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Optical Design of Multilayer Filter by using PSO Algorithm

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Abstract: Particle swarm optimizer (PSO) algorithm has been used for optimum designing of optical thin film filters in wavelength of 1520-1560 nm. The obtained results has been compared with best previous methods such as genetic algorithm. In the same condition our results have more convergence rate and higher performance. 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 0.9992 which is 20% better than flip-flop results. The calculated results for band pass filter also show that transmittance parameter is about 0.9907 which is better than other method.

Key words: Band pass filter, optical thin film and particle swarm optimizer algorithm

INTRODUCTION

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 and Dobrowolski, 1996). Different methods have been used for optimization and designing of optical films (Jun *et al*., 2008; Yalkovev and Tempea, 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). In this study the PSO algorithm has been used for designing band pass filters. The obtained results show that PSO algorithm has more convergence rate and higher performance.

MATERIALS AND METHODS

Particle Swarm Optimizer Algorithm: 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 random plan (Kennedy, 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, 1997). In each iteration the velocities and positions of all the particles are updated. For each particle *i*, its velocity vector $\bar{v}_i$ is updated according to Eq. 1. The inertia weight w > 0 ontrols the influence of the previous velocity vector. The current position of the particle is denoted by $\bar{x}_i$. Parameter $c_1 > 0$ controls the impact of the best position $\bar{y}_i$, i.e. Parameter $c_2 > 0$ determines the impact of the position $\bar{y}_i$ 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.

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

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

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

The different structures have presented for the PSO method. They are including of star topology, ring

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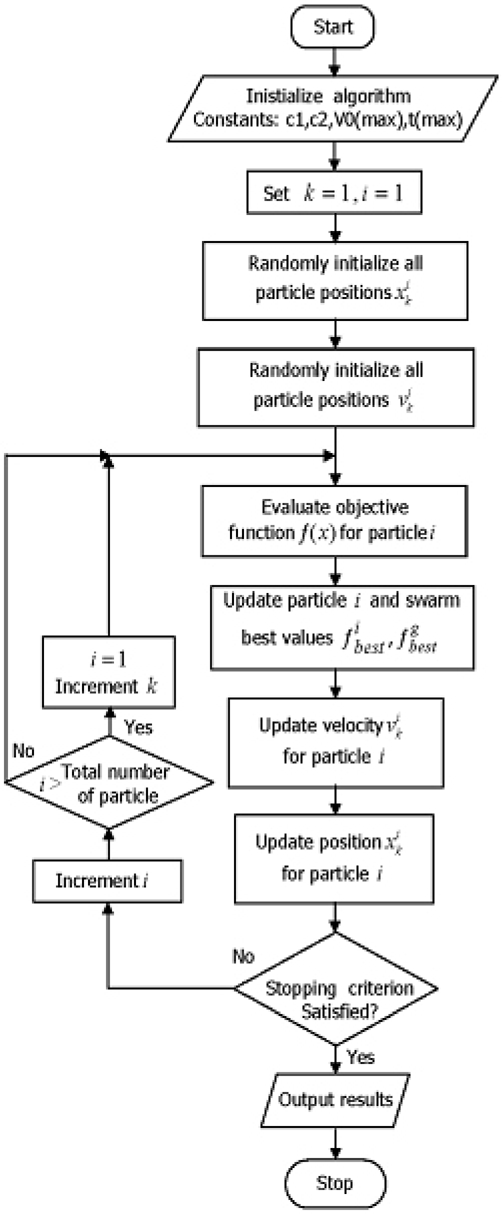

Fig. 1: Flowchart of PSO algorithm

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 neighboreds. 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. Fig. 1 shows the process of the PSO method.

RESULTS AND DISCUSSION

Optical Filter Design and Results:

Narrows band pass filter design: Here we want to design a C band filter (in wavelengths of 1528-1560 nm) which has been applied in WDM (Wavelength-Division Multiplexing) optical communication systems. The angle of incidence with polarization plan is 45º, the refractive indices of substrate is 1.5 and layers constituted from two materials SiO_2, Ta_2O_5 with refractive indices of 1.465 and 2.065, respectively. In this design, fitness function is equaled to the following equation,

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

Where is the wavelength of the i th sample and R_s and R_p are the reflectance for S and P polarization. According to Eq. 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 730 iteration the fitness function has been equal to 0.034.

