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Effect of Adding an Outer Layer on the Optical Performance of a Fabry-Pérot Filter at Oblique Incidence in the Thermal Infrared Region

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Abstract

The paper examines the design of a Fabry-Perot filter constructed of dielectric materials with varying reflecting indices in the (8-12 μm) range. for the oblique incidence of light using a modified characteristic matrix method that adopts analytical methods, specifically at laser CO_2 wavelength ($\lambda_0=10\mu\text{ m}$). To address the issue of non-normal incidences, which is a problem, matching the optical thickness for the layers of the suggested filter was introduced. the spectral shift in the transmission. Without changing the transmission setting, a rise in filter performance was noted. Additionally, the potential for enhancing optical width transmission for the outer layer of design was investigated. The work also demonstrates that high transmission for p- and s-polarization can be achieved by using matching in the optical width in conjunction with widening the outer layer. This exact result disproves the notion that an increase in transmission is not conceivable by demonstrating that this method can be utilized to create narrow-band pass filters that are unaffected by changes in incident angles. Additionally, this design can be used to create omnidirectional high reflectors for angles between 20 and 90 degrees using a quarter-wave dielectric stack.

Keywords

Fabry-Perot Filter,
Quarter-Wave Optical Thickness,
Transmittance,
Matching Method



Introduction

Narrow-band interference filters, which permit a narrow band of wavelengths to pass through with a width of a few nanometers or less, are becoming more important in optical devices that operate in the thermal region because they are thought to be the foundation for designing and producing what is known as "Barak mirrors." Bragg reflectors, also referred to as "Perfect Mirrors" [1], which constitute the main parts of Microcavity Lasers, and are also used in Radiometry Spectral) (which are measures of radiation energy density) installed on satellites as a basic element for separating a narrow beam of wavelengths of up to a few nanometers or less without the need to use elements of dispersion (such as prisms or gratings).

Gratings. In addition to using the laser communications field to tune a wave the laser used (Wavelength Laser Tuning) and controlling the failure of the communication channels (Channel) Dropping [2]. The study of atmospheric physics, in particular the glow of atmospheric particles for use by Hawass, [3] "Arawana" Yalal (Air Glow Studies of the Atmosphere), Medical Patients, such as the Awn Awthl, [4], is also important. The first candidate with a gap from the scientist GEFCKEN) was chosen in 1939 [5].

This candidate is made up of a filter and another buffer that failed on the Zajaj and represents it (MDM), which was followed in 1944. substituting a stack of insulating materials (Dielectric of Stack) for the silver-half layer. Aside from coming from the physicist layers Geffken [6], where he saw a "significant" enhancement in the materials The numerical method in insulating flap creating a

filter with a Fabry-Pérot filter composed the optical performance of the filter and became known as "All-Dielectric Fabry-Perot Filters" from that point on. Using numerical methods to treat the changes brought on by the change in angles of incidence in addition to passing the narrow beam [7]. According to, the single resonator or several resonators comprise a multi-layer structure that makes up the narrow bandpass filter, in the following order [8]

Incident Medium R1 S R2 Substrate
.....(SHW)

Incident Medium R1 S1 R2 S2 R3
Substrate(DHW)

It has the representation Air IRSR ISub, where the reflectors R denote the multi-layer structure made up of a series of layers stacked in a regular pattern in two shapes $[HL]^S$, $[LH]^S$ where S indicates the basic periodicity of order and H, L indicates a quarter-wave optical thickness. For materials with a high refractive index, n_H , and a low refractive index, n_L , it is determined by the following relationship [9]:

$$n_L d_L = n_H d_H = \lambda_0 / 4$$

The middle layer is also constructed of insulating material, but its optical thickness is (Optical Wave-Half) $(m\lambda_0/2)$, which is half a wavelength.

Optical performance specifications of the Fabry-Perot filter

We can summarize the most important specifications of the optical performance of the Fabry-Perot filter is [10]:

- 1- The transmission value is high T_{peak} .
- 2- The wavelength of the pass beam (λ_0) which corresponds to (T_{Peak}) of the filter with symmetrical behavior of the transmittance spectrum.

3- The width of the passband is represented by the symbol (FWHM) and represents the difference between two wavelengths ($\Delta\lambda$) corresponding to 50% of the high transmittance value.

4- The lowest value of permeability ($T_{\min}$) is called the subtraction zone.

