Design optical filters using two different synthesis approaches

Alaa Nazar

Baghdad University

آلاء نزار

جامعة بغداد /كلية العلوم للبنات

Abstract

It is difficult to find any modern optical system that does not have components with single or multiple layers of optical coatings, scientists and engineers use optical coating filter based on the interference property of electromagnetic wave to achieve a desired reflectivity of light over a range of frequencies.

In this paper we propose a two different efficient methods, needle optimization method and genetic algorithms (GAs), for synthesis optical coatings. The task was to overcome the difficulty to obtain high quality coatings, with optical constants and low number of layers and demonstrate that a highly efficient global optimization of optical filter can be performed. Results includes the comparison between the results needle approach in frame Open Filter (new software) and the results of genetic algorithm technique , it is considered the first comparison between Open Filter and (GAs). In addition they show us the advantage and disadvantage of each approach in design high reflection optical filters

Key words: multilayer optical filter, synthesis methods, needle method interference filters

1-Introduction

Optical multilayer interference filters or sometimes called optical filters are used in much application for example in photography, display projectors, optical storage devices, digital cameras and optical telecommunication. Multilayer optical interference filter are coatings which consists of a stack of thin layers of materials with differences in refractive indices [1-3]. In practice optical coatings are required to modify the reflectance and transmit of the surfaces involved. The performance of these coatings is determined by the interference that occurs due to the multiple reflections within the coating. Designing optical filter determining the optimal number of layers as well as the composition and thicknesses of each layer, is an elaborate optimization problem. Several approaches were developed for the design of thin film multilayer coatings [4]. Among these approaches the use of digital design methods offers a number of advantages. These in turn are generally classified as either refinement or synthesis methods [5]. Refinement methods need a optical filters. Consider

2- multilayer design, promising design without a starting design [6, 7]. This promising design can be refined afterwards.

This paper introduces several improvements for designing multilayer high reflection (HR)optical filters with two different approaches needle method and genetic algorithms (GAs) allowing for the design of more complex filters at low number layers of wavelength in the spectrum. The task presents the comparison between these two synthesis methods and explains the advantage of each method.

2-Theory

2-1 Characteristic matrices

1- The characteristic matrix approach developed by Abelès [8] was presented in detail in most optical coating textbooks such as Macleod's [9]. This matrix calculation determines the spectral transmittance and reflectance profile for multilayer structures on a substrate. The matrix approach was employed for M-layers design of antireflection and reflection coatings. The main idea of this method is matching the E- and H-fields of the incident light on the interfaces of multilayer then the reflection coefficient r and the reflectance R are respectively, given by

$$r = \frac{n_0 - Y}{n_0 + Y}$$

$$R = r\, r^*$$

where n_0 is the refractive index of the medium (air) and

$$Y = \frac{m_{21} + n_s m_{22}}{m_{11} + n_s m_{12}}$$

n_s the refractive index of substrate

2-2 Needle Method

The needle method was first described by Tikhonravov in 1982 [10]. However, it only began to be widely used in the middle of the 1990s [11, 12]. It consists of adding thin layers at optimal positions in the filter and then adjusting their thickness. Needles are added until a satisfactory solution is found .The optimal position to add needles is determined by calculating the derivative of the merit function (MF) [5-7]with regard to the thickness of an infinitesimally thin layer as a function of the position where it is added.

2-3 Genetic algorithms (GAs)

The (GAs) refers to a model introduced and investigated by John Holland starting design which should be close to the optimal design, otherwise no good results are obtained. Synthesis methods are more general. They create a normally incident radiations, and assume that films are optically homogeneous, the matrix is calculated at each boundary throughout the multilayer as the magnitude of electric and magnetic field vectors alter with the properties of the layer. The characteristic matrix at a wavelength λ for the assembly of k layers is given by

$$M = M1 \;\; M2 \;\; \text{---} \;\; M_k$$

where the characteristic matrix of the j^{th} layer is giving by

$$M_j = \begin{pmatrix} \cos\phi_j & i\frac{\sin\phi_j}{n_j} \\ in_j \sin\phi_j & \cos\phi_j \end{pmatrix}$$

