GRASSHOPPER OPTIMIZATION ALGORITHM IN OPTICAL FILTER DESIGN FOR TRANSMISSION APPLICATIONS

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ABSTRACT

This research concentrates on developing the optical band pass filter based on the grasshopper optimization algorithm (GOA) for the transmission applications. The optimal design is obtained by evaluating the various parameters, like thickness, refractive index and the influence of selecting optical parameters, which in turn boost the transmission potential. At first, the alternative multi-layer stack with 32, 30 and 28 layers are designed by varying the thickness and maintaining the constant low and high refractive indices integration of the dielectric substances. The algorithm is used to obtain the best feasible solution by optimizing the thickness of every layer. The proposed method is implemented using the MATLAB tool and the experimental outcome reveals the effectiveness of the proposed methodology.

Keywords: grasshopper optimization algorithm, optical band pass filter, dielectric material, and transmission application.

1. INTRODUCTION

The optical thin film is defined as the multilayer stack, which comprised of numerous layers with stipulated thickness in the dielectric material that is settled on the substrate. To determine the construction parameter of the framework so as to attain the desirable optical instruments is the main issue experienced in the modeling of the optical filters. The extinction co-efficient of the surface of the medium, refractive index, layers of the system, layer in the framework and thickness are considered as the major construction parameters. The parameter vector is formed by integrating these quantities. The productiveness of the multilayer at any phase is determined by estimating the measure of merit function, which is characterized as the single value function and it is determined through evaluating the various quantities in multi-layer [6]. Different quantities are utilized in traditional method [9] for developing the optical thin film design. The quantities such as, angle of incidence, reflectance of the particular wavelength and the plane of polarization obtain the significant consideration among various quantities. Developing the transmittance or optical spectral reflectance in the multilayer thin film coating by varying the reflective index, which is called as optical interference filter is the well utilized method [2]. Numerous strategies are utilized in the traditional methods for the design of multi-layer optical filter [10]. The conventional strategies are classified into graphical, analytical and the numerical methods.

The analytical techniques are the fastest techniques among them, yet they are not flexible. At the same time the numerical methods are effective in solving the complicated issues and also provide the better solution to the problems that are found to be inaccurate and time consuming with other methods. The synthesis and the refinement methods are the most common numerical methods. The initial modeling, which is nearest to the required performance, is the crucial factor in the numerical techniques [14]. The alterations in the parameters in the starting design are established for improving the performance of the numerical method. Yet, in the synthesis methods the starting design is not required and they are effective for the complex issues due to its tediousness in obtaining the optimal design. Hence, there is an urgent requirement for the pre-fabrication design so as to attain the better performance and the preferable cost [12]. Yet, attaining the global optimal solution is now became the hectic challenge as most of optimization techniques are trapped in the local optima, as there is an enhancement in the dimension of the problem. Various global and the local optimization algorithms such as annealing method, Monte Carlo method, needle method and GA techniques are utilized to model the multilayer optical interference filters [13]. The Needle methods are particularly used to design the interference filters design and it is utilized to attain the optimal modelling parameters of the filter [2].

This paper proposes an optimization strategy named GOA for optimally designing the optical filters in such a way to make them efficient for better transmission purpose. Among the number of stochastic optimization strategies, the nature inspired, population-based algorithms are of more concern, as they mimic the characteristics of the creatures, trying to solve the real-world problems. The GOA, intakes the parameters of the optical thin film filters to be processed to attain the optimal measures of the parameters to be suitable for design purposes. In other words, the GOA algorithm considers the combination of the design parameters and the transmittance profile as the input to attain the thickness of the layers optimally.

The major contribution of the proposed grasshopper optimization algorithm is the optimal model of optical thin film filters. The proposed GOA is used to obtain the optimal model parameters of the optical filters in terms of transmittance and reflectance by optimally tuning both the number and the thickness of the layer with constant refractive index measure.

