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Design and analysis Narrowband filters

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Abstract

In this peaper 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 These designs consist of two material TiO2 / SiO2 as high / low index. analyze band-pass filter The wavelength range from 600 to 850nm and the design wavelength 700nm. 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.

Keywords: Narrow bandpss filter, Design Narrow bandpass filter

1. Theory of Narrow bandpass filters:

The basic design of narrow bandpass 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) 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].

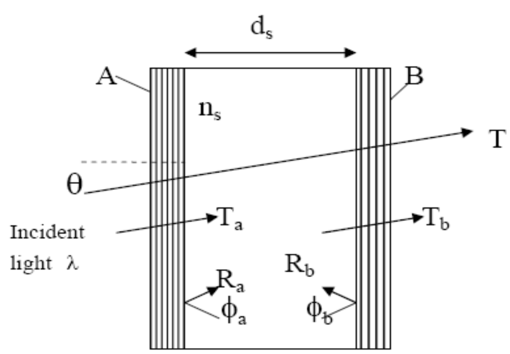

Fig. 1 Structure of a Fabry-Perot interferometer

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

φa and φb are the phase change of the light on the reflecting surface A and B.

Ta and Tb are the transmittances of the reflecting surface A and B.

Ra and Rb are the reflectances of the reflecting surface A and B.

The amplitude reflection and transmission coefficients are defined as shown. The basic theory of the multiple-beam interferometers shows that the transmittance for a plane wave is given by

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

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

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

a- <u>Central wavelength:</u>

Because of the reflectance's of the reflecting surface A and B are not zero, the maxima transmission T=Tmax are happened when λ is at the central wavelength $\lambda_{p,}$ and relationship is as follows.

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

So, the central wavelengths are given by

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

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].

b- Halfwidth 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

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

The halfwidth can be found by noting that at the half-peak transmission points.

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

So, we get the halfwidth of the pass band

$$2\Delta\delta = \frac{2}{\sqrt{F}} \quad \text{or} \quad \Delta\lambda_h = \frac{2\Delta\delta}{m\pi}\lambda_p = \frac{2}{m\pi\sqrt{F}}\lambda_p. \quad (4)$$

If the reflecting surfaces are symmetric, we have $R_a = R_b = R_s$. So,

$$\Delta\lambda_h = \frac{(1 - R_s)}{m\pi\sqrt{R_s}}\lambda_p. \quad (5)$$

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.

c- **Maximum transmittance:**

If the reflectance's and transmittances of the two surfaces are equal, and let them be Rs and Ts,then the maximum transmittance can be written as,

$$T_{max} = \frac{T_s^{\,2}}{[1-R_s]^2} .$$

When absorption is neglected in the reflecting coating, the maximum transmittance should be equal to 1. However, if the absorption A is equal to (1-Ts-Rs), the maximum transmittance should be written as follows,

$$T_{max} = \frac{T_s^{\,2}}{(1-R_s)^2} = \frac{T_s^{\,2}}{[1-(1-T_s-A)]^2} = \frac{1}{\left(1+\frac{A}{T_s}\right)^2} . \qquad (6)$$

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,

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

$$\approx \frac{T_s^{\,2}}{(1-R_s)^2}\frac{1+\frac{\Delta}{T_s}}{\left[1+\frac{1}{2}\left(\frac{\Delta}{T_s}\right)\right]^2} \approx (1+\frac{\Delta}{T_s})(1-\frac{\Delta}{T_s}) \approx 1-(\frac{\Delta}{T_s})^2<1 \qquad (7)$$

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

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

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2. Design concept and discussion:

A narrow bandpass 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 ($\lambda < \lambda_1$ and $\lambda > \lambda_2$). The transition from the rejection regions to the psssband should be as rapid as possible (square bandpasses). Narrow bandpass filters consist in general of two parts:

1. A design which generates the actual narrow bandpass 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 bandpass 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 consist of (9) layers table (1) below shows layers thickness as a function of layers materials for TiO2 / SiO2 as high / low index (2.1 & 1.45). The analysis of the design using openfilter software [7].