where n_j is the refractive index of the layer and Φ_j is its phase thickness given by

$$\phi_j = \frac{2\pi n_i d_j}{\lambda}$$

with the physical thickness of the layer being d_j. If the calculated characteristic matrix M of the assembly is

$$M = \begin{pmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{pmatrix}$$

represent a better solution to the target problem are given more chances to "re-produce "than those chromosomes representing poorer solution .The "goodness" of a solution may be computed by comparing its evaluation against the population average, or it may be a function of the rank of that individual in the population relative to other solutions [14].

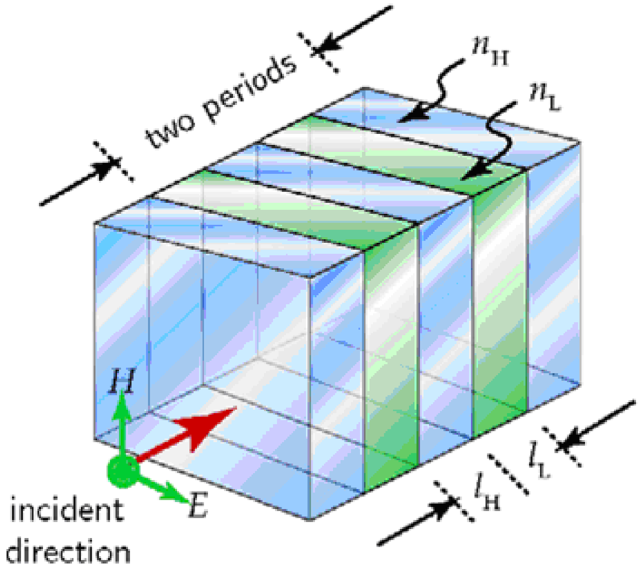
3- RESULTS AND DISCUSSION

Optical Filter Design and Results

High-reflectance dielectric coatings are one of the most important of the optical filters coating, based upon as dielectric alternately high- and low-refractive-index materials are applied to the substrate to form a dielectric multilayer stack cascading these layers to form a periodic structure this structure called (High-reflectance stack), as shown in figure1. By choosing materials of appropriate refractive indices, the various reflected wave fronts can be made to interfere constructively [13] and by his Ph.D. students [14].The application of genetic algorithms to the design of a thin film multilayer coating to achieve a particular reflectance over a definite wavelength region.

In this section we outline the genetic algorithm which we have employed to synthesize optical thin-film systems with various number of layers.

Genetic algorithm (GAs) is based on ideas borrowed from genetics and natural selection. It is a generally adaptable approach for problem solving and is well suited for solving difficult optimization problems where traditional methods are less efficient. Genetic algorithms are a family of computational models inspired by evolution. Encode a potential solution to a specific problem on a chromosome-like data structure and apply recombination operators. Mutation operators are also used to alter potential solution. An implementation of a genetic algorithm begins with a population of (typically random) artificial chromosomes. One then evaluates these structures and allocates reproductive opportunities in such a way that those chromosomes that reflector.



number of layers (M) was varied between 4 and 9. In these properties, we design three efficiency examples of HR in the two different groups of optimization techniques that have been used for designing. The first group of designing uses needle optimization method in the frame of program called (Open Filters), as open source software under the GNU General Public License (GPL) [15].The second groups of designing uses genetic algorithms as synthesis optimization methods.

