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Optimization Design of Band Pass Filter in The Infrared Region

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ABSTRACT

In the present work theoretically optimization design of wide and narrow band pass filters have been suggested over the range (1300-1800 nm.) within infrared (IR) region to use in modern optical laser system. These design based on quarter-wave stack, for the numerical calculation, we used glass as the substrate, Zinc sulfide (ZnS) as and Cryolite (Na3AlF6) as high and low refractive index respectively. For the normal incidence at the wavelength design 1550 nm, the results shows that the transmittance for the suggested design, (A / (HL) (HH)(LH) L(HL) (HH)(LH) / S), was (99.18). Also the number of order and the effect of incidence angle were investigated. The results shows when the number of order increase, the transmittance increase and the full width at half maximum decreases, while when the angle of incidence increase the transmittance will decreases with shifting of wavelength design toward shorter wavelengths of electromagnetic spectrum.

Keywords: Coating Filter, Band pass Filter, Infrared Region

1.INTRODUCTION

A filter which possesses a region of transmission bounded on either side by regions of rejection is known as a band-pass filter. Band-pass filters can be very roughly divided into broadband-pass filters and narrowband-pass filters. There is no definite boundary between the two types and the description of one particular filter usually depends on the application and the filters with which it is being compared [1]. The most complete information on the performance of a filter is provided by spectral transmittance (T), reflectance (R), absorbance (A), and optical density [2]. By a careful choice of the exact composition, thickness, and the number of coating layers, it is possible to extend the reflectance and transmittance of the coating to produce almost any desired characteristic [3]. Single cavity band pass filters have a triangular shape with high transmission at the center wavelength of the spacer. The bandwidth of the filter is determined by the relative indices of the materials, the material chosen for the spacer layer and the number of layers, or periods, in the mirror structures [4]. Multilayer coatings are necessary to produce antireflection (AR) systems, several thin film deposition techniques such as thermal oxide growth, vacuum sputtering, can be used to produce the multilayer stacks. Most of these methods allow the production of high quality interference filters but the production costs are relatively high [5]. Band pass filters (BPF) are key devices in communication systems [6]. Band pass filters serve a variety of functions in communication, radar and instrumentation subsystems. Of the available techniques for the design of band pass filters, those techniques based upon the low pass elements of a prototype filter have yielded successful results in a wide range of applications [3]. The aim of this work is to Design band pass filters and calculate transition for suggestion designs using computer program (mat lab 7) .

2. THEORETICAL BASIS

Suppose that a plane electromagnetic wave with wave-vector **k** and electric field amplitude $\mathbf{E}_0$ is incident on a plane surface separating isotropic mediawith refractive indices n_1 and n_2.At normal incidence, the reflection and transmission coefficients are given by[7,8]:

$$r = \frac{n_1 - n_2}{n_1 + n_2} \qquad (1)$$

The reflectance given by:

$$R = rr^* = |r|^2 \qquad (2)$$

$$R = \left(\frac{n_1 - n_2}{n_1 + n_2}\right)\left(\frac{n_1 - n_2}{n_1 + n_2}\right)^* \qquad (3)$$

The reflectance of an assembly of thin films is calculated through the concept of optical admittance we replace the multilayer by a single surface which presents an admittance Y, which is the ratio of the total tangential magnetic and electric fields and is given by

$$Y = {}^{C}/_{B} \qquad (4)$$

Where

$$\begin{bmatrix} B \\ C \end{bmatrix} = \left\{\prod_{r=1}^{q} \begin{bmatrix} \cos\delta_r & (i\sin\delta_r)/\eta_r \\ i\eta_r \sin\delta_r & \cos\delta_r \end{bmatrix}\right\} \begin{bmatrix} 1 \\ \eta_m \end{bmatrix} \qquad (5)$$

$\delta_r = 2\pi N d\cos\theta/\lambda$ andη_m = *substrate admittance*.Where η_r tilted optical admittancewhich is given by:

$$\eta_r = \frac{N\gamma}{\cos\theta} \text{ for } p-\text{waves}, \eta_r = N\gamma\cos\theta \text{ for } s-\text{waves}$$