The paper is organized as: Section 1 provides a brief introduction to the research, and Section 2&3 deliberates the Existing and Design methods of optical filter design with their limitations. Section 4 explains the principle of the proposed GOA strategy in optical filter design, Section 5 Deliberates the results of the proposed method and finally, section 6 elucidates the conclusion of this research.

2. LITERATURE SURVEY

This section deliberates the existing methods of optical filter design and the challenges associated with the existing model that acts as the motivation for the development of the proposed model.

2.1 Related Works

The literature review of the existing methods are stated as, Sunita Parinam *et al.* [1] introduced a method of optical parameter optimization strategy by utilizing the Genetic Algorithm (GA) and Taguchi is utilized to device the optical filter with high transmittance. The main advantage of the system is that it is highly powerful and it is utilized to device the optical filters in live stream application. However, the method undergoes issues related to convergence, and hence less preferred. Rabi I. Rabady and Almahdi Ababneh [2] employed particle swarm optimization algorithm to achieve the global best framework for optical filters. The method outperformed the GA method in reaching the global optimal solution. However, the drawback of the method is that the solution may get trapped into the local optimal measure, and may fail to attain the global optimal solution.

Paul Azunre *et al.* [4] introduced a parallel pre-determined strategy for optical coatings. This method is better in providing the rigid and preferable solution in the existence of realistic manufacturing restraints. However, this method is confined due to some persistent issues. Efrem K. Ejigu and Beartys M. Lacquet *et al.* [5] introduced an optical thin film pattern based on Fourier transform to generate a starting population, which utilize the GA to optimize the parameters. The outcome reveals that the GA performs better than the optimization of optical thin film construction. Yet, the method that utilizes the GA for design and optimization purpose requires high computation time to generate the preferable results.

2.2 Problem Statement

The challenges associated with the existing methods of optical filter design are deliberated as follows:

- The hectic challenge experienced in the method using the GA as the optimization means is that the achievement of concluding outcome reliable on creating the quality is the complex problem [5].
- The spectrum fails to attain high performance with high wavelength regions as compared with the domain of very less wavelength [5]
- It is the hectic challenge to preserve the regularity in the spectrum of transmission, particularly in the domain of high wavelength, when there is a transmission in the central wavelength [5].

3. DESIGN METHODOLOGY

An optical band pass filter of multilayer is developed for the central wavelengths of 656.3 nm, 486.1 nm, 464.7 nm, 656.3 nm, 486.1 nm, and 464.7 nm and normal incidence in visible range. Alternative layers of both high and low refractive index components were utilized. Three arrangements of materials are selected for low and high refractive index measures. High refractive index materials are Zinc sulfide (ZnS), and Titanium dioxide (TiO_2), and the low refractive index materials are magnesium fluoride (MgF_2) and silicon dioxide (SiO_2). An optical filter for high transmission is designed in the wavelength of range 400nm to 700 nm. Three diverse levels of thickness limits are considered with three different substrate refractive indexes. The design was made for 28 layers or 30 layers or 32 layers with substrate refractive index as 1.5143, 1.5224, and 1.524, respectively. A computer program using MATLAB setting was designed that uses the parameters of the optical thin film filter as input and makes an attempt to obtain better transmittance and reflectance profile by optimizing the optical parameters using the GOA optimization algorithm.

4. PROPOSED GRASSHOPPER OPTIMIZATION ALGORITHM IN OPTICAL FILTER DESIGN

Most of the standard optimization strategies are developed based on the foraging characteristics of the swarms that involve in searching their food. Similarly, the proposed GOA optimization strategy exhibits the features of the grasshopper in attaining its food. The proposed GOA optimization strategy exhibits a dynamic quality in solving the problems of the optimization strategy in terms of convergence. In addition, the GOA optimization strategy balances a better trade-off among the phases, such as exploration and exploitation, leading to the generation of local optimal solutions and global optimal solutions, and finally concludes with the optimal global solution [8]. The proposed GOA algorithm is used for optimizing the parameters of the optical filter, such as thickness, number of layers, and the refractive indices to attain the best model that satisfies the expected characteristics of the filter in transmission. The algorithmic steps followed by the GOA algorithm is described as:

Step 1: Initialize parameters: Initialize the parameters, such as high and low refractive index, thickness, and the count of layers of the optical then film. In addition, initialize the maximum number of iterations.

