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Pattern Simulation for Optical Edge Filter Using Octive Software

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ABSTRACT

Optical filter provides some features of special functions to either block a specific wavelength or range of wavelengths and transmit the rest of the spectrum. A lot of researcher attention have been called for the past few decades. Recently, optical filter based on multilayer coating are more focused due to potential to manipulate filter properties by changing layer thickness in order to apply in various fields. Therefore, in this study aims to design optical edge filter-based Quarter wave stack model using optical matrix methods in GUNU Octave software. Prior to the design, molybdenum sulphide and silicon (MoS_2 and Si) are being selected for high (H) and low (L) refractive index materials respectively. The optimum twenty-four (24) number of layers are determined by calculating maximum transmittance obtained. The Rayleigh wavelength (λ_{ex}) of 405 nm and 532 nm were selected and 'glass|12HL|air' configuration was set for the design simulation. Then, the cut-on wavelength (λ_{cut-on}) and cut-off wavelength ($\lambda_{cut-off}$) of successful designed optical edge filter were measured. The result shows that the cut-on wavelength of 408.11 nm, 536 nm with minimum effective transmission (MET) of 32.3% and 31.3% respectively were obtained.

Keywords:
Quarter wave stack,
Filter,
Refractive index,
Multi-layer,
Number of layer.

INTRODUCTION

In most of the optical thin film coating technology design the wavelength thickness can be either thick or thin depending on the illumination and the detection condition, and also names and functions were used to distinguished them (Piegari and Flory, 2013). In optical coating used to enhanced transmission, reflection or polarization of an optical element at a well define angle of incident for both in S polarization (perpendicular to the plane) and P polarization (parallel to the plane), or accidental polarization (Buckberger and coclite, 2019). In multilayer optical edge filter high reflection quarter-wave edge filter design using simulation and fabrication, several methods have been used by different authors such as spray pyrolysis (Deokate Kabarme, 2017). Radio frequency (R.F) magnetron sputtering method (Benetti et. al., 2017), sol-gel method (Kitui and Mwamburi, 2015).

In this present work, Octave software was used to design and simulate a computer program for MTF filter design. The aforementioned software have advantages over other types of software due to easy to usage, built-in support of a complex number, and extensibility in form of a user-defined function (Selhofer and Oliver 2019). The molybdenum sulphide and silicon material (MoS_2 and Si) have been selected for high (H) and low (L) refractive index materials. In addition, twenty-four (24) number of layer was used.

Effect of number of layer on thin film edge filter design

Thin film optical structure comprises of Several layers of contrasts materials with different refractive index and are arranged based on high (H) and low (L) index. The layers were in the range of friction of nanometer (nm) or micrometer (μm) thin film thickness. The filter design can be arranging in a stack (Vaida, Birdeanu, & Bîrdeanu, 2019) as follows

Air |HLHLHLHLHLHLHLHLHLHLHLHL|Glass

Almost all of the multilayer optical edge filter design, the number of the layer played a vital role on reflectance and transmittance. Therefore, the reflectance or transmittance can either increase or decrease by just increases the number of layers as shown in Figure 1. (Erdogan 2011; Macleod 2010).

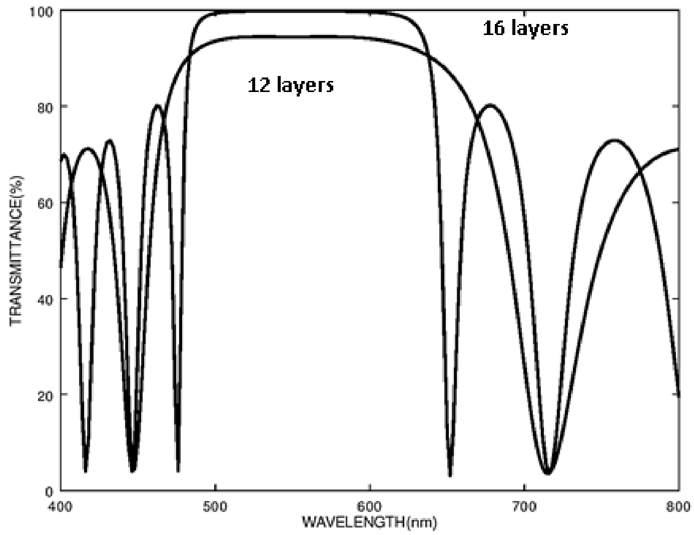

Figure 1: show effect of number of layer

Simulation Flow Chart

The process in Figure 2 begins by input parameter to start the design and continued by calculating thin film equations then the result can be obtained. But, if the result is not good then parameter such as refractive index, thin film thickness, reference wavelength and a number of layers can be changed to obtain the desire design.