$\gamma$is the optical admittance of free space ,N is therefractive index. The order of multiplication is important. If qis the layer next to the substrate then the order is

$$\begin{bmatrix} B \\ C \end{bmatrix} = [M_1][M_2]\ldots[M_q]\begin{bmatrix} 1 \\ \eta_m \end{bmatrix} \qquad (6)$$

M_1Indicates the matrix associated with layer 1, as in the case of a single surface, $\eta_0$must be real for reflectance and transmittance to have a valid meaning. With that proviso, then [1]

$$R = \left(\frac{\eta_0 B - C}{\eta_0 B + C}\right)\left(\frac{\eta_0 B - C}{\eta_0 B + C}\right)^* \quad (7)$$

This concept is used to calculate the reflectance of an assembly of thin films and the transmittance and derived through the relationship of (T=1-R), the expression for transmittance and phase changes on reflection are given respectively as follow [1]:

$$T = \frac{4\eta_0 \, Re(\eta_m)}{(\eta_0 B + C)(\eta_0 B + C)^*} \quad (8)$$

3. RESULTS AND DISCUSSION

Figure (1) shows Transmittance of faction of weave length of normal incident for the suggestion designs. This suggestion design Implemented on MATLAB program, this program depends on refractive index of materials (coating) and number of layers, where H and L are materials with high and low refractive index. For the numerical calculation, we used two coatings, the first coating consist from glass with refractive index (n=1.52) as the substrate, we used Zinc sulfide (ZnS) as the high refractive index (n=2.35) and Cryolite (Na_3AlF_6) as low refractive index (n=1.35). The second coating consist from fused silica with refractive index (n=1.44) as the substrate, we used (Ta_2O_5) as the high refractive index (n=2) and (SiO_2) as low refractive index (n=1.46).
We can see from thefigure (1 a, 1 b), the transmittance in Increase when the number of layers in Increase.

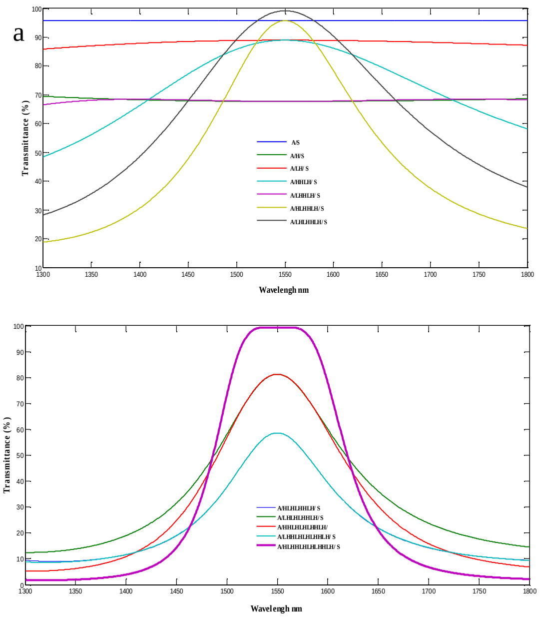

Figure1:Transmittance as a function of wavelength at normal incidence for coating n(ZnS)=3.35, n(Na_3AlF_6)=1.35 and n(glass)=1.52 for many designs until getting to design A / (HL) (HH)(LH) L(HL) (HH)(LH) / S.

Figure2(a , b) shows the Transmittance at faction of weave length of normal incident for the designs.A / (HL) (HH)(LH) L(HL) (HH)(LH) / Swith other coating (material) which are n(Ta_2O_5)=2n(SiO_2)=1.44 andn(fused silica)=1.46. Table 1 show the results obtained from Figures 1 and 2 ,From the results obtained from figure (1) , (2) andthe results in table 1 we can find the best design using the materialn(ZnS)=3.35, n(Na_3AlF_6)=1.35 and n(glass)=1.52.