Step 2: Population initialization: In the next step, the numbers of grasshoppers are initialized based on the materials, such as MgF_2, ZnS, TiO_2, and SiO_2. Each GOA possess a position vector indicating the current position as,

$$G_u = (G_1, G_2, ..., G_n); \qquad (u = 1,2,...,n) \tag{1}$$

where, G_u indicates the total grasshoppers in the search space that varies from $1,2,...,n$ and G_n is the n^{th} search

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agent. The fitness of each swarming search agent is stored as,

$$F_u = (F_1, F_2, .., F_n) \quad (2)$$

The equivalent fitness values of each grasshopper are stored in the form of the above expression that assists in the determination of the survival of the fittest among the entire number of the grasshoppers.

Step 3: Update of position: The position of the grasshoppers can be updated, based on equation (3) as,

$$G_j^{t+1} = \sum_{\substack{l=1 \\ l \neq j}} str\left|G_l - G_k\right|\left(\frac{G_l - G_k}{z_{kl}}\right) - a\,\hat{w}_c + b\,\hat{w}_f \quad (3)$$

where, a represents the constant of gravitation, and $\hat{w}_c$ is the vector of unity over the axis of the earth, b is a drift constant, and $\hat{w}_f$ is the vector in the route of wind. However, the above expression cannot be used directly to solve the optimization problem, and hence some modifications are made in such a way to make the algorithm to converge at a specific point. Hence the above equation becomes,

$$G_j^{t+1} = Const \sum_{\substack{l=1 \\ l \neq j}} Const \frac{uu_z - ll_z}{2} str\left|G_l - G_k\right|\left(\frac{G_l - G_k}{z_{kl}}\right) + \hat{M}_z \quad (4)$$

where, uu_z is the upper bound of the W^{th} dimension and ll_z is the lower bound of W^{th} dimension, $\hat{M}_z$ indicates the measure of W^{th} dimension in the objective. $Const$ is declining coefficient to contract the repulsion, attraction and the comfort zones. Thus, the above equation is the final update equation of the GOA algorithm, based on which the parameters of the optical filter is tuned optimally that assist in enhancing the performance of the filter.

Step 4: Sorting of solutions: The grasshoppers are arranged based on the values of fitness and the solutions with less fitness measures are neglected. The solution with best fitness measure is replaced with the existing solution. Otherwise, the old solution is considered as the best solution.

Step 5: Termination: The algorithm is terminated after the completion of maximum number of iterations, through which the best solution is achieved [8]. The pseudocode of GOA is given in Table-1.

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Table-1. Pseudocode of GOA in optical filter design.

S. No	Pseudo code of Grasshopper optimization algorithm
1	Begin
2	Input: $G_u = \left(G_1, G_2, ..., G_n\right)$
3	Output: G_j^{t+1}
4	Initialize the population of grasshoppers based on the materials
5	Initialize parameters: High and low refractive index, thickness, and number of layers
6	Initialize maximum iteration
7	For each search agent
8	{
9	Update the new solution based on equation (4)
10	Evaluate fitness measure for each solution, F_u
11	Arrange the solutions based on fitness measure
12	Re-evaluate the fitness measure
13	If
14	{
15	$f_{u,old} < f_{u,new}$
16	}
17	Replace the old solution with the new solution
18	Else
19	Maintain the old solution as the best solution
20	}
21	Update position of grasshoppers based on fitness
22	End
23	Result G_j^{t+1}

5. RESULTS AND DISCUSSIONS

This section describes the results obtained using the proposed GOA model in the optimal design of the optical thin film filter.

