of a Fabry-Perot interferometer in diagrammatic form. The Fabry-Perot interferometer consists of two identical parallel reflecting surfaces (A and B) spaced apart a distance d_s, called "*spacer*". In collimated light, the transmission is low for all wavelengths except for a series of very narrow transmission bands in which the half of the central wavelengths are equal to integer times of the optical thickness of the spacer [1].

n_s and d_s are the refractive index and the physical thickness of the spacer. Θ is the incident angle of the collimated light λ is the wavelength of the collimated light ϕ_a and ϕ_b are the phase change of the light on the reflecting surface A and B . T_a and T_b are the transmittances of the reflecting surface A and B . R_a and R_b are the reflectance of the reflecting surface A and B .The amplitude reflection and transmission coefficients are defined as shown. Thebasic theory of the multiple-beam interferometers shows that the transmittance for a plane wave is given by [1]:

$$T = T_{\max} \cdot \left[\frac{1}{1 + F \sin^2\left(\frac{1}{2}(\phi_a + \phi_b) - \delta \right)} \right] \tag{1}$$

Where [2]:

$$T_{\max} = \frac{T_a T_b}{\left[1 - (R_a R_b)^{1/2}\right]^2} \quad , F = \frac{4(R_a R_b)^{1/2}}{\left[1 - (R_a R_b)^{1/2}\right]^2} \quad , \delta = \frac{2\pi}{\lambda} n_s d_s \cos\theta$$

.

Equation (1) propounds some information of a Fabry-Perot interferometer. The analyses are as follows [2]:

Bandpass Filters Mathematical Analyses

Central Wavelength

Because of the reflectance's of the reflecting surface A and B are not zero, the maxima transmission $T = T_{\max}$ are happened when λ is at the central wavelength λ_p ,and relationship is as follows [3]:

$$\phi = \frac{2\pi}{\lambda_p} n_s d_s \cos\theta - \frac{\phi_a + \phi_b}{2} = m\pi, \qquad m = 0, \pm 1, \pm 2, \pm 3, ... \tag{2}$$

So, the central wavelengths are given by [3]:

$$\frac{1}{\lambda_p} = \frac{1}{2 n_s d_s \cos\theta}\left(m + \frac{\phi_a + \phi_b}{2\pi} \right) \tag{3}$$

If $\phi_a = \phi_b = 0$, the central wavelength of the filter is only dependent on the optical thickness of the spacer layer and the angle of incident. When changing the angle of incident, the central wavelength of the filter will therefore be shifted to the shortwave side of the central wavelength [3].

Half Width of Pass Band

Normally, the definition of the halfwidth of pass band is the width of the band measured at half the peak transmission. Now let the pass bans be sufficiently narrow, with F being sufficiently large, so that near a peak we can replace [3]:

$$\sin^2\left(\frac{1}{2}(\phi_a + \phi_b) - \delta\right) \text{ by } (\Delta\delta)^2 \tag{4}$$

The halfwidth can be found by noting that at the half-peak transmission points [3]:

$$\frac{1}{2} = \frac{1}{1 + F\sin^2\left(\frac{1}{2}(\phi_a + \phi_b) - \delta\right)} \approx \frac{1}{1 + F(\Delta\delta)^2} \tag{5}$$

So, we get the halfwidth of the pass band [3]:

$$2\Delta\delta = \frac{2}{\sqrt{F}} \text{ or } \Delta\lambda_h = \frac{2\Delta\delta}{m\pi}\lambda_p = \frac{2}{m\pi\sqrt{F}}\lambda_p \tag{6}$$

If the reflecting surfaces are symmetric, we have $R_a = R_b = R_s$. So [3], $\Delta\lambda_h = \frac{(1 - R_s)}{m\pi\sqrt{R_s}}\lambda_p$.

To reduce the halfwidth of the pass band, we can ether use high order of m (increase the thickness of the spacer) or increase the reflectance of the reflecting surfaces.

Maximum Transmittance

If the reflectance's and transmittances of the two surfaces are equal, and let them be R_s and T_s,then the maximum transmittance can be written as [2]: $T_{max} = \frac{T_s^2}{[1 - R_s]^2}$.