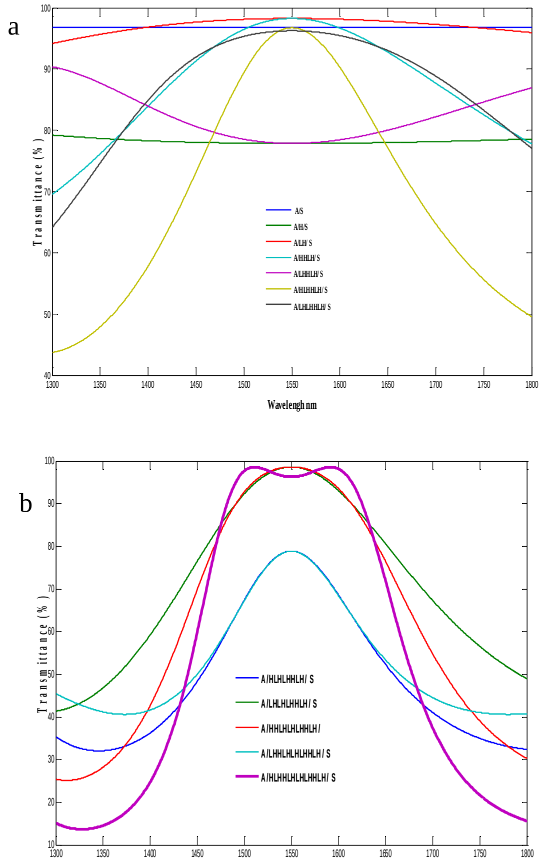

Figure 2:Transmittance as a functionof wavelength at normal incidence for coating n(Ta_2O_5)=2, n (SiO2) =1.44 and n(fused silica)=1.46 for many designs until getting to design A / (HL) (HH)(LH) L(HL) (HH)(LH) / S

Table 1: Transmittance forsuggestion designs with two Coating

Coating(material)	Design	Transmittance (%)	FWHM (nm)
the substrate glass=1.52 Zinc sulfide (ZnS)=2.35 Cryolite Na_3AlF_6	A / (HL) (HH)(LH) L(HL) (HH)(LH) /A	99.18	137
The substrate fused silica=1.44 (Ta_2O_5)=2 (SiO_2)=1.46		96.25	238

Now we take the suggestion design (A / (HL) (HH)(LH) L(HL) (HH)(LH) / S)and change the number of layers order (N) to know the effect on the transmittance and Bandwidth. From figure 3 we find the transmittance in Increase when the number of layers in Increase and the Bandwidth decrease when the number of layers in Increase.

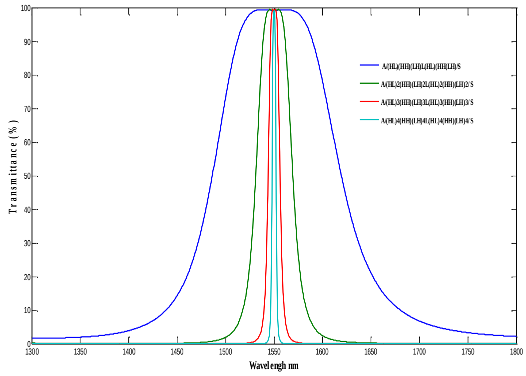

Figure 3: Transmittance as a function of wavelength at normal incidence forfour designs:

(1) $A / (HL)\ (HH)(LH)\ L(HL)\ (HH)(LH) / S$

(2) $A / (HL)^2 (HH)(LH)^2\ L(HL)^2\ (HH)(LH)^2 / S$

(3) $A / (HL)^3 (HH)(LH)^3\ L(HL)^3\ (HH)(LH)^3 / S$

(4) $A / (HL)^4 (HH)(LH)^4\ L(HL)^4\ (HH)(LH)^4 / S$

Effect of order change on transmittance and full width at half maximum (FWHM) for the suggestion design $A / (HL)^N(HH)(LH)^N\ L(HL)^N\ (HH)(LH)^N / S$.

From figure (3)showswhen the order increasesthe transmittance increases and the Full width at half maximum (FWHM) decreases.From results opting from figure 3 as shown in table 2 we canfine thesuggested design wide and narrow band pass filter depending onfull width at half maximum.

The most common technology for performing such a task uses optical interference filters [1]. Such filters are obtained by optical coating technology, i.e.deposition of a sequence of low and high refractiveindex materials on top of a substrate. However, in order to achieve complex functions with high efficiencies, it is required to deposit several hundreds of layer resulting in very thick stacks which arevery sensitive to errors of depositions [9].