Table (1) layer structure of 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

The characteristic design of this filter shows in figure (2) below.

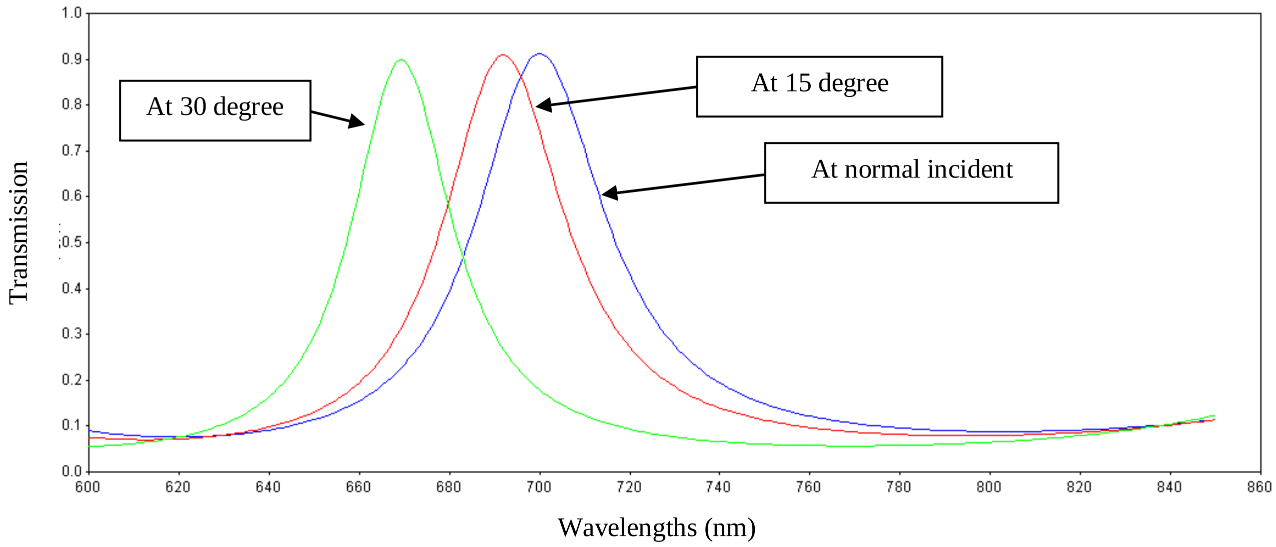

Fig. (2) Transmission vs. wavelength for design band pass filter.

The other design consists of 13 layers, below the table (2) of constructions parameters and the characteristic of the transmission curve for this design.

Table (2) layer structure of 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