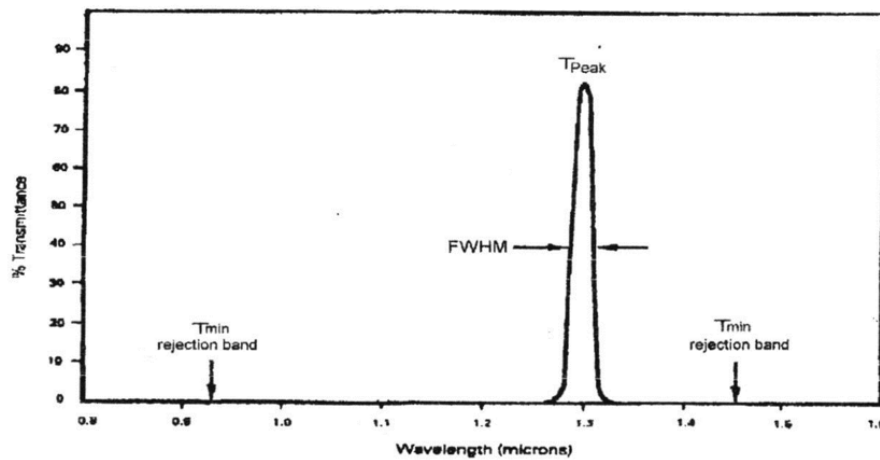


Fig (1): Optical performance specifications of the Fabry - Pérot filter

Mathematical basis

width of a quarter the most basic version of these filters consists of a middle layer (Layer Spacer) made of an insulating substance with an optical wavelength of ($\lambda_0/2$) that separates two reflective heaps with an optical wavelength of ($\lambda_0/4$) for each layer [10,11]. Designing a Fabry-Perot filter with a single of gap thickness is possible. It is made of an intermittently organized insulating substance with n_H and low slant refractive indices. Based on the modified characteristic matrix theory and the vertical incidence situation with light, n_L [10,13].

The reflectivity of each stack on both sides of the middle layer, which in turn depends on the refractive indices of the materials used, determines the transmittance of the Fabry-Pérot filter made of insulating materials, which is used to treat changes brought on by oblique incidence of light. If the spacer index is high, van

$$T = \frac{4n_L^{2x} \cdot n_{sub}}{n_H^{2x+1}} \dots\dots\dots (1)$$

When the middle layer has a low refractive index (Spacer Index-Low), then:

$$T = \frac{4n_L^{2x-1} \cdot n_{sub}}{n_H^{2x}} \dots\dots\dots (2)$$

The two equations take two different forms based on the two polarization patterns - S - and P. Determine the phase thickness of the thin film for the case of inclined incidence with the equation: -

$$\delta = 2\pi n d \cos\theta / \lambda \dots\dots\dots (3)$$

For an ideal Fabry-Pérot filter with an effective or equivalent refractive index n^* , the locations of the appearance of the high transmittance peaks are determined by the condition:

$$\delta = m\pi \dots\dots\dots (4)$$

Where m represents the interference rank, so:

$$2\pi n^* d * \frac{\cos\theta}{\lambda} = m\pi \dots\dots\dots (5)$$

Since λ_0 and λ are related to each other through the wave number g , the above equation can be written in the form:

$$\left(\frac{2\pi n^* d}{\lambda}\right) g \cos\theta = m\pi \dots\dots\dots(6)$$

That is $g \cos\theta = 1$

By performing mathematical simplifications, the lateral displacement in the wavelength of the high transmittance peak is:

$$\Delta g = \left(\frac{1}{\cos\theta} - 1\right) \dots\dots\dots(7)$$

For small incidence angles (Incidence of Angle Small), the amount of displacement becomes:

$$\Delta g = \frac{\Delta v}{v_o} = \frac{\Delta \lambda}{\lambda_o} = \frac{\theta_o^2}{2n^{*2}} \dots\dots\dots(8)$$

The last two equations gain their importance through the possibility of pre- determining the amount of displacement at the wavelengths of the high transmittance peak, based on knowledge of both the angle of incidence and the effective refractive index of the filter n^* .

Results and discussion

Requires design Fabry - Perot filter Within the thermal zone to work (8-12 μm) oblique light falling transmission peak of up to $T_{\text{Peak}} \sim 100\%$ at the chosen design wavelength two subtraction zones of λ_o .