In Table 1 the designing results by PSO 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,

Table 1: Thickness of films in three methods

PSO Algorithm (This work)		GA Algorithm [6]		Flip-flop Algorithm [6]	
R	d (A)	R	d (A)	R	d (A)
H	1957.3	H	2237	L	1360
L	3256.1	L	2730	H	1500
H	1749.9	H	2207	L	3500
L	3018.5	L	2313	H	2000
H	1771.4	H	2144	L	4600
L	3250.8	L	2587	H	1400
H	1933.9	H	2275	L	2600
L	3492.6	L	2731	H	1500
H	2027.6	H	2343	L	6100
L	3574.1	L	3933	H	800
H	2027.7	H	2017	L	5000
L	3492.6	L	2946	H	1900
H	1933.9	H	2322	L	2000
L	3250.4	L	2347	H	2700
H	1771.7	H	2177	L	2700
L	3018.5	L	3084	H	2000
H	1749.5	H	1625	L	3300
L	3256.7	L	3033	H	1800
H	1957.1	H	2321	L	600

R= Refractive Index; d= Thickness; $H \rightarrow Ta_2O_5(2.065)$; $L \rightarrow SiO_2(1.465)$

Table 2: The different parameters for three methods

	PSO Algorithm (This work)	GA Algorithm [6]	Flip-flop Algorithm [6]
$\sum d$ (μm)	4.8491	4.7372	5.96
$\sum Rd$ (μm)	8.2367	8.2401	9.6674
Max.(P)	1	1	0.9995
Min.(P)	0.9978	0.9954	0.9710
Mean.(P)	0.9992	0.9986	0.9927
Iteration	730	13400	25
Design Time	2 min Processor: 1.7GHz	25min Processor: 0.7GHz	30sec Processor: 0.7GHz

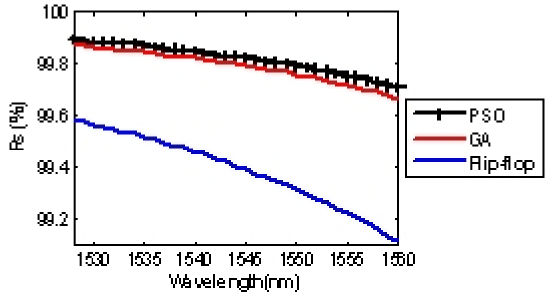

Fig. 2: The reflectance curves (*Rs*) for three methods: PSO (present paper), GA and flip-flop

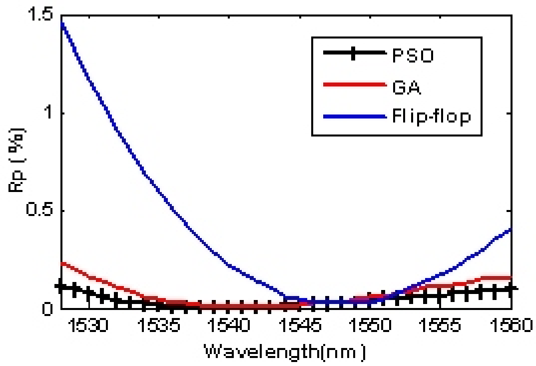

Fig. 3: The reflectance curves (*Rp*) for three methods: PSO (present paper), GA and flip-flop

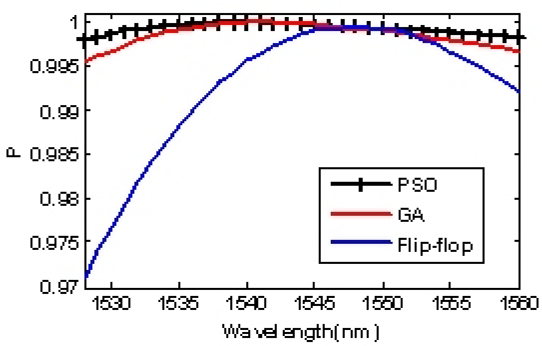

Fig. 4: The quality coefficient curves (*P*) for three methods: PSO (present paper), GA and flip-flop

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

Which can be seen the quality of optical filter is higher for larger value of *P*.