In this present simulation work, optical matrix method is proposed for design MTF filter as adapted by (Abbas et al. 2017). Thus, the coding is divided into S. polarization (perpendicular) and P polarization (parallel), built in GNU Octave software for dissimilar polarization incident light. This method is used to obtained the optical the performance and thickness of the optical filter. In addition, thin film layers are based on high and low refractive index up to the required twenty-four (24) number of layers.

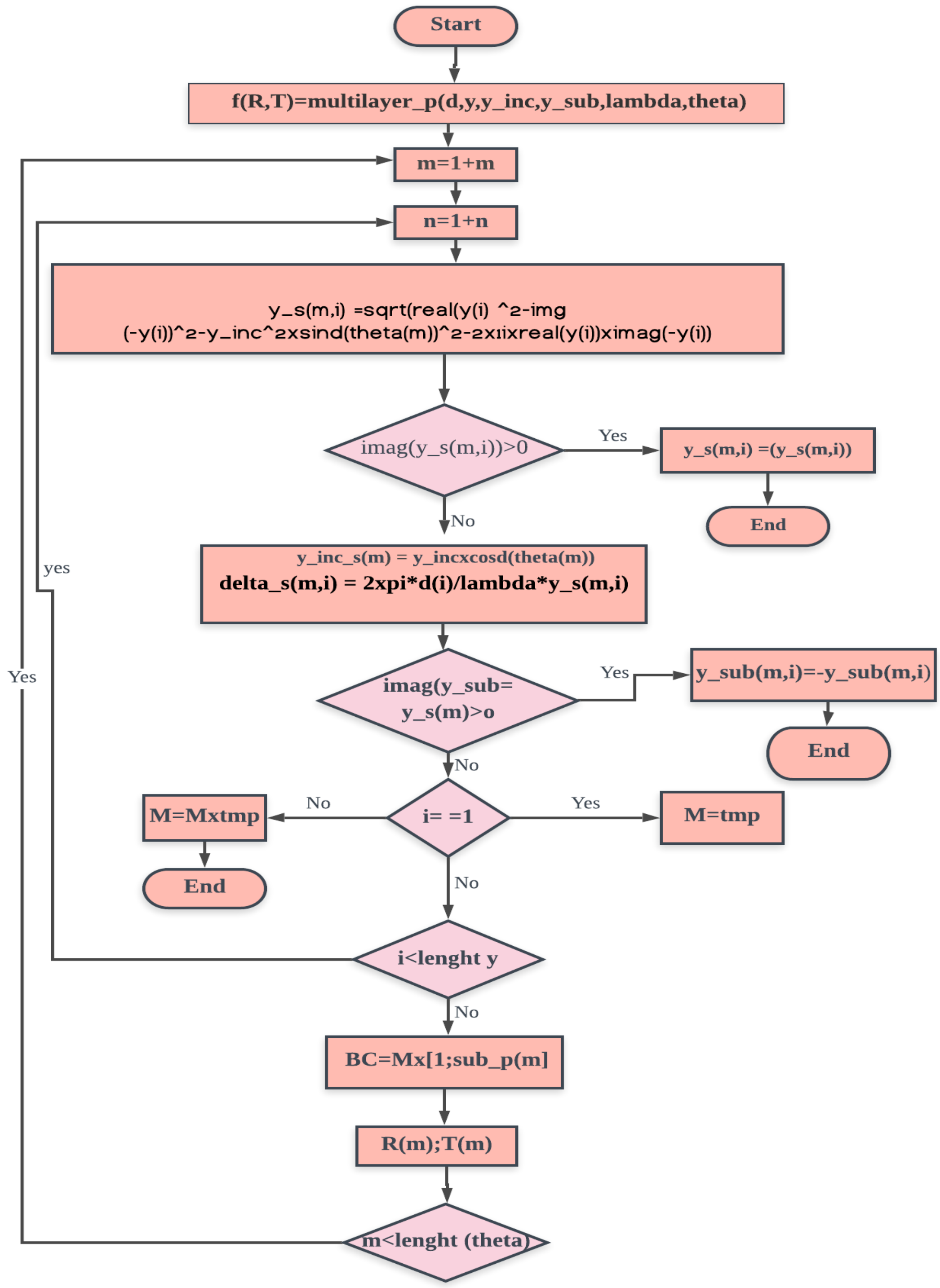

Figure 2: Flow chart of MTF edge filter design

Algorithm for thin film optical edge filter design
This algorithm explained the steps used to calculate the multilayer thin film optical filter using alternative high and low refractive index materials in Octave software as shown in table 1.