5.1 Experimental Setup

The experimentation of the model is done in MATLAB tool installed in Windows 10 OS and 64-bit operating system with 16GB RAM that offers simple and effective implementation of the proposed model.

5.2 Evaluation Indices

The evaluation indices taken into consideration for the proposed model are the reflectance and transmittance. Transmittance is the rate of flux transmitted by the surface, generalized with the rate of flux incidence on the surface. Reflectance is the rate of flux reflected by a surface, generalized by the rate of flux incidence on the surface.

5.3 Analysis Based on Transmittance and Reflectance

The analysis of the proposed method in terms of transmittance and reflectance is explained in this section through six cases. In the analysis using GOA, the thickness value is varied, and the refractive index value is maintained constant. Table-2 shows the number of layers considered for the six cases.

Table-2. Description of layers.

S. No	Cases	Number of layers
1	Case 1	30
2	Case 2	32
3	Case 3	28
4	Case 4	30
5	Case 5	28
6	Case 6	32

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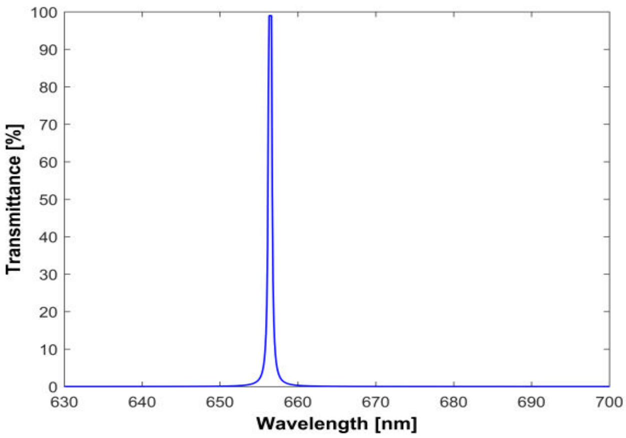
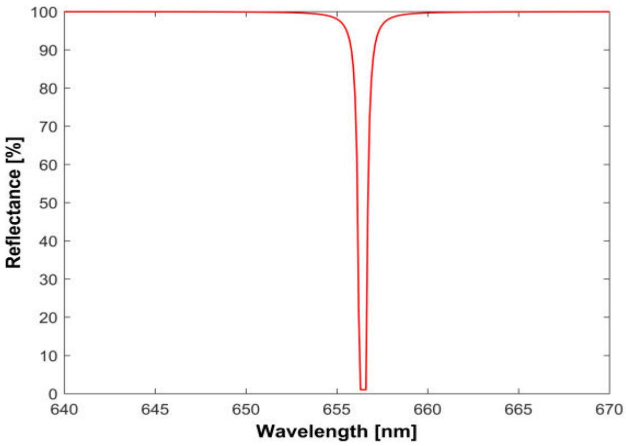
Case 1: In case 1, the central Wavelength =656.3 nm, ZnS (High refractive index) =2.3432, MgF2 (Low refractive index) =1.3766, and the Substrate (BK7 glass) = 1.5143. Figure-1 shows the transmittance and reflectance measures corresponding to case 1. When the wavelength is 656.3 nm, the transmittance is 99% and the reflectance is 1%.



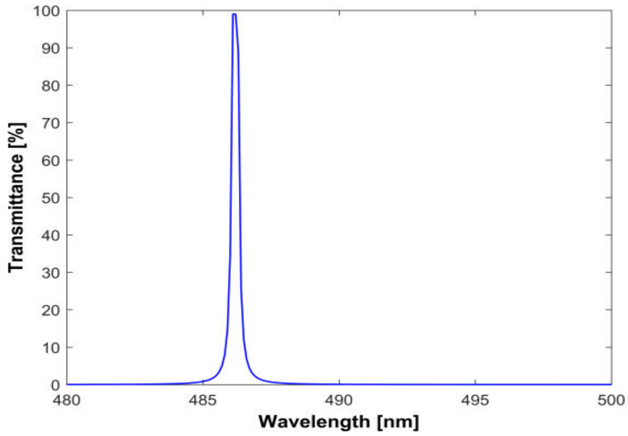
(a)