When absorption is neglected in the reflecting coating, the maximum transmittance should be equal to 1. However, if the absorption $A = 1 - T_s - R_s$, the maximum transmittance should be written as follows [2]:

$$T_{max} = \frac{T_s^2}{[1 - R_s]^2} = \frac{T_s^2}{[1 - (1 - T_s - A)]^2} = \frac{1}{\left(1 + \frac{A}{T_s}\right)^2} \tag{7}$$

So, the absorption will decrease the maximum transmittance of the filter. Besides, if the reflectance's and transmittances of the two surfaces are unequal and the absorptions are negligible, the maximum transmittance of the filter can be written as follows [2]:

$$T_{\max} = \frac{T_a T_b}{\left[1-(R_a R_b)^{1/2}\right]^2} = \frac{T^2(T_s+\Delta)}{\left[1-(R_s(R_s-\Delta))^{1/2}\right]^2} = \frac{T_s(T_s+\Delta)}{\left(1-R_s\left[1-\frac{1}{2}\left(\frac{\Delta}{R_s}\right)+........\right]\right)^2} \quad (8)$$

Where: $R_a = R_b - \Delta = R_s - \Delta, \quad T_a = T_b + \Delta = T_s + \Delta, \Delta \langle\langle R_s$ and $R_s + T_s = 1$.

So, when the reflectance of the two surfaces are unequal, the maximum transmittance of the filter will decrease [2-4]:

$$\approx \frac{T_s^{\,2}}{(1-R_s)^2} \frac{1+\frac{\Delta}{T_s}}{\left[1+\frac{1}{2}\left(\frac{\Delta}{T_s}\right)\right]^2} \approx (1+\frac{\Delta}{T_s})(1-\frac{\Delta}{T_s}) \approx 1-(\frac{\Delta}{T_s})^2 \langle 1 \quad (9)$$

Simulation Result and Discussion

A narrow band-pass filter has high transmittance in a narrow wavelength region (λ_1 to λ_2) and high rejection (low transmittance high reflectance) in all other wavelength regions ($\lambda \rangle \lambda_1$ and $\lambda \rangle \lambda_2$). The transition from the rejection regions to the pass-band should be as rapid as possible (square band-passes). Narrow band-pass filters consist in general of two parts:

1. A design which generates the actual narrow band-pass characteristic (transition from low to high transmittance band, a high transmittance band, and the transition from high to low transmittance).
2. Blocking filters which provide rejection in wavelength regions where, due to their periodic nature, the narrow band-pass designs have high transmittance zones [2-6].

The most common structure for narrow band-pass filters (multi-cavity band-pass filters) is an all-dielectric filter consisting of a quarter-wave optical thick layers for the mirrors and half-wave optical thick, or multiple half-wave optical thick layers for the spacers. In this work we will limit ourselves to the design of actual narrow band-passes.

The first design consists of (9) layers, the characteristic design of this filter shows in Figure 2 below. Table 1shows layers thickness as a function of layers materials for TiO_2/SiO_2 as high/low index (2.1 and 1.45). The 2nd design consists of (13) layers andthe characteristic of the transmission curve for this design are shown in Figure 3. While, table 2 shows the constructions parameters. Figure 4 show the last design, it consist of (23) layers. From this design we see the bandwidth is very narrow compared with the tow design above. All the design tested at normal and oblique angle of incidence, therefore the bandwidth shifted to the short wavelengths at oblique angle of incidence. The constriction parameters and characteristics of the 3rd design transmission shows in table 3 below:

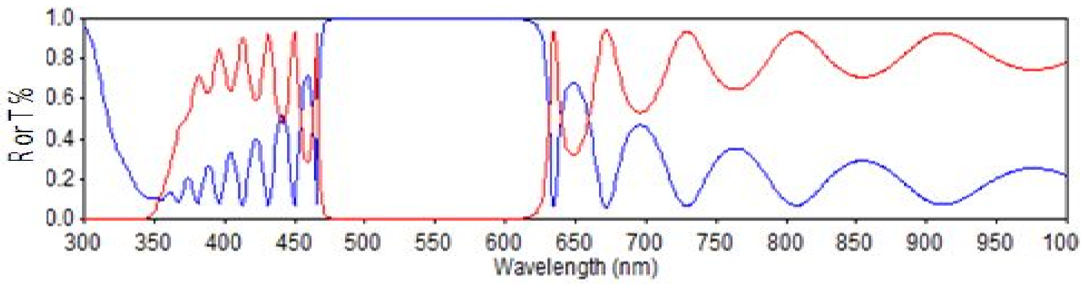

Figure 2: Transmission vs. wavelength for 1st design band-pass filter.

Table 1: Layer structure of 1st design narrow band pass filter.