Table 1: Algorithm Parameters

Parameter	**Symbols**	**Description**
Refractive index	y	Admittance for the film next to the incident medium is first [H,L,H…]
Thickness	D	Thin film thickness [dH,dL,dH. ..]

Define the following as

parameter name	**symbols**	**Description**
Theta	y	incident angle (unit in degree), can be a vector
Air	y_inc	admittance of incidence medium in the form of (n-ik)
GLASS	y_sub	admittance of substrate medium in the form of (n-ik)
MoS_2	H	Higher refractive index
Si	L	lower refractive index
Lambda		wavelength of incident light
MoS_2 thickness	dH	physical thickness of the thin film high layer lamda_f/4H
Si	dL	physical thickness of the thin film lower layer lamda_f/4L

Matrix Equations Multilayer Thin Film (MTF) Assembly Optical thin Filter Design

The equation below shows the thin film edge filter design to calculate the optical properties, of rth thin film layers. The following layer generates in a matrix equation which determined change the electric and magnetic field. The final results were related to the admittance of the incidence medium of the admittance of the thin film filter and glass substrate to obtained the coefficient of reflectance or transmittance. (Nazar et al., 2018; Nazar, Rashid, et al., 2016). Note that admittance has no units the mathematical expression for thin film equation can be proof as follows.

$$\begin{bmatrix} E \\ H \end{bmatrix} = M \begin{bmatrix} 1 \\ \eta_S \end{bmatrix} \quad (1)$$

E and H signified electric and magnetic field vector and also M represent matrix

$$\begin{bmatrix} E_a \\ H_a \end{bmatrix} = \begin{bmatrix} \cos\delta & \mathrm{i}\sin\delta/\eta_1 \\ \mathrm{i}\eta_1 \sin\delta & \cos\delta \end{bmatrix} \begin{bmatrix} \cos\delta_2 & \mathrm{i}\sin\delta_2/\eta_2 \\ \mathrm{i}\eta_2 \sin\delta_2 & \cos\delta_2 \end{bmatrix} \begin{bmatrix} 1 \\ \eta_3 \end{bmatrix} \quad (2)$$

$$M_r = \begin{bmatrix} 1 \\ \eta_S \end{bmatrix} \begin{bmatrix} cos\delta r & \frac{i}{\eta} sin\delta r \\ \eta i sin\delta r & cos\delta r \end{bmatrix} \quad (3)$$

$$\mathrm{M} = M_L M_{L-1} \;\ldots\;\ldots\ldots\;\ldots\ldots\; .Mr \;.\;\;\ldots\; .M_2 M_1 \quad (4)$$

M= is 2 x2 matrix signified the rth thin film of the system.

where $\begin{bmatrix} B \\ C \end{bmatrix}$ is define as the characteristic matrix assembly

B (E) = regulated electric field at the front interface of the thin film.

C (H)= regulated magnetic field at the front interface of the thin film.

Nevertheless phase (δi) of the wave length inside layer is given by

$$\delta r = \frac{2\pi}{\lambda} nidicos\phi$$

$$\delta_r = \left(\frac{2\pi}{\lambda}\right) d_r (n_r^2 - k_r^2 - n_o^2 \cos^2 \nu_o - 2in_r k_r)^{1/2} \quad (4)$$

$$\eta_p = \frac{n}{cos\phi} \text{ for P- polarization}$$

$$\eta_S = ncos\phi \text{ for S- polarization} \quad (5)$$

And also

$\rho = \left[\frac{\eta_{o-}\Upsilon}{\eta_{o+}\Upsilon}\right]$ but Υ is admittance of multilayer thin film

$$\boldsymbol{\Upsilon} = \frac{B}{C} = \frac{\eta_{O \cos\delta} + \eta_1 \sin\delta}{\cos\delta + i(\eta_s/\eta_1)\sin\delta}$$

$R = \rho\rho^* = \left[\frac{\eta_{o-}\Upsilon}{\eta_{o+}\Upsilon}\right] \left[\frac{\eta_{o-}\Upsilon}{\eta_{o+}\Upsilon}\right]^*$ the amplitude of the reflectance coefficient is representing by ρ (6)

$$\tau = \frac{2\eta_o}{\eta_o + \Upsilon} \quad (7)$$

$$T = \frac{4\eta_0 Re(\Upsilon)}{(\eta_{0+}\Upsilon)(\eta_{0+}\Upsilon)} \quad (8)$$

RESULT AND DISCUSSION

The simulation, value of cut-on and cut-off wavelengths is determined using Raman shift equations. The design programmed is used first to observe the role of the increased in the number of a layer on edge filter designed. Based on the result obtained laser line (Rayleigh wavelength) of 405 nm and 532 nm wavelength optical edge filter were designed.