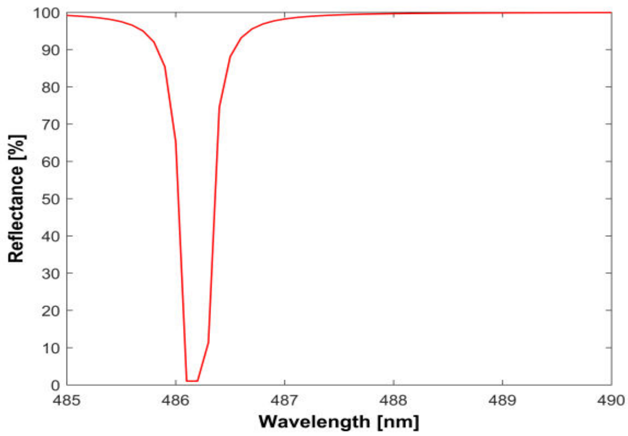
(b)

Figure-1. Case 1, (a) Transmittance, and (b) Reflectance.

Case 2: In case 2, the central Wavelength =486.1 nm, ZnS =2.4319, MgF2=1.3802, Substrate (BK7 glass) = 1.5224. Figure 2 shows the transmittance and reflectance measures corresponding to case 2. When the wavelength is 486.1 nm, the transmittance is 99% and the reflectance is 1%.



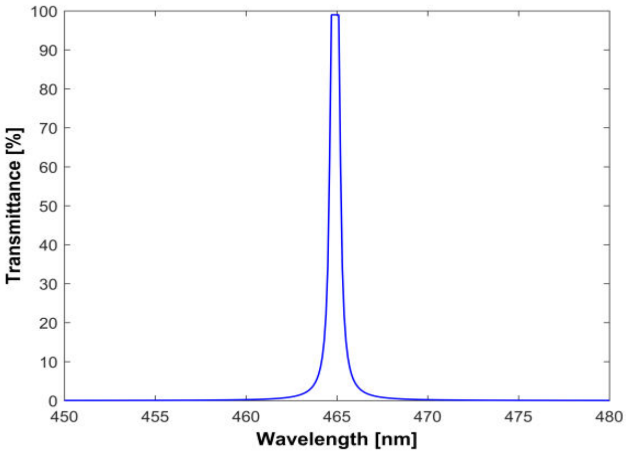
(a)



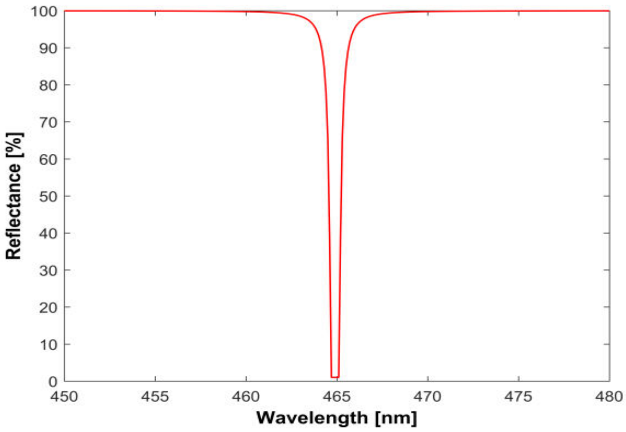
(b)

Figure-2. Case 2, (a) Transmittance, and (b) Reflectance.

Case 3: In case 3, the central Wavelength =464.7 nm, ZnS =2.4533, MgF2=1.3809, Substrate (BK7 glass) = 1.5224. Figure-3 shows the transmittance and reflectance measures corresponding to case 3. When the wavelength is 464.7 nm, the transmittance is 99% and the reflectance is 1%.