A narrow pass band width of up to ~ 50 nm or less, with a minimum value for the $T_{\text{min}} \sim 0.05\%$ or less. In addition to the weak sensitivity of the transmittance spectrum to changes resulting from the oblique incidence of light. Single-gap filter (SHW) consisting of two materials. Based on Selected filter the above, it was first proposed to design two insulators that achieve a high quantity ratio (n_H/n_L). It was studied for the case of vertical drop, taking into account the effect of the number of layers and their arrangement within the best filter design on the maximum transmittance values. And the width of the beam passing through it to reach the filter, where two materials were used ($n_H = 4.2$) and ($n_L = 2.2$) as materials with a high refractive index and a low one, with an optical thickness of a quarter of a wavelength

$$n_L d_L = n_H d_H = \lambda_o/4$$

, and at the design wavelength $\lambda_o = 10.0\mu\text{m}$ o Deposited on germanium as a basis. Figure (2) shows the transmittance

spectrum versus wavelength for the proposed design, as it becomes clear that it achieves the required specifications, i.e.

$$\left. \begin{array}{l} T_{\text{Peak}} \sim 99.095 \% \\ \text{FWHM} \sim 63 \text{ nm} \\ T_{\text{Min}} \sim 0.180 \% \end{array} \right\} \text{ at } \lambda_o = 10.0\mu\text{m}$$

The effect of changing incidence angles on the transmittance spectrum

was approved, changes in the general behavior of the filter of the proposed filter: **Air I (HL)³ 2L (LH)³ L I sub** After the design were studied when light falls obliquely over a range of angles (0-90) and Figures (2) explain these effects, as we notice that at vertical and near vertical incidence angles (up to ~ 10), The polarization modes S and P have no effect on the filter. The transmittance spectra of the filter can be separated as the angle of incidence rises: (the outer curve) of the polarization mode -P. For the S-polarization pattern, and (Inner curve). with a lateral shift of the S- and P-pattern transmittances away from the main region of the passing beam and in the direction of short wavelengths. The transmittance bandwidth for the S-mode is seen to be decreasing, whereas the bandwidth for the P-mode is clearly increasing. There is also a reduction. With a lesser drop in transmittance at the S-polarization's maximum transmittance value. Figure (2) shows the maximum transmittance spectrum as a function of incidence angles (0-90) $^\circ$ at $\lambda_o = 10\mu\text{m}$ for designing **Air I (HL)³ 2L (LH)³ L I sub** proposed design of this filter as multi-directional reflectors for the range of angles (20-90) after the width of the high reflectivity band is controlled.

Table (1): Optical thickness corresponding angles of incident

Angle of incidence	Optical thickness
20 $^\circ$	1.015 L,H
45 $^\circ$	1.067 L,H
65 $^\circ$	1.098 L,H
85 $^\circ$	1.143 L,H
80o with increase of thickness	1.149 H , 1.0