Edge Filter of Rayleigh Wavelength (λ_{ex}) 405 nm

Table 1 shows the thickness of MoS_2 and Si materials obtained from the simulation and the arrangement of layer on a glass substrate. Figure 3 shows graphs of reflectance and transmittance against wavelength (λ) for MTF edge filter. The result shows 100% reflectance with high distortion at the right-hand side with λ_{cut-on} and $\lambda_{cut-off}$ of 408.11 nm and 700 nm are obtained. The result shows that the MET of the filter is 33%.

Table 2: Calculated thickness of individual layer of MoS_2 and Si for optical filter match to λ_{ex} = 405 nm

Number of layers	Materials	Thickness (nm)
Air		
24	Si	32.65
23	MoS_2	21.56
.	.	.
.	.	.
.	.	.
2	Si	32.65
1	MoS_2	21.54
Substrate		

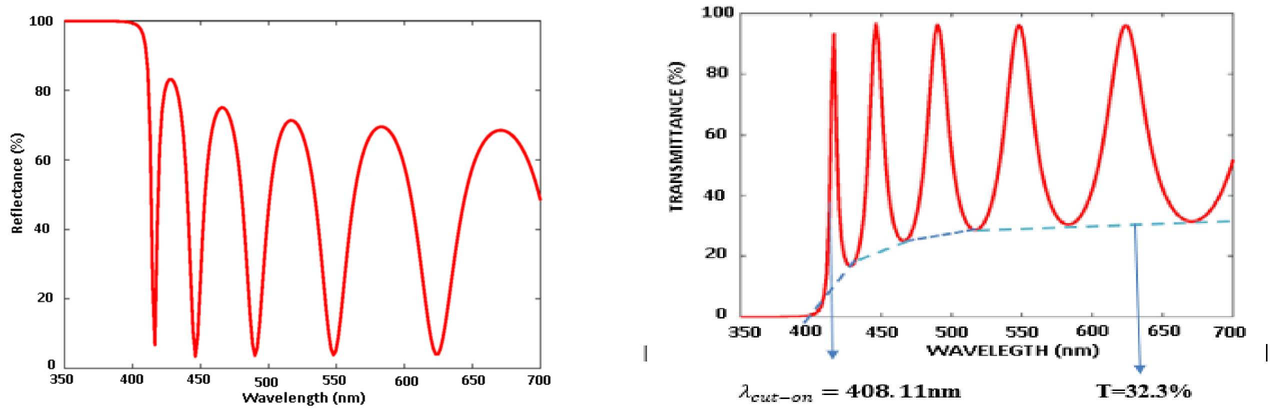

Figure 3: Reflectance and transmittance against λ for λ_{ex} = 405 nm

Edge Filter of Rayleigh Wavelength (λ_{ex}) of 532 nm

The thickness of each layer arrangement is shown in Table 2 on a glass substrate. Figure 4 shows the graph of reflectance and transmittance against wave length (λ) of the edge filter for λ_{ex} = 532 nm, with λ_{cut-on} = 536 nm and $\lambda_{cut-off}$ = 800 nm respectively. The result show that the MET of the filter is 31.3%.

Table 3: Calculated thickness of individual layer of MoS_2 and Si for optical edge filter match to λ_{ex} = 532 nm

Number of layers	Materials	Thickness (nm)
Air		
24	Si	36.90
23	MoS_2	27.34
.	.	.
.	.	.
.	.	.
2	Si	36.91
1	MoS_2	27.33
Substrate		