Open Filters and genetic algorithms calculate the filter properties which using the characteristic matrix approach presented in section 2.
Figures (2.a, 3.a, 4.a) report the design of an HR coating which

to produce a highly efficient

Fig(1)

Air-High index-Low index-Substrate

periodic structure, periods, $(HL)^2$

In this paper we report the design of high reflection filter (HR).The incident medium is air and the substrate index of refraction n_s is 1.5.The high index material ZnS (n_H = 2.35) and low index material MgF_2 (n_H = 1.38) were assumed to be non-dispersive and non-absorbing in the wavelength region of interest. The total optimization physical thickness of design reflectance curve

Figure(2) shows the spectral reflection of high reflection filter design in just only four layers for 300 – 750 nm spectral range, the parameters of this filter are explained in Table 1.

using needle optimization in the frame of program Open Filters. In the same pervious examples of HR filters are designed in the second group of optimization methods called genetic algorithms shown in figures (2.b, 3.b, 4.b).All these Figures presented (offer) the

Table1. The coating parameters of the HR filter in two optimization methods(4 layers)

Needle optimization				**Genetic algorithms**			
	Materials	**Thickness**	**Index**		**Materials**	**Thickness**	**Index**
1	nh	50.472	2.3500	1	nh	88.000	2.3500
2	nl	108.405	1.3800	2	nl	70.000	1.3800
3	nh	48.209	2.3500	3	nh	92.000	2.3500
4	nl	182.318	1.3800	4	nl	124.000	1.3800

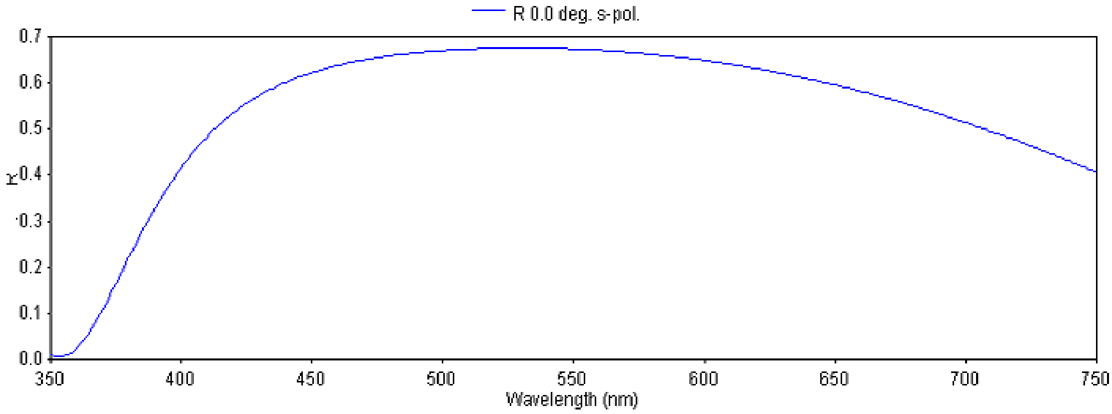


Fig. (2.a): high reflection filter designed by needle optimization method used four layers coating

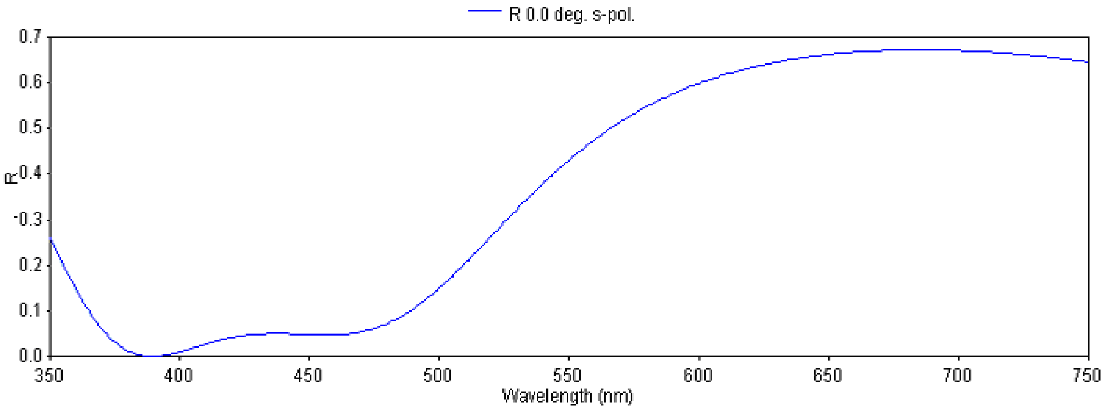


Fig. (2.b): high reflection filter designed by genetic algorithm optimization method used four layers coating

From figure2 is noticed that design of wide band high reflection in just four layers.