Table 2: Suggestion designs of band pass filter

Design number	Design	Transmittance (%)	FWHM (nm)
1	A / (HL) (HH)(LH) L(HL) (HH)(LH) / S	99.18	137
2	A / (HL)^2 (HH)(LH)^2 L(HL)2 (HH)(LH)^2 / S	99.18	38
3	A / (HL)^3(HH)(LH)^3 L(HL)^3 (HH)(LH)^3 / S	99.21	12
4	A / (HL)^4 (HH)(LH)^4 L(HL)^4 (HH)(LH)^4 / S	99.35	4

At normal incidence, the filter reflects S and P polarized light equally. We choose two designs for studying the effect of the change of the incident angle on the Transmittance as a function of wavelength, thefirst is Narrow Band and the second is wide-Band Filter.

Now we take the suggestion designwideband pass filter $(A / (HL)\ (HH)(LH)\ L(HL)\ (HH)(LH) / S)$ and studying the effect of the change of theincident angle on theTransmittance as a function of wavelength, from figure 4 and 5 we find when the incident angle increases we can discrimination between a typical polarization (magnetic polarization (TM) and electric Polarization (TE)). When theincident angle increase the magnetic polarization (TM) increases and the electric Polarization (TE) decreases depending on the phase thickness as equation $(\delta_r = 2\pi N d \cos\theta / \lambda)$

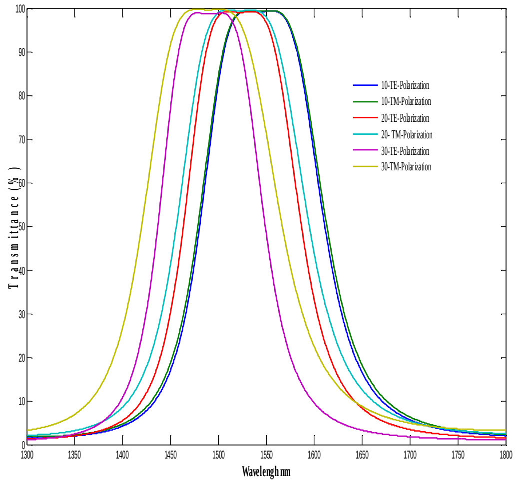

Figure 4: Transmittance as a function of wavelength at incident angle (10° , 20° and 30°) forfour designs: $A / (HL)\ (HH)(LH)\ L(HL)\ (HH)(LH) / S$

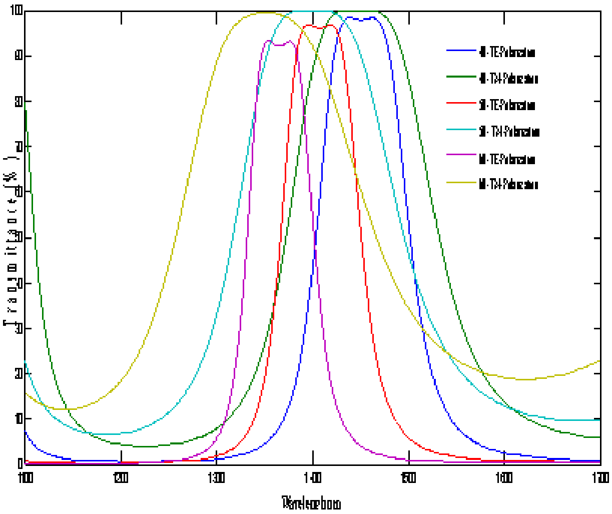

Figure 5: Transmittance as a function of wavelength at incident angle (40°, 50°, and 60°) forfour designs: $A / (HL)\ (HH)(LH)\ L(HL)\ (HH)(LH) / S$

Now we take the suggestion designnarrow band pass filter depending on Full width at half maximum $A / (HL)^3 (HH)(LH)^3\ L(HL)^3\ (HH)(LH)^3 / S$, from figure 6 and 7 we find also when the incident angle increases we can discrimination between a typical polarization magnetic polarization (TM) and electric Polarization (TE)). When theincident angle increase the magnetic polarization (TM) increases and the electric Polarization (TE) decreases depending on the phase thickness as equation ($\delta_r = 2\pi N d \cos\theta/\lambda$) Table 3 shows the effect of the incidence angle in transmittance as a function of wavelengthInterference filters decreases as the angle of incidence increases.

