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Numerical Modelling of Edge Filters for (MWIR) (3-5 µm)

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Abstract: ***An efficient and accurate approach called needle technique is proposed for synthesis of edge filters in (MWIR) region. This proposed approach investigated optimal construction stacks of long and short- wave pass edge filters by adopting of its own strategy that based on using a suitable number of layers with controlling the thickness of each layer. The new designs have optimal specifications such as the high transmittance in passband with reducing ripples, appropriate optical performance in stopband, and keeping a severe edge steepness. Results appear that problems of design edge filters are solved by using a few layers and that is significant to overcome the problems of manufacturing.***

Keywords: edge filter, passband, stopband, needle technique, characteristic matrix

1. Introduction

Edge filters generally have a blocked region(called stopband) and transmission region (called passband) . The transition between these bands is the edge. High transmittance in the passband is usually desired [1].

Such filters consist of a number of thin films deposited on substrate, and have the property of being able to reflect some wavelengths and transmit others; the particular range of wavelengths for which a filter is highly reflected or transmitted could be altered by changing the characteristics of the thin films components [2,3,4].

Edge filters are divided into two main groups, long-wave pass (LWP) and short-wave pass (SWP). These filters are widely used for various optical purposes, especially in wavelength division multiplexers (WDM) and multimedia color projection display [5,6].

The analytical (classical) design approach had put design of an edge filters based on eighth-wave stack, that is $[(L/2)\ H\ (L/2)]^S$ and $[(H/2)\ L(H/2)]^S$ where H and L are quarter-wave thickness of high index layer and low index layer respectively [7, 8] .

The increase of the degree of edge steepness and improving it could achieve by using more layers, but increasing the number of layers will increase the ripples in the passband [9]. These ripples in passband is principal deficiency in analytical approach which appear because of the mismatching between the coating materials and the surrounding medium [10,11] .

Ripples are severe and the performance of the edge filter designs would be better if these ripples could be reduced to enhance the transmittance region [7,9] . generally the optical performance of edge filters should has characteristics of the high transmittance without ripples, making the transition from passband to stopband as sharp as possible, is meant to have a severe boundary between wavelength regions that are reflected and those that are transmitted [2,12] .

2. Theory and Numerical Design Method

The problem in design of optical multilayer coatings is to find the construction of systems which satisfy the desired optical specifications [13] . Numerical methods are powerful for the solution of complicated spectral problems and can be applied to the design of coatings with very complicated specifications which requiring a large number of layers for their solution [14,15] .

Refinement method and synthesis method are two widely used categories of numerical methods for optical thin film designs [13,16] . Synthesis method generates its own starting design automatically whilst refinement requires an initial design as a starting solution [17,18].

One of the most commonly synthesis method is the needle technique which we have adopted in this work . Needle synthesis is a powerful method for producing designs with complex performance [19,20] .

The optical performances profiles of numerical synthesis designs are fitted by minimizing a merit function which computes the distance between the desired optical properties and those achieved with the optimized design [21,22] . Widely working merit function is that proposed by Dobrowolski can be defined in the following equation [20,23,24]:

$$MF = \left[\frac{1}{m}\sum_{i=1}^{m}\left[\frac{Q_i^T - Q_i}{\delta Q_i}\right]^k\right]^{\frac{1}{k}}$$

The general formulation of calculating the spectral transmittance and reflectance profile for multilayer structures based on a characteristic matrix . The characteristic matrix approach developed by Abelès was presented in detail in most optical coating textbooks such as Macleod's. The main idea of this approach is matching the E- and H-fields of the incident light on the interfaces of multilayer [25] .

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The characteristic matrix of assembly q thin film layers, simply is the product of individual matrices for the individual layers of assembly taken in the correct order, which is given by [3,26]:

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

where, C and B are normalized total tangential electric and magnetic fields respectively at the input surface.

$$\delta r = 2\pi\, n_r\, d_r/\lambda$$

n_r, d_r are refractive index and physical thickness of layers

q is the number of layers next to substrate.

n_S is the refractive index of the substrate.

$\begin{bmatrix} B \\ C \end{bmatrix}$ is defined as the characteristic matrix of the assembly.

The transmittance of the multilayer system is obtained by following:

$$T = \frac{4 n_0 Re(n_s)}{(n_0 B + C)(n_0 B - C)}$$

$Re(n_s)$ represents to real part of refractive index of substrate

3. Designs and Discussion

In this work, we apply approach depends on the needle optimization as numerical synthesis method to design edge filters for long-wave pass and short-wave pass for mid IR (MWIR) (3-5 μm) and submit new optimal design constructions with utilize a silicon as substrate (Si), and adopted (ZnSe) as a high refractive index material and (MgF_2) as a low refractive index material .