Figure3 shown the spectral reflection of high reflection filters design in seven layers for 300 – 1000nm spectral ranges and gave in this few layers reflection approach 95 %. The parameters of this filter are explained in table 2. Figure shown in (3.a) and (3.b) designed without need the refinement method.

Table 2. The coating parameters of the HR filter in two optimization methods (7 layers).

Needle optimization				**Genetic algorithms**			
	Materials	**Thickness**	**Index**		**Materials**	**Thickness**	**Index**
1	nh	58.110	2.3500	1	nh	47.000	2.3500
2	nl	98.974	1.3800	2	nl	119.000	1.3800
3	nh	58.087	2.3500	3	nh	51.000	2.3500
4	nl	98.982	1.3800	4	nl	97.000	1.3800
5	nh	58.098	2.3500	5	nh	57.000	2.3500
6	nl	98.963	1.3800	6	nl	107.000	1.3800
7	nh	58.118	2.3500	7	nh	99.000	2.3500

.

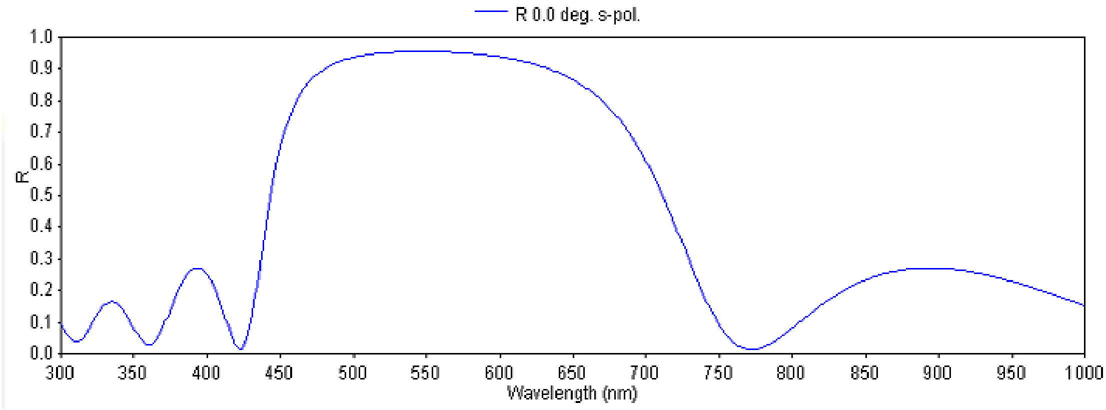


Fig. (3.a): high reflection filter designed by needle optimization method used (7) layers coating

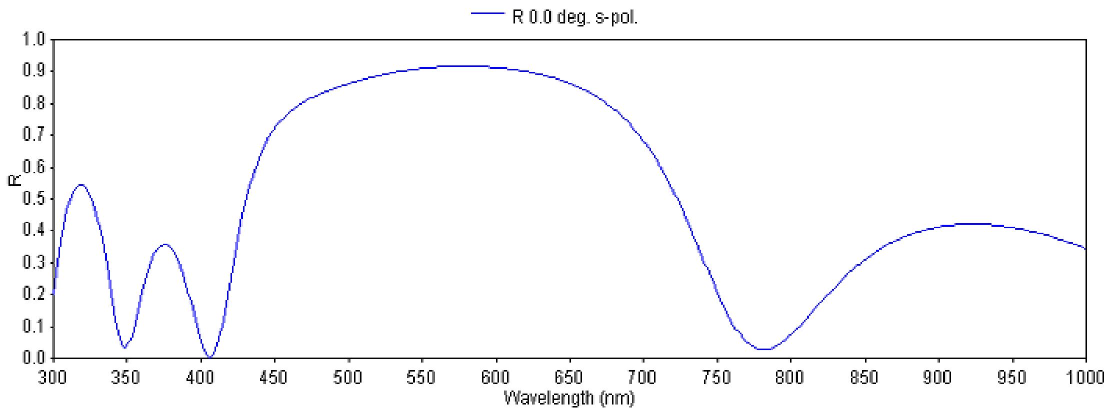


Fig. (3.b).high reflection filter designed by genetic algorithms optimization method used (7) layers coating