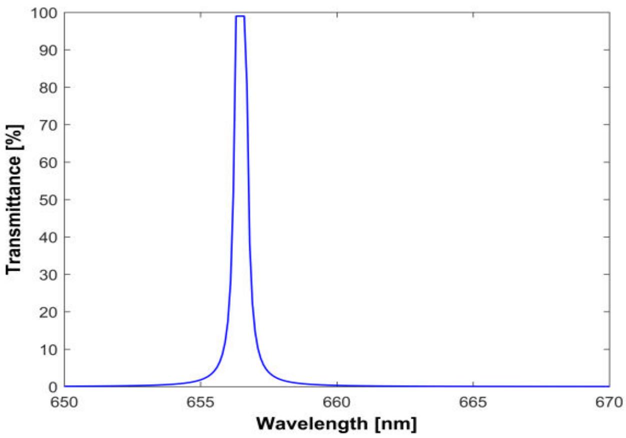
(a)



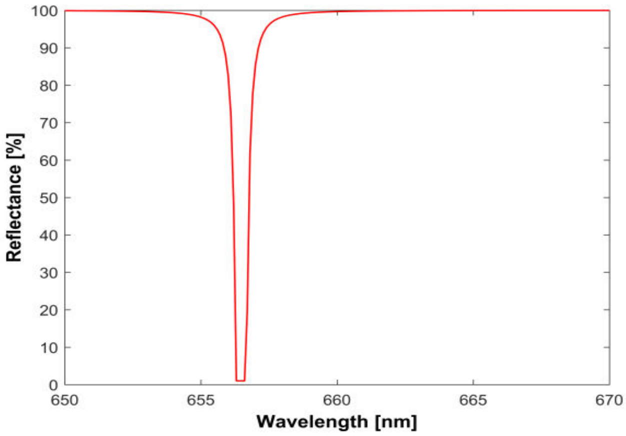
(b)

Figure-3. Case 3, (a) Transmittance, and (b) Reflectance.

Case 4: In case 4, the central Wavelength =656.3 nm, High refractive index (TiO2) =2.5709, Low refractive index (SiO2) =1.4564, substrate (BK7 glass) = 1.5143. Figure-4 shows the transmittance and reflectance measures corresponding to case 4. When the wavelength is 656.3 nm, the transmittance is 99% and the reflectance is 1%.



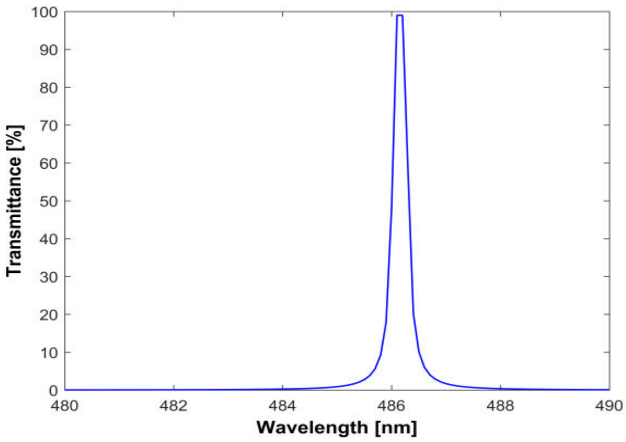
(a)



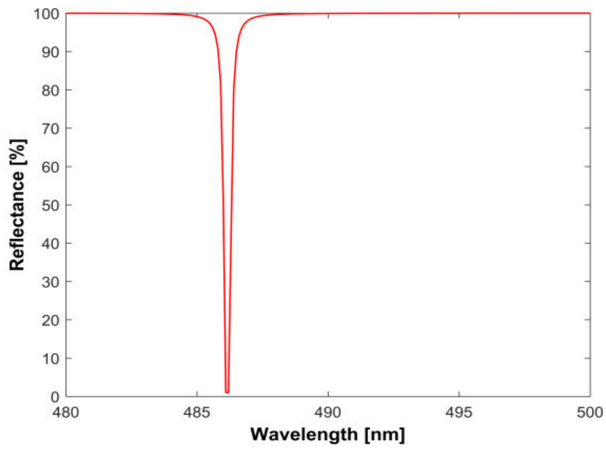
(b)

Figure-4. Case 4, (a) Transmittance, and (b) Reflectance.

