International Journal of Physical Sciences Vol. 5 (01), pp. 057-061, January, 2010
Available online at http://www.academicjournals.org/ijps
ISSN 1992 - 1950 © 2010 Academic Journals

Full Length Research Paper

Optimum designing of thin film filter layers of SiO_2 and SnTe based on optical particle swarm opimizer

H. Arabshahi[1]* and M. Asmari[2]

[1]Physics Department, Ferdowsi University of Mashhad, Mashhad, Iran.
[2]Climatology of Atmospheric Disasters Group, Climatological Research Institute, P. O. Box 91735–676, Mashhad, Iran.

Accepted 19 November, 2009

Optical design of multilayer filter has been carried out using a particle swarm optimizer algorithm. The filters are designed to work for wavelength in the range of 1550 - 1600 nm. Our calculation results show good convergence rate and higher performance in comparison with results based on genetic algorithm. The calculated result for band pass filter layers of Sio_2 and SnTe have also shown that the transmittance parameter is about 0.994. The results for narrow filters show that the values of *S* and *P* reflectance parameter are in fair agreement with other methods and average transmittance parameter is about 0.985 which is 25% better than flip-flop results.

Key words: Optical design, genetic algorithm, narrow filters, transmittance.

INTRODUCTION

It is known that the interference filters are well perspective as for their application in optical devices and actually determine the efficiency and reliability of an apparatus (Fekesh gazi et al., 2000). Therefore, these filters must meet such requirements as the maximum passing energy in the transmission band and the minimum passing energy outside it. This characteristic and the transmission band width determine the least number of layers formed by a simple and known technological procedure that must provide a high reliability of filters. It should be noted that the primary purpose of developers is to provide the maximal selectivity and operational stability of interference filters. The multilayer interference coatings have special characteristics including the spectral characteristics of the passed and reflected light, since the transmittance and the reflectance are determined by the number of layers, their thicknesses and refraction indices (Yafaeva and Valeev, 1969). The transmittance of 99.9% can be obtained due to the multilayer coatings with 3 – 15 and more repeated layers with high and low refractive indices. However, a large number of interference layers in the form of film structures with, at least, seven layers leads to a significant complication of the process of synthesis of such systems. It is basically connected with the difficulty to control the thickness of sputtered layers. In addition, the random statistical errors in separate layers highly influence the resulting optical description of coatings. By developing of optical systems, especially optical communication, research in optical devices has been interested. One of the important filters in optical communication and many other optical apparatus is optical band pass filters. The optical thin films are formed from dielectric thin films which have different thicknesses and polarization. Generally band pass filters desining is used for one-quarter wavelength films. This films are made from two matters with high and low break coefficient (Macleod, 2001; Thelen, 1986). Advantages of this designing style are its simplicity but for designing a proper filter, the number of thin films and their thickness is important. Therefore the final product is sensitive to thickness parameters and designing style (Li et al., 1996). Different methods have been used for optimization and designing of optical films (Jun et al., 2008; Yalkovev et al., 2002). The GA algorithm at global optimization is one of the best methods, but its disadvanteges is low convergence rate in reaching to final response (Shokooh-Saremi et al., 2004).

Model of particle swarm optimizer

The different groups of optimization technique have been used for designing optical filters. The first group is the methods which need to initial design and the second group like PSO are the methods which start with an initial

*Corresponding author. E-mail: Arabshahi@um.ac.ir.

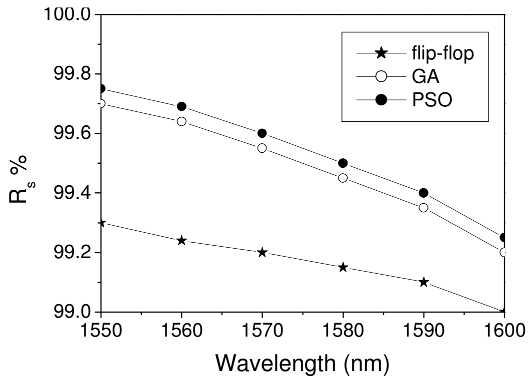

Figure 1. The reflectance curves (*Rs*) for three methods: PSO (present paper), GA and flip-flop.