Figure 4 shows the spectral reflection of high reflection filter design in nine layers for 300 – 800nm spectral range .The parameters of this filter are explained in table 3

Table 3: The coating parameters of the HR filter in two optimization methods (9 layers).

Needle optimization				Genetic algorithms			
	Materials	Thickness	Index		Materials	Thickness	Index
1	nh	18.810	2.3500	1	nh	18.000	2.3500
2	nl	36.912	1.3800	2	nl	36.000	1.3800
3	nh	82.979	2.3500	3	nh	79.000	2.3500
4	nl	44.028	1.3800	4	nl	64.000	1.3800
5	nh	33.636	2.3500	5	nh	29.000	2.3500
6	nl	56.082	1.3800	6	nl	43.000	1.3800
7	nh	40.206	2.3500	7	nh	24.000	2.3500
8	nl	49.355	1.3800	8	nl	76.000	1.3800
9	nh	25.749	2.3500	9	nh	38.000	2.3500

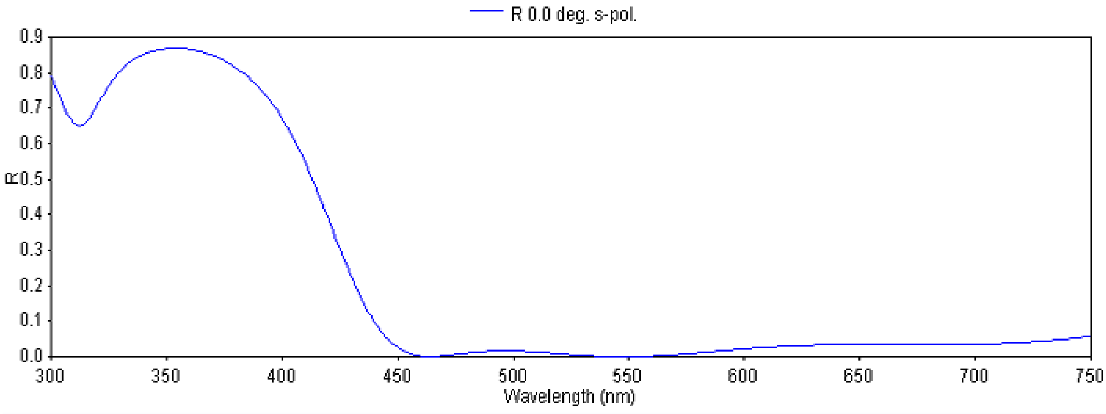


Fig (4.a). high reflection filter designed by genetic algorithms optimization method used (9) layers coating

Figure (4.a) shows design of band pass filter in just only 9 layers without need of refinement technique to improve this design. This figure refers to the cold mirror