Case 5: In case 5, the central wavelength =486.1 nm, high refractive index (TiO2) =2.7346, Low refractive index (SiO2) =1.4631, Substrate (BK7 glass) = 1.5224. Figure-5 shows the transmittance and reflectance measures corresponding to case 5. When the wavelength is 486.1 nm, the transmittance is 99% and the reflectance is 1%.



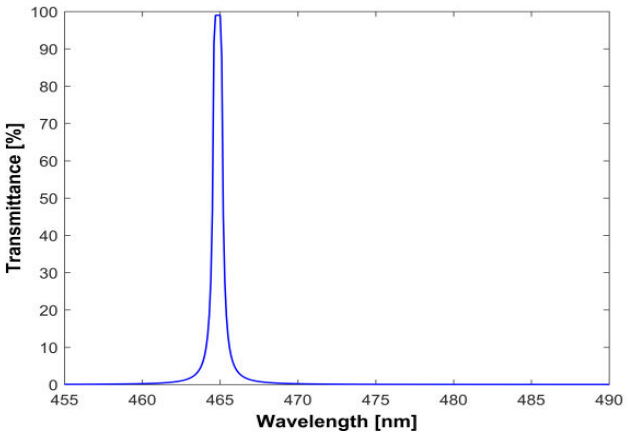
(a)



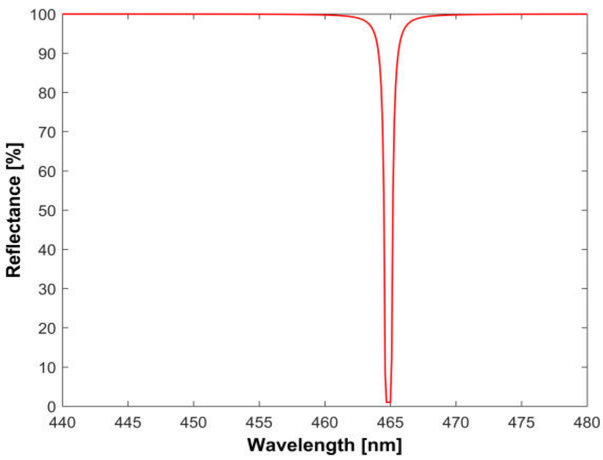
(b)

Figure-5. Case 5, (a) Transmittance, and (b) Reflectance.

Case 6: In case 6, the central wavelength =464.7 nm, high refractive index (TiO2) =2.7771, Low refractive index (SiO2) =1.4645, substrate (BK7 glass) = 1.524. Figure-6 depicts the reflectance and transmittance measures corresponding to case 6. When the wavelength is 464.7 nm, the transmittance is 99% and the reflectance is 1%.



(a)



(b)

Figure-6. Case 6, (a) Transmittance, and (b) Reflectance.

6. CONCLUSIONS

An optical thin film filter was designed using the grasshopper optimization algorithm with the consideration of constant refractive index. The consequence of the optical constraints, such as thickness and reflectance on convergence of the design resolution was analyzed. GOA is used to optimize the refractive index and thickness measures to attain a model that shows enhanced transmittance profile. The convergence with respect to fitness function with the constraints of GOA was obtained with the population of 100 and thickness measure as optimization variable. Thus, thickness as optimization variable has offered enhanced outcomes as compared to refractive indices as per modern modeling expectation is considered. In future, the optical thin film will be designed to provide enhanced performance with the use of hybrid optimization algorithms, instead of single meta-heuristics algorithms.

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