No	**Materials**	**Thicknesses (nm)**
1	TiO2	76.987
2	SiO2	118.632
3	TiO2	76.987
4	SiO2	118.632
5	TiO2	76.987
6	SiO2	237.263
7	TiO2	76.987
8	SiO2	118.632
9	TiO2	76.987

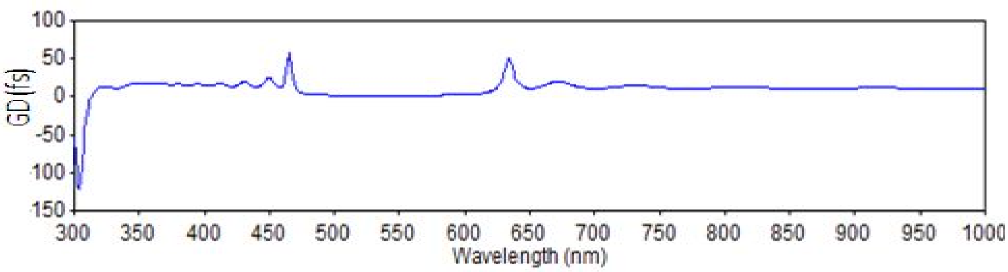

Figure 3: Transmission vs. wavelength for 2nd design band-pass filter.

Table 2: Layer structure of 2nd design narrow band-pass filter.

No.	Materials	Thicknesses (nm)
1	TiO2	76.987
2	SiO2	118.632
3	TiO2	76.987
4	SiO2	118.632
5	TiO2	76.987
6	SiO2	237.263
7	TiO2	76.987
8	SiO2	237.263
9	TiO2	76.987
10	SiO2	118.632
11	TiO2	76.987
12	SiO2	118.632
13	TiO2	76.987

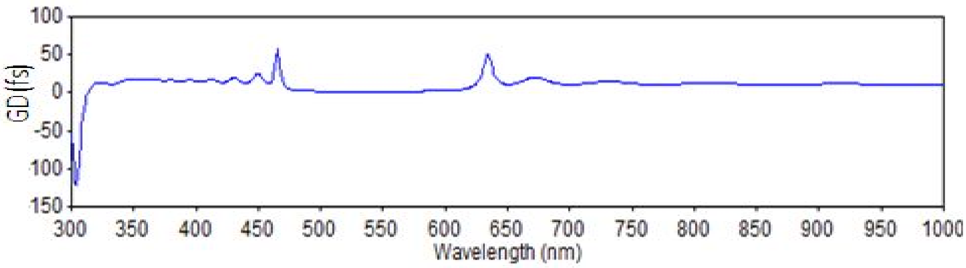

Figure 4: Transmission vs. wavelength for 3ed design band-pass filter.

Table 3: Layer structure of 3rd design narrow band-pass filter.

No.	Materials	Thicknesses (nm)	No.	Materials	Thicknesses (nm)
1	TiO2	76.987	12	SiO2	237.263
2	SiO2	118.632	13	TiO2	76.987
3	TiO2	76.987	15	SiO2	118.632
4	SiO2	118.632	16	TiO2	76.987
5	TiO2	76.987	17	SiO2	118,987
6	SiO2	237.263	18	TiO2	76.987
7	TiO2	76.987	19	SiO2	118.632
8	SiO2	118.632	20	TiO2	76.987
9	TiO2	76.987	21	SiO2	118,987
10	SiO2	118,987	22	TiO2	76.987
11	TiO2	76.987	23	SiO2	118.632

Conclusion

The basic design of narrow band-pass filter is constructed on the Fabry-Perot interferometer. The bandwidth of the multi-cavity filter depends on the ratio of the refractive indices of the materials chosen, the material chosen for the cavity layer and the number of periods in the mirror structures. It also depends on the number of half-wave optical.

References

[1] H. A. Macleod, ″Thin-Film Optical Filters″, 3rdEd. Chap.7, Institute of Physics Publishing, Bristol and Philadelphia, (2001).
[2] A. Thelen, "design of optical interference coatings",McGRAW-HILL Book Company, (1989).
[3] J. S. Seeley,"Resolving power of multi-layer filter", J. Opt. Soc. Am., 54, 342-346, (1964).
[4] P. H. Berning, “Use of equivalent films in the design of infrared multilayer Antireflection coatings”, J. Opt. Soc. Am., 52, 431-436, (1962).
[5] D. Morton, "Design of Multi-Band Square Band Pass Filters", Society of Vacuum Coaters, 505/856-7188 ,moorestown , (2003).
[6] Moreno, J. Araiza and M. Avendano, "Thin-Film Spatial Filters", Optics Letters, 30, 8, 914-916, (2005).