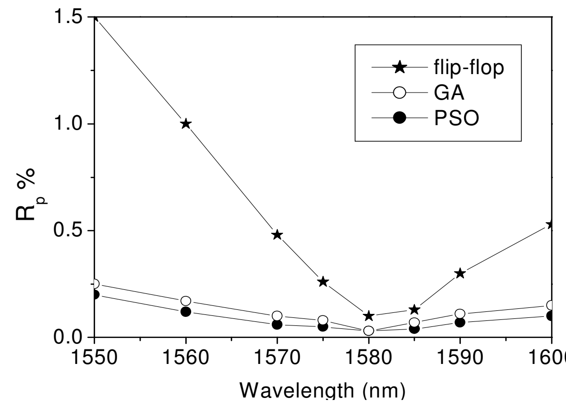

Figure 2. The reflectance curves (*Rp*) for three methods: PSO (present paper), GA and flip-flop.

random plan (Kennedy et al., 1995; Van Den Berg, 2002).

The PSO method is an iterative method that is based on the search behavior of a swarm of *m* particles in a multidimensional search space (Kennedy et al., 1997). In each iteration the velocities and positions of all the particles are updated. For each particle *i*, its velocity vector $\vec{v}_i$ is updated according to equation 1. The inertia weight $w > 0$ controls the influence of the previous velocity vector. The current position of the particle is denoted by $\vec{x}_i$. Parameter $c_1 > 0$ controls the impact of the best position $\vec{y}_i$, that is, Parameter $c_2 > 0$ determines the impact of the position $\hat{y}_i$ that has been found so far by any of the particles in the neighborhood of particle i. Usually c_1 and c_2 are set to the same value. Random values r_1 and r_2 are drawn with uniform probability for each particle at every iteration.

$$\vec{v}_i(t+1) = W.\vec{v}_i(t) + c_1.r_1.(\vec{y}_i - \vec{x}_i) + c_2.r_2.(\hat{y}_i - \vec{x}_i) \quad (1)$$

$$\vec{x}_i(t+1) = \vec{x}_i(t) + \vec{v}_i(t+1) \quad (2)$$

After updating particle velocity, the particles move with their new velocity to their new positions. Then, for each particle i, the objective function f is evaluated at its new position. If $f(\vec{x}_i(t+1)) < f(\vec{y}_i)$ the best position $\vec{y}_i$ is updated accordingly, that is and $\vec{y}_i$ is set to $\vec{x}_i(t+1)$.

The different structures have presented for the PSO method. They are including of star topology, ring topology and wheel topology. In this work ring topology has been carried out (Dobrowolski and Kemp, 1992). In this structure each particle is connected only by nearest neighbored. The convergence rate ring topology is smaller than other structures. But because of increasing independence of search for each particle, we reach to global optimization by high probability.

RESULTS

The results of calculations of the reflectance curves R_s and R_p spectral curves are shown in Figures 1 and 2, respectively. The angle of incidence with polarization plan is 45°, the refractive indices of substrate is 1.5 and layers constituted from two materials SiO_2, SnTe with refractive indices of 1.465 and 2.1, respectively. In this design, fitness function is equaled to the following equation

$$F = \sum_{\lambda_i} (|R_s - 1| + |R_p|) \quad (3)$$

Where; λ_i is the wavelength of the i th sample and R_s and R_p are the reflectance for S and P polarization. According to equation 3, the value of F decrease when R_s and R_p approach to 1 and 0, respectively. The filter will be stronger if the value of F be less. After 500 iteration the fitness function has been equal to 0.025.

In Table 1 the designing results by present method have been compared to GA method (Asghar et al., 2009) and flip-flop (Asghar et al., 2003). Usually for comparing quality of optical filter in two *S* and *P* polarization the following equation is used,

$$P = \left| \frac{R_s - R_p}{R_s - R_p} \right| \quad (4)$$

Which can be seen in the quality of optical filter is higher for larger value of *P*. In Table 2 the designing results have been brought for all the method. It is seen from this

Table 1. Thickness of films in three methods.