3.1 Short-Wave Pass Filter

Several construction designs of short-wave pass filter are designed . Needle technique submitted new varied designs of (SWP) filter as in Figures (1-3). The optical performance of such designs provided a high transmittance approach to (100%) with completely eliminating the ripples, wide range of transmittance, zero transmittance in stopband through extensive range of wavelengths more than 1200 nm, and retained the steepness of the edge.

Figure (1) shows the optical performance of short-wave pass filter constructed by 26 layers. This is depicted the high transmittance with suppressed the ripples, and very wide stopband .

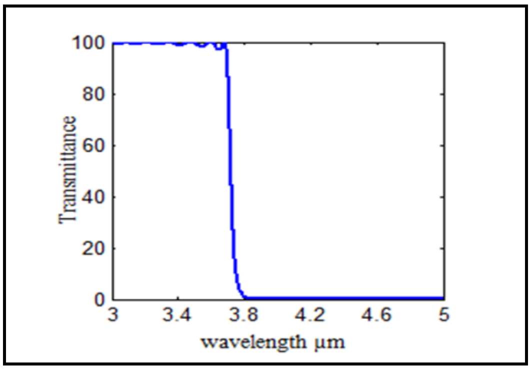

Figure 1: Optical performance of (SWP) designed by needle technique using 26 layers with construction design stack

[1.242L 1.59008373H 0.94144152L 1.06703223H 1.179762L 1.07679777H 1.0116918L 1.02972433H 1.07277198L 1.07874801H 1.0548941L 1.0337467H 1.03588044L 1.05039066H 1.06581264L 1.06337314H 1.04733168L 1.03572323H 1.04522304L 1.06743375H 1.08843084L 1.08926879H 1.004088L 1.0898878H 1.242L 0.32545108H]

Increased the layers with one extra layer to the construction design as shown in Figure (2). It obvious that gave design with increasing the width of the stopband, kept the better performance at the passband, and got better steepness of the edge.

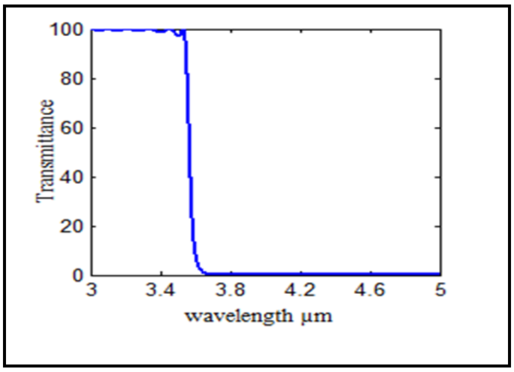

Figure 2: Optical performance of (SWP) designed by needle technique using 27 layers with construction design stack

[1.33440066L 1.62411733H 0.8746233L 1.07993823H 1.24280592L 1.07333466H 0.98284152L 1.04619143H 1.13364654L 1.09916817H 1.02974358L 1.02395487H 1.0698105L 1.10517424H 1.08595788L 1.03163394H 1.02046584L 1.08260547H 1.13442072L 1.06612403H 0.99432864L 1.05594741H 1.19931936L 1.12716941H 0.96082914L 1.94273301H 0.15975432L]

In the same number of layers (27 layer) needle technique provided another new design construction stack of (SWP) has optimal performance in the passband, it is free of any ripples as shown in Figure (3) .

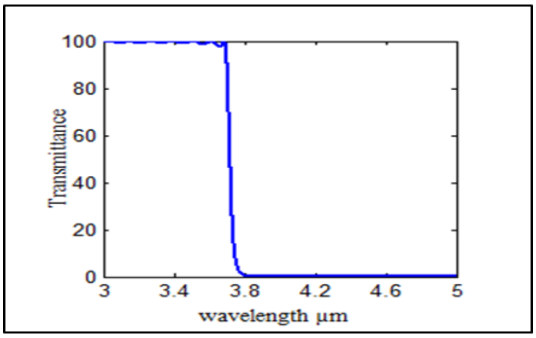

Figure 3: Optical performance of (SWP) designed by needle technique using 27 layers with construction design stack

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[1.57907539H 0.83396298L 1.07771314H 1.2922182L 1.0717979H 1.0149348L 1.10558771H 1.1754344L 1.08025132H 1.04686662L 1.09103261H 1.1303994L 1.10477511H 1.06701324L 1.07918777H 1.1043726L 1.11562332H 1.1022888L 1.06250318H 1.0847421L 1.14503466H 1.13016756L 1.04813211H 1.0928841L 1.29392449H 1.05951018L 2.2927748H]

3.2 Long-wave pass filter

In this section optimized designs of long-wave pass are submitted as shown in Figures (4-6) . These Figures demonstrate designed (LWP) by using few number of layers with controlling thickness . Figure (4) viewed that (LWP) characterized by the high transmittance along wide passband between (3.8-5μm) with reducing the ripples, and zero transmittance in stopband along 800 nm was obtained.