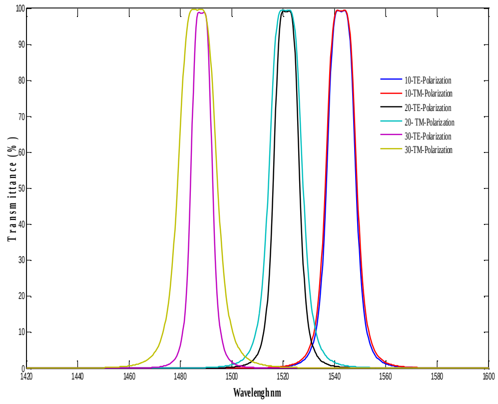

Figure 6: Transmittance as a function of wavelength at incident angle (10°, 20° and 30°) forfour designs $A / (HL)^3 (HH)(LH)^3 L(HL)^3 (HH)(LH)^3 / S$

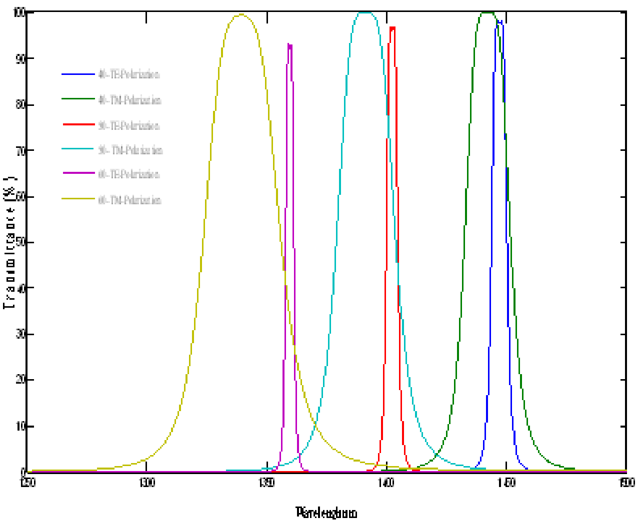

Figure 7: Transmittance as a function of wavelength at incident angle (40°, 50°, and 60°) forfour designs: $A / (HL)^3 (HH)(LH)^3 L(HL)^3 (HH)(LH)^3 / S$

The primary effect of an increase in the incident angle on an interference coating is a shift in spectral performance toward shorter wavelengths. In other words, the principal wavelength of all types of interference filters decreases as the angle of incidence increasesas show in Figures (4, 5, 6 and 7).

We obtain a high Transmittance by increases the number of layers, we use incident angle as a variable,as the incident angle increases, the admittance of magnetic polarization (TM) increases and that of electric Polarization (TE) decreases , So the Transmittance bandwidth of TM polarization is wider than that at normal incidence, and that of TE polarization is narrower..

Table 3: Suggestion designs of band pass filter for incident angle (10° ,20° , 30°,40°,50° and 60°)

Design number	Design	incident angle	Transmittance (%) TE	Transmittance (%) TM
1	A / (HL) (HH) (LH) L (HL) (HH) (LH) / S	10	99.27	99.33
		20	99.17	99.45
		30	98.86	99.67
		40	98.04	99.88
		50	96.1	100
		60	92.13	99.39
2	A / $(HL)^3$ (HH) $(LH)^3$ L $(HL)^3$ (HH) $(LH)^3$ / S	10	99.24	99.24
		20	99.23	99.54
		30	98.96	99.7
		40	98.31	99.99
		50	96.84	100
		60	92.67	99.44

4. CONCLUSION

Theoretically optimization design of wide and narrow band pass filters have been suggested over the range (1300-1800 nm.) within infrared (IR) region to use in modern optical laser system.By using optical material Zinc sulfide (ZnS) and Cryolite (Na_3AlF_6) as a low and high refractive index respectively to coated glass as a substrate. The results shows that, the transmittance 99.18 % for the design (A / (HL) (HH) (LH) L (HL) (HH) (LH) / S)and 99.21% for the design $A(HL)^3 (HH)(LH)^3 L(HL)^3 (HH)(LH)^3 / S$. the results of angle incidence effect on filter shows shift in reference wavelength to toward the shorter wavelengths of electromagnetic spectrum with an increase of incident angle. Also ,when the incident angle increase the transmittance of P- polarization increase with increase in the full width at half maximum while the transmittance of S- polarization decrease with decrease in the full width at half maximum.

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