PSO Algorithm (This work)		**GA Algorithm**		**Flip-flop Algorithm**	
R	d (A)	R	d (A)	R	d (A)
H	1943.3	H	2237	L	1360
L	3225.1	L	2730	H	1500
H	1724.9	H	2207	L	3500
L	3055.5	L	2313	H	2000
H	1761.4	H	2144	L	4600
L	3340.8	L	2587	H	1400
H	1763.9	H	2275	L	2600
L	3292.6	L	2731	H	1500
H	2127.6	H	2343	L	6100
L	3274.1	L	3933	H	800
H	2127.7	H	2017	L	5000
L	3662.6	L	2946	H	1900
H	1883.9	H	2322	L	2000
L	3110.4	L	2347	H	2700
H	1221.7	H	2177	L	2700
L	2818.5	L	3084	H	2000
H	1849.5	H	1625	L	3300
L	3356.7	L	3033	H	1800
H	1987.1	H	2321	L	600

R = Refractive Index; $H \rightarrow SnTe(2.1)$; d = Thickness; $L \rightarrow SiO_2(1.465)$

Table 2. The different parameters for three methods.

	PSO Algorithm (This work)	**GA Algorithm**	**Flip-flop Algorithm**
$\sum d$ (µm)	4.8566	4.6787	5.9
$\sum Rd$ (µm)	8.2783	8.1276	9.5
Max.(P)	1	1	0.999
Min.(P)	0.8970	0.9899	0.97
Mean.(P)	0.9908	0.9955	0.99
Iteration	500	1500	50

Table that the designing result for the present method is better than other models.

A band pass filter is designed at the limit of 400 - 800 nm in *S* polarization. This filter has broad application in industry. A sample of this filter was designed and corrected in five stages. We applied the final result of designing (Asghar et al., 2009) with the PSO purposed method. The incident angle related to polarization plane is 90˚ and the refractive indices of incident circumference and sublayer are selected 1 and 1.52, respectively. All of mentioned coefficients are calculated in 500 nm wavelength and thickness. Figure 2 shows this BPF filter. The initial thickness which is used in the algorithm is one-quart wavelength. Consequently we reach to final response after 500 iterations.

The following fitness function is used

$$F = \sum_{\lambda_i} (|T-1| + |\overline{T}|) \tag{5}$$

Where; *T* is the transmission value in the range of 500 - 700 nm. Also $\overline{T}$ is the transmission value in out of range 500 - 700 nm in *S* polarization. It is obvious that the smaller value of *F*, make the better filter. In Figure 3 the curve of transmittance is compared for two methods of PSO and classic (Kennedy et al., 1997). Also this filter optimized by use of GA algorithm that its result was as same as PSO algorithm. In Table 3 the thickness values for three methods have been shown. It is seen from

Table 3. The parameters for comparison between the qualities of designed filters.

	PSO Algorithm	Classic	GA Algorithm
Max. (T)	1	0.999	1
Mean. (T)	0.99	0.975	0.99
Min. $(\overline{T})$	0.0001	0.00009	0.0001
$\Delta\lambda_{0.5}$ (nm)	200	230	250
$\Delta\lambda_{0.1}$ (nm)	250	250	250
Iteration	500	1500	2000

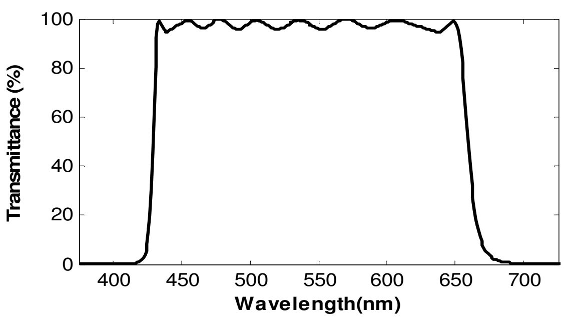

Figure 3. The transmittance curve of designed filter.