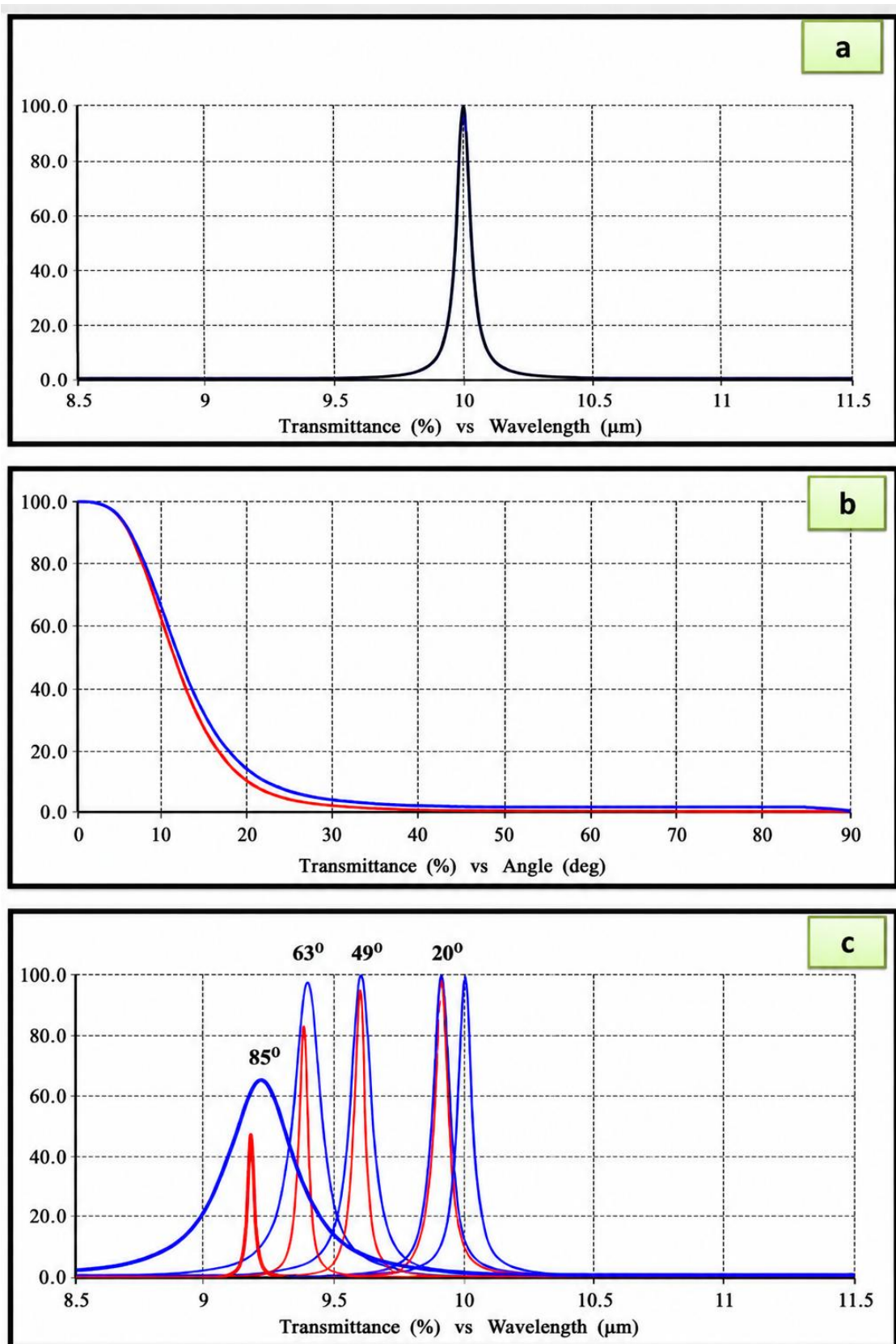


Fig (2): - (a) Transmittance vs wavelength for normal incident (b) Transmittance vs angle (c) effect the angle of incident on Transmittance filter. at design Air | L (LH)³ 2L (HL)³ | Sub

Processing in the transmittance spectrum of the filter

calculating the variations in the maximum transmittance values and the amount of inclined incidence of S and P's two polarization modes' lateral displacement. Since it was suggested to undertake harmonization in the optical thickness of the case of incidence, analytical methods were utilized in a novel approach to handle these changes. By increasing the optical thickness of the material with a low refractive index, the slant is in relation to the normal incidence.

Figures (3) illustrate the effect of increasing the thickness of the material with a low refractive index on the transmittance spectrum in the normal case, where we notice that the shift for the S- and P-polarization modes has been removed. A comparison with the laterality in the transmittance spectrum of the S- and P-polarization modes from each other and from the basic beam location, i.e. the location of the transmittance peak ($\lambda_0 = 10\mu\text{m}$) in addition to eliminating the asymmetry in the transmittance value for the two modes. Table (1) shows the increase in optical thickness. For a material with a low refractive index corresponding to the angles of incidence.

A modification in the optical thickness of the outer layer within the range (from $\lambda_0/4$ to $\lambda_0/2$) was made in order to explore the effects of modifying the outer layer's optical thickness. It becomes evident that, following Harmonization in the optical thickness, it is possible to enhance the transmittance at the design wavelength $\lambda_0 = 10\mu\text{m}$.

Due to the difficulty of processing the transmittance spectrum of the filter and the

high angles, the incidence angle of 85° was chosen (as an example), adopting the design below after introducing the concept of harmonization in the thickness of the layers for the incidence angle of 85° (1.051L, 1.149H). As an initial design to begin treating the effect of the inclined fall by increasing the thickness of the outer layer, where we notice a clear improvement in the transmittance spectrum for the two polarization modes compared to the vertical fall as shown in Figure (3). The resulting design is:

Air 11.88L (1.149H1.051L)³ 2.3L (1.051L 1.149H) | Sub

This study showed that the modified characteristic matrix theory can be used to create narrow-band interference optical filters since the transmittance spectrum has two forms. The fall of the fall has an impact on polarization; the higher the fall of the fall, the more permeable the candidate for as it is noted that it is possible to adopt the shortness in addition to a decrease in the high value of the permeability, polarization styles - S and -p with a side of the possibility from the main site towards the wavelengths are used.