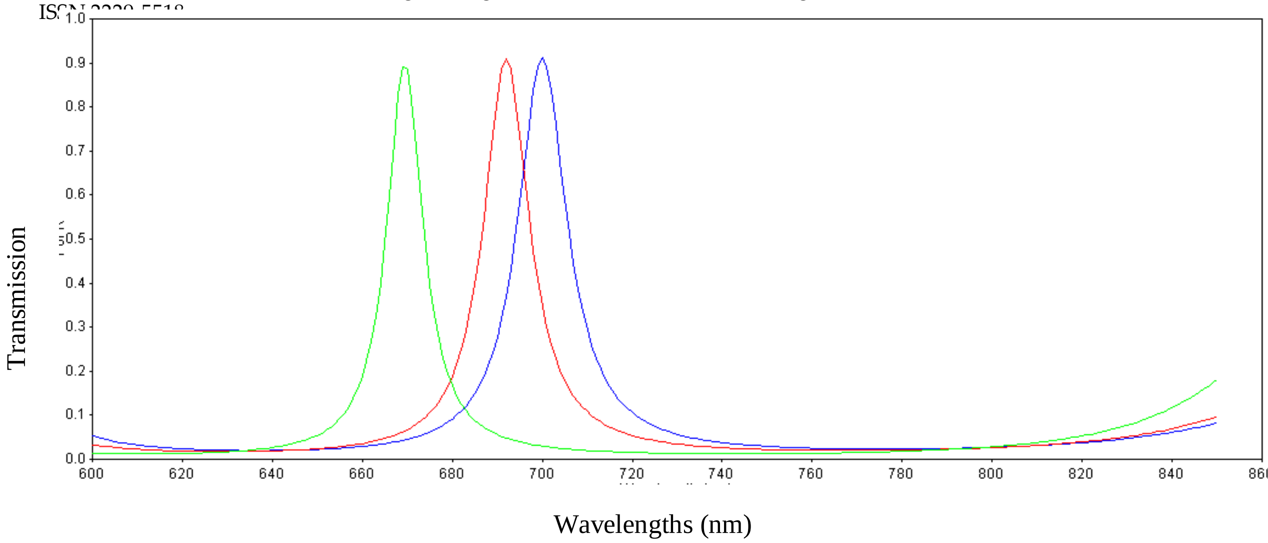

Fig. (3) Transmission vs. wavelength for design band pass filter.

Another design consist of (23) layers the constraction parameters and characteristics of the transmission design shows in table (3) below. 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.

Table (3) layer structure of 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
10	SiO2	118,987
11	TiO2	76.987
12	SiO2	237.263
13	TiO2	76.987
15	SiO2	118.632
16	TiO2	76.987
17	SiO2	118,987
18	TiO2	76.987
19	SiO2	118.632
20	TiO2	76.987

21	SiO2	118,987
22	TiO2	76.987
23	SiO2	118.632

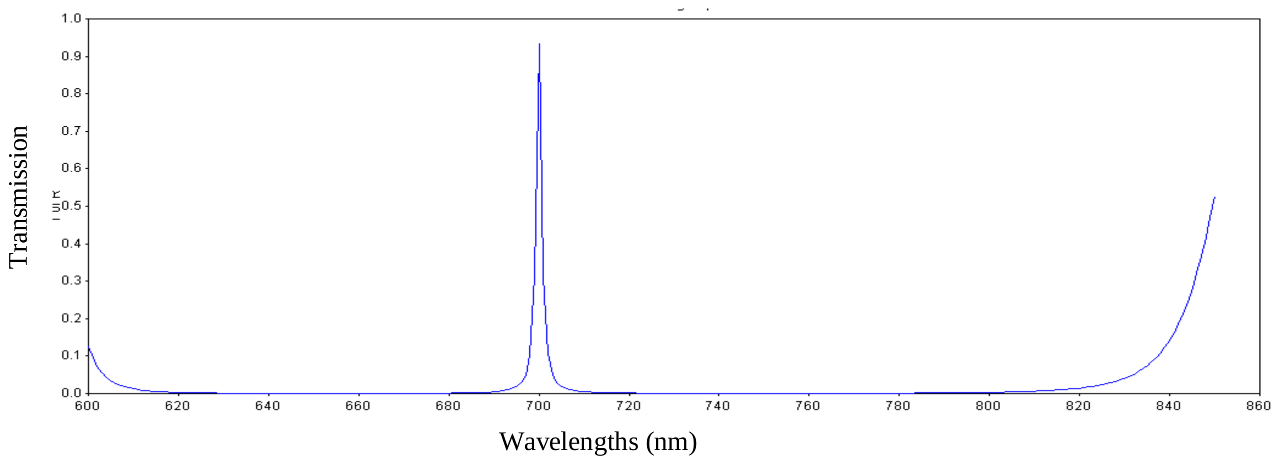

Fig. (4) Transmission vs. wavelength for design band pass filter.

3. Conclusion:

The basic design of narrow bandpass filter is constructed on the Fabry-Perot interferometer. The bandwidth of the multi-cavity (MC) 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 thick layers in the spacers.

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