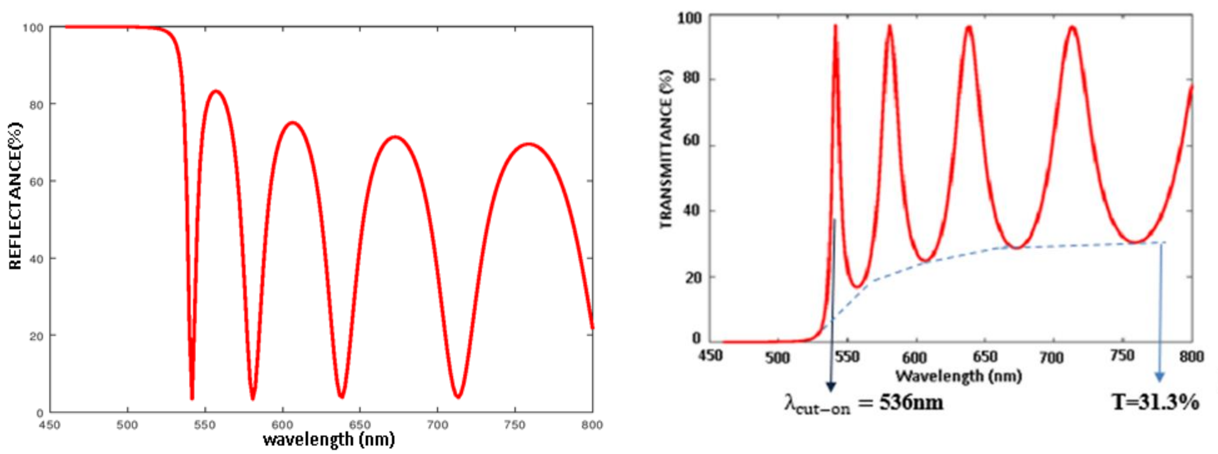

Figure 4: Reflection and transmittance against λ for λ_{ex} = 532 nm

CONCLUSION

The QWS model simulation for optical filter application is designed using Octave software. This program can be used to design different types of edge filter using different materials series. The edge filter of λ_{ex} of 405 nm and 532 nm, with the λ_{cut-on} different of 0.2 nm and 1.7 nm from the calculated value using the same configuration of Glass|12(HL)|Air. This simulation program is applicable to other materials either dielectric, semiconductor or metal provide the refractive index of the materials are known. The simulation result reveals that the optical performance of the filter is determined by increasing in number of layers. This study reveals that using GNU octave software to design optical filter before fabrication reduce the cost of fabrication time and so on.

REFERENCES

Abdullah G. H., Mhdi B. R., and Aljaber N. A Jun, (2012) "Design Thin Film Narrow Band-pass Filters For Dense Wavelength Division Multiplexing," *Int. J. Adv. Appl. Sci.*, vol. 1, no. 2, p. pp 65-70.

Benetti D. *et al. (*Dec. 2017) "Combined magnetron sputtering and pulsed laser deposition of TiO 2 and BFCO thin films," *Sci. Rep.*, vol. 7, no. 1, p. 2503,

Boyd, A. R. Rutledge L, L. Randolph D., and Meenan B. J (2015) "Strontium-substituted hydroxyapatite coatings deposited via a co-deposition sputter technique," *Mater. Sci. Eng. C*.

Buchberger A, Peterka S, Coclite A. M, and Bergmann A.(2019) "Fast Optical Humidity Sensor Based on Hydrogel Thin Film Expansion for Harsh Environment," *Sensors (Basel).*, vol. 19, no. 5, pp. 1–11

Deokate R. J., Kalubarme R. S, Park., C and Lokhande C. D (Jan. 2017). "Simple Synthesis of $NiCo_2O_4$ thin films using Spray Pyrolysis for electrochemical supercapacitor application: A Novel approach," *Electrochim. Acta*, vol. 224, pp. 378–385,

Elyutin V. V, Butt M. A., and Khonina S. N (2017) "Cold mirror based on High-Low-High refractive index dielectric materials," in *3nd international conference ' 'information technology and Nanotechnology*, no. 1, pp. 5–9.

Kitui M., Mwamburi M. M., Gaitho F., and Maghanga C. M.(2015). "Optical Properties of TiO 2 Based Multilayer Thin Films : Application to Optical Filters .," *Int. J. Thin Film. Sci. Technol.*, vol. 21, no. 1, pp. 17–21

Piegari A and Flory F.(2013) *Optical thin films and coatings: From materials to applications*. United kingdom: Elsevier,.

Saliba M., Correa-Baena J.-P and Grätzel M., A (Mar, 2018) Hagfeldt, and A. Abate, "Perovskite Solar Cells: From the Atomic Level to Film Quality and Device Performance," *Angew. Chemie Int. Ed.*, vol. 57, no. 10, pp. 2554–2569.