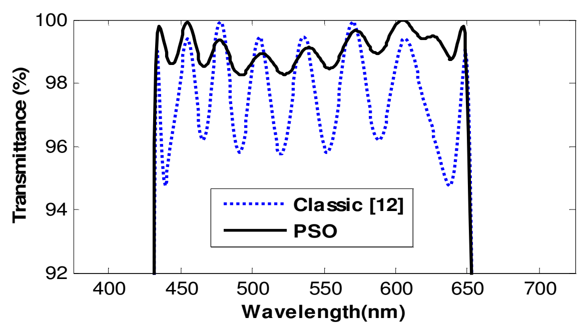

Figure 4. Comparison of optimized filters between PSO (proposed method) and classic method.

Table 4. The thickness values for three methods.

PSO Algorithm (This work) D (A)	Classic d (A)	Algorithm GA (Our work) d (A)
1760.2	1770	1760
958.8	963	958.5
1238.0	1206.3	1188
750.4	963	750.4
850	960	850
973	977.4	971.3
1073.5	963	1071.5
987.9	977.4	928.2
770.5	963	1154.3
978	977.4	974.7
1158.9	963	768.3
1122.8	1106.3	1202.7
645	960	650
1108.1	1106.3	1111
1464.8	963	1466
1282.1	1444.3	1282.7

Table 4 and Figure 4 that the PSO method has the better improvement in comparison with classic method (Asghar et al., 2009).

Although the optimization results by the PSO method are same of GA method but convergence rate of PSO is different.

CONCLUSION

Here optical design of multilayer filter has been carried out to calculate optimum designing of optical multilayer filters. The obtained results by swarm optimizer algorithm show that the designing of filters by PSO has more convergence rate and higher performance in comparison with other methods. The results for narrow filter show that the values of *S* and *P* reflectance parameter are in fair agreement with other methods and average transmittance parameter is about 0.985 which is 25% better than flip-flop results.

REFERENCES

Asghar MH, Khan MB, Naseem S (2003). Modeling thin film multilayer broad-band-pass filters in visible spectrum, Czechoslovak J. Phys. 53: 1209–1217.

Asghar MH, Shoaib M, Placido M, Naseem S (2009). Modeling and pre-

paration of practical optical filters, Curr. Appl. Phys. 9: 1046-1053.
Dobrowolski JA, Kemp A (1992). Flip-flop thin-film design program with enhanced capabilities, Appl. Opt. 31: 3807-3812.
Fekeshgazi V, Yu V, Pervak Y, Pervak A (2000). Properties and application of the unequal thickness two-component interference systems 3: 371-378.
Jun M, Jing-Shan W, Denker C, Wang H (2008). Optical Design of Multilayer Achromatic Waveplate by Simulated Anneling Algorthm, Chin. J. Astron. Astrophys. 8(3): 349-361.
Kennedy J (1995). Particle swarm optimization, Phys. Rev. B. 13: 5344-5348.
Kennedy J (1997). A discrete binary version of the particle swarm optimization, Rev. B. 13: 5776-5781.
Li L, Dobrowolski J (1996). Visible broadband, wide-angle, thin-film multilayer polarizing beam splitter, Appl. Opt. 35: 2221-2225.
Macleod H (2001). Thin Film Optical Filters, IOP, Bristol.
Shokooh-Saremi M, Nourian M, Mirsalehi M, Keshmiri H (2004). Design of multilayer Polarizing beam splitters using genetic algorithm, Optic Commun. 233: 57-65.
Thelen A (1986). Design of Optical Interference Coating, Mac Graw-Hill.
Van den Bergh F (2002). An Analysis of Particle Swarm Optimizers, Ph.D. dissertation, Department Computer Science University Pretoria, Pretoria, South Africa.
Yafaeva VB, Valeev AS (1969). Wideband systems for band-pass filters 7: 28-32.
Yalkovlev V, Tempea M (2002). Optimization of Chirped Mirrors, Appl. Opt. 41: 1653-1657.