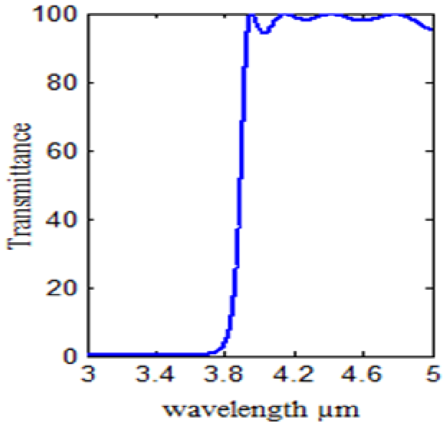

Figure 4: Optical performance of (LWP) designed by needle technique using 22 layers with construction design stack [0.470528263H 0.988016175L 1.055397113H 1.00867995L 0.968102363H 0.96185655L 0.984542575H 1.0080831L 1.012935775H 1.00165575L 0.99069085H 0.988775175L 0.996492575H 1.007398275L 1.006336388H 0.9882732L 0.96851165H 0.9719685L 1.004809775H 1.041991425L 0.9767213H 0.53351145L].

Figure (5) demonstrates another design of (LWP) constructed by also 22 coating layers, but this time we got wider passband with high reducing the ripples . also the total thickness of this design is smaller than the previous design where it is significant benefit in manufacturing processes.

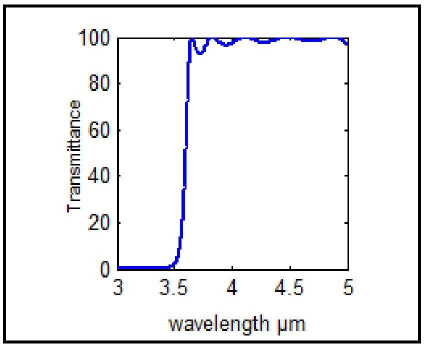

Figure 5: Optical performance of (LWP) designed by needle technique using 22 layers with construction design stack

[0.52394775H 0.8137446L 1.0192872H 0.988188675L 0.875785625H 0.85120815L 0.90563075H 0.95766825L 0.958345188H 0.92253345L 0.893352125H 0.900117075L 0.9279145132H 0.95625375L 0.951324562H 0.90183345L 0.862078975H 0.8822271L 0.963513563H 1.02185895L 0.858971975H 0.486624225L]

Optimal design of (LWP) is shown in Figure (6) represented by the wide passband with highly suppressed the ripples, and more steep edge . This design constructed by 23 layers.

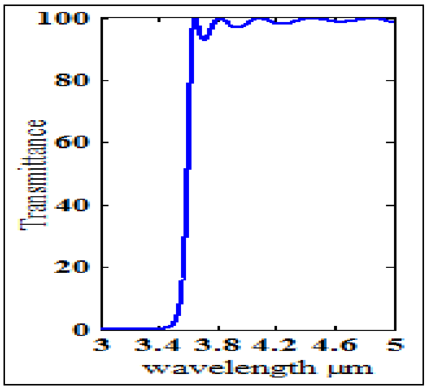

Figure 6: Optical performance of (LWP) designed by needle technique using 23 layers with construction design stack

[0.459710H 0.917304975L 0.99274923H 0.933671775L 0.8759828H 0.8768451L 0.91766738H 0.946716225L 0.941184987H 0.919361175L 0.9048779H 0.916652925L 0.933659475H 0.940378575L 0.925569325H 0.897984975L 0.899814087H 0.93689235L 0.9522851175H 0.88783335L 0.788431125H 0.842015625L 1.927788938H]

4. Conclusions

We managed to put up needle technique as a powerful approach to design new stacks for edge filters of long and short- wave pass using a proper number of layers with controlling thickness of each layer. We were able to overcome the problems of designing edge filters and obtained stacks of edge filters with optimal optical performance in the passband and stopband, which clarified by the high transmittance reaches to 100%, zero transmittance at stopband across wide range of wavelengths, and keep severe edge steepness.

We used specific coating materials in design to keep not use materials which are not available in nature or hazardous to health, and offered new design stacks with adopting suitable number of layers coating and overall thickness are limited within agreement range, that is significant to overcome the problems of manufacturing.

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