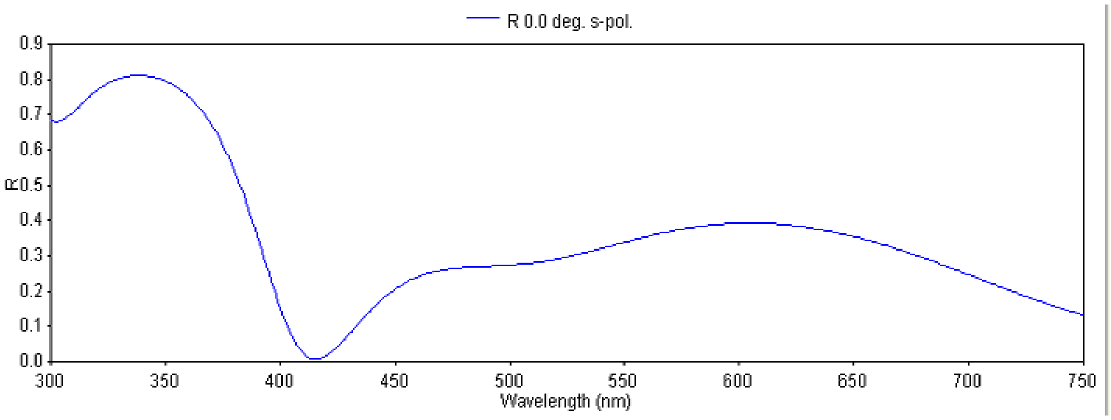


Fig. (4.b). High reflection filter designed by genetic algorithms optimization method used (9) layers coating

4-Conclusion

Needle and genetic algorithms are different in systematic techniques design. The results demonstrate these two different approaches are efficient for designing high reflection filters with very small number of coating layers, this makes us to pass the most difficult problems arise in the design. Result shows that needle method in designing high reflection filters is higher quality than (GAs) method but genetic algorithm is flexible , very fast and faster than needle method for expect the good initial design, with (GAs) approach one does not have to spend as much effort in designing. In this paper we have developed Open Filters, software program for the reflectivity spectrum of non-absorbing dielectric multilayer optical filters.

5-References

1. Optical interference coatings, proceeding of Topical Meeting on Optical Interference Coatings (Optical Society of America, Washington, D. C), 2001.

2. N. Kaiser, and H.K. Pulker, Optical Interference Coatings (Springer, Berlin), 2003.

3. Li Li "Optical coatings for displays," in Optical Interference Coatings, N. Kaiser and H.K.Pulker, ed. (Springer, Berlin), 423-540, 2003.

4. H.A. Macleod," Thin-Film Optical Coating Design in Thin Films for Optical Systems", F.R. Flory(3^{ed}).(Marcel Dekker, Inc., NewYork),1995.

5. J. Dobrowolski and .R. Kemp, "Refinement of optical multilayer systems with different optimization procedures," Appl. Opt., vol. 29, no. 19, pp. 2876–2893, 1990.

6. J. A. Dobrowolski, "Comparison of the fourier transform and flip-flop thin-film synthesis methods," Appl. Opt., Vol. 25, No. 12, pp. 1996–1972, 1986.

7. L. Li and J. A. Dobrowolski, "Computation speeds of different optical thin-film synthesis methods," Appl. Opt., Vol. 31, No. 19, pp. 3790–3799,1992.

8. F. Abelès, "Recherches sur la propagation des ondes lectromagnétiques sinusoïdales dans les milieux stratifiés. Application aux couches mince," Ann. Phys. (Paris) 5, 596–640, 706–782, 1950.

9. H. A. Macleod, Thin-Film Optical Filters, 3rd ed. (Institute of Physics Publishing), 2001.

10. A. V. Tikhonravov, "A method of synthesis of optical coverings which uses the necessary optimality conditions," Vestn. Mosk. Univ. Fiz. Astronomiya 37, 91–93 (1982); translation, Mosc.Univ. Phys. Bull. 37, 108–110, 1982.

11.A. V. Tikhonravov, M. K. Trubetskov, and G. W. DeBell,"Application of the needle optimization technique to the design of optical coatings," Appl. Opt. 35, 5493–5508, 1996.

12. A. V. Tikhonravov, M. K. Trubetskov, and G. W. DeBell, "Optical coating design approaches based on the needle optimization technique," Appl. Opt. 46, 704–710, 2007.

13. J. Holland, Adaptation in Natural and Artificial Systems.(University of Michigan Press), 1975.

14. D. E. Goldberg, Genetic Algorithms in Search, Optimization and Machine Learning. Reading, MA: Addison-Wesley, 1989.

15.S. Larouche and L. Martinu, "OpenFilters: an open source software for the design and optimization of optical coatings," in Optical Interference Coatings on CD-ROM (Optical Society of America), 2007 .