The analytical method (optical thickness matching method), i.e. (increasing the thickness of the layer with a low refractive index only) in addition to changing the thickness of the outer layer of the design as a way to obtain high transmittance at the design wavelength, i.e. removing the effect resulting from the increase in angles of incidence without using numerical methods In addition , it was noted that it is possible to benefit from the proposed design as a multi-directional reflector for a range of incidence angles (20-90).

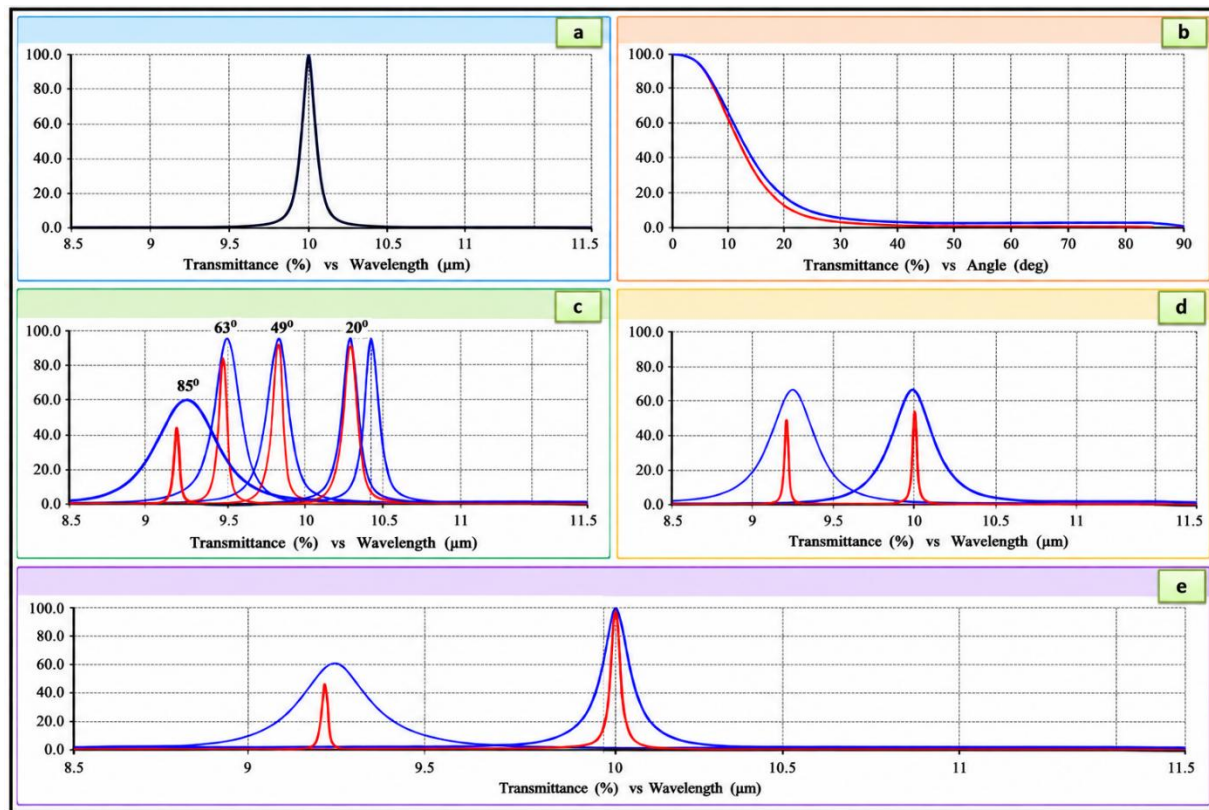


Fig (3): Transmittance of the filter with the design: Air | L (LH)³ 2L (HL)³ | Sub for an angle of incidence Before fitting (light curve), after fitting (dark curve) a- angle of incident (20°) b- angle of incident (45°) c- angle of incident (65°) d- angle of incident (85°) e- The optimal design of the proposed filter as a function of the change in wavelength and the angle of incidence (85°) (the curve on the left) filter design before alignment. (Curve on the right) Optimal filter design (increase in the thickness of the outer layer while matching the thickness of the layers).

Conclusions

By connecting two theorems: equivalent layers and the modified characteristic matrix theory, narrow band pass Fabry-Perot filter interference for the thermal region (8-12 μm), particularly at Co₂ layer wavelength ($\lambda_0 = 10 \mu\text{m}$), can be designed. results indicate that the stop band region around the pass band peak has been enlarged, therefore glass or absorption filters are not necessary.

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