Fig. 2 and 3 show the reflectance curves R_s and R_p for all of the method. Fig. 4 shows also the quality curves. In Table 2 the designing results have been brought for all the method. It is seen from this table that the designing result for PSO method is better than other models.

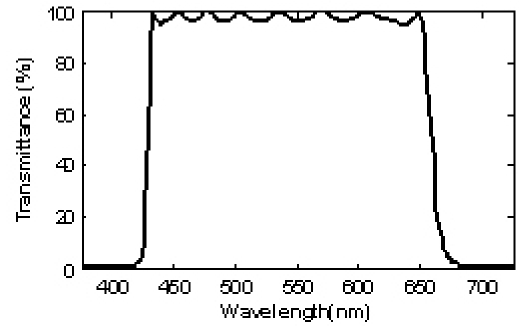

Fig. 5: The transmittance curve of designed filter

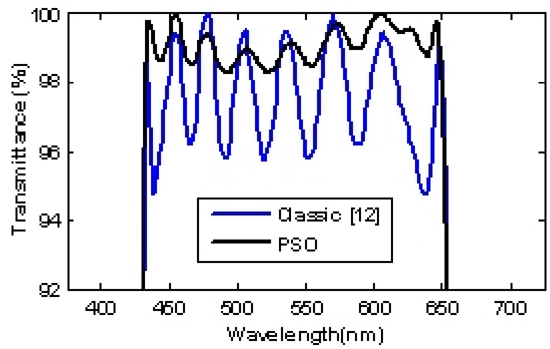

Fig. 6: Comparison of optimized filters between PSO (proposed method) and classic method

Band pass filter design: A band pass filter is designed at the limit of 375-750 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. This filter is designed one-quart wavelength films by components of

$$2\bar{L}L(2HL)^2(2\bar{H}L)^5(2HL)^2 2M$$

where $L \rightarrow Cryolite(135)$,

$\bar{L} \rightarrow SiO_2(1.46)$,

$M \rightarrow Y_2O_3(1.8)$,

$H \rightarrow ZnS(235)$ and.

$\bar{H} \rightarrow ZnSe(2.66)$

All of mentioned coefficients are calculated in 520 nm wavelength and thickness. Fig. 3 shows this BPF filter. The initial thickness which is used in the algorithm is one-quart wavelength. Consequently we reach to final response after 460 iterations.

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

	PSO Algorithm	Classic [33]	GA Algorithm
Max. (*T*)	1	0.9995	1
Mean. (*T*)	0.9907	0.9755	0.9907
Min. ($\bar{T}$)	0.0001	0.00009	0.0001
$\Delta\lambda_{0.5}$ (nm)	230	232	230
$\Delta\lambda_{0.1}$ (nm)	247	244	247
Iteration	450	13400	2750

Table 4: The thickness values for three methods

PSO Algorithm (This work) d (A)	Classic [12] d (A)	GA Algorithm (Our work) d (A)
1760.2	1780.8	1760.8
958.8	963	958.5
1138.0	1106.3	1138.1
750.4	963	750.4
1115.9	1106.3	1115.9
1098.8	963	1099.2
929.4	977.4	929.3
1135.4	963	1135.7
962.4	977.4	962.5
858	963	855.1
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
646.2	963	650.6
1108.1	1106.3	1111
1464.8	963	1466
1282.2	1444.4	1282.8

The following fitness function is used

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

Where *T* is the transmission value in the range of 430-660 nm. Also is the transmission value in out of range 430-660 nm in *S* polarization. It is obvious that the smaller value of *F*, make the better filter. In Fig. 5 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 shown from Table 4 and Fig. 6 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

In this research particle swarm optimizer algorithm has been used for optimum designing of optical multilayer filters. The obtained results show that the designing of filters by PSO has more convergence rate and higher performance. 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 0.9992 which is 20% better than flip-flop results.

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