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Synthesis of Chained Achromatic Layer Systems Forming Controlled Low Transmittance Bands

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Abstract

The approach utilized in the design of achromatic periods formed of two layers a high-index and a low-index is developed by combining the first two periods together. These two periods are therefore reduced to three layers a central one, an upper layer and a lower layer. Both the upper and lower layers are matched to the central at two different wavelengths. This forms the so called a combined achromatic period or the basic unit. Multilayers showing low transmittance bands are then synthesized of this basic unit. Parameters used in the synthesis of such multilayers are pointed out and their control role is investigated.

Keywords: Thin Films, Design, Light Propagation

1. Introduction

Recalling the procedure followed in forming two layer combination [1-3] which are matched according to the relation

$$h_H \underset{\lambda_{oN}}{\left(n_H G_H\right)} = h_L \underset{\lambda_{oN}}{\left(n_L G_L\right)} \tag{1}$$

where n_H and n_L are the refractive indices for the high- and low-layers, respectively, and the h are the physical thicknesses. Multilayers systems of N such achromatic periods were formed so that each period matched at specified wavelength λ_{oN}, where N stands for period number. The different wavelengths, at which the different periods are formed, are specified according to the quantity ξ defined as

$$\xi = \frac{\lambda_{oN}\left[h_H\left(\mathrm{d}n_H/\mathrm{d}\lambda_{oN}\right) - h_L\left(\mathrm{d}n_L/\mathrm{d}\lambda_{oN}\right)\right]}{\left[n_H h_H - n_L h_L\right]} \tag{2}$$

In the present work equation (1) is modified to [4]

$$\mathscr{M}\, h_H \underset{\lambda_{oN}}{\left(n_H G_H\right)} = \mathscr{N}\, h_L \underset{\lambda_{oN}}{\left(n_L G_L\right)} \tag{3}$$

where $\mathscr{M}$ and $\mathscr{N}$ are real numbers [5].

Another modification is introduced here in the multilayer synthesis process. In a previous work [2,3] multilayers of achromatic periods (Equation (1)) were built up by calculating the first achromatic period then subsequent periods were automatically built up by the way of (1) and (2). In the present work the first achromatic period is calculated by choosing an initial central layer then an upper layer is calculated by matching to this central at the design starting wavelength, by way of (3), then a lower layer is matched to the central at another wavelength. The convention of lower and upper is considered according to positions of substrate and surrounding medium with respect to the first central. Once the above three layers are calculated they are considered as the basic unit. The process of building this basic unit is the same as combining the two middle layers in the first two achromatic periods. Subsequent layers are calculated by considering the lower layer in the basic unit a central for the following layer, in a chained manner, and so on. By this means each layer, except the first and the last layers in whole system, serves as a central layer.

2. Design

Six quantities are first specified, namely the film materials, starting wavelength, number of layers, design number ξ, $\mathscr{M}$ and $\mathscr{N}$. **Table 1** shows design details for a multilayer formed of Zinc Sulphide and Cryolite. These materials are chosen here only for illustration without having any particular significance in the theory *i.e.* any two materials (high and low) will work. The first central layer is chosen as a high index layer which is calculated as a quarter of the starting wavelength 1060 nm. $\mathscr{M}$ is

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chosen as 0.77, $\mathscr{N}$ as 1.3 and ξ as 1.01. The upper layer, to the air side, is then calculated by way of (3). By way of (2) the second reference Wavelength, after the starting wavelength, is then calculated and then the lower layer by way of (3) is calculated but at the second reference. It is worth mentioning here that the first central layer may be chosen as a low index as well. This will not affect our design approach. This last calculated layer is then considered the central for the subsequent layer, a new reference wavelength, by way of (2), and so on.

Design details are listed in **Table 1** and the resulting transmittance spectrum in **Figure 1** shows high-transmittance bands alternating with low transmittance bands [6]. The transmittance simulations are performed by means of a program based on an algorithm presented by Liddell [7]. Throughout this paper only the region of spectrum including the central second order low transmittance band approx. 400 nm - 900 nm will be considered.

3. Illustrations

If in the above design all calculations are done by way of (1) instead of (3) ($\mathscr{M}$ =1, $\mathscr{N}$ = 1) and ξ also taken as unity the resulting design is listed in **Table 2**. Setting all parameters to unity results in the suppression of the central minimum and all even orders (**Figure 2**). Comparing with thicknesses in **Table 1** it can be seen that increasing the ratio h_L/h_H is one way for keeping transmittance minima in place. Another way is assigning ξ values bigger than unity. This is shown in the design listed in **Table 3** and the resulting transmittance curve in **Figure 3**. Notice the appearance of central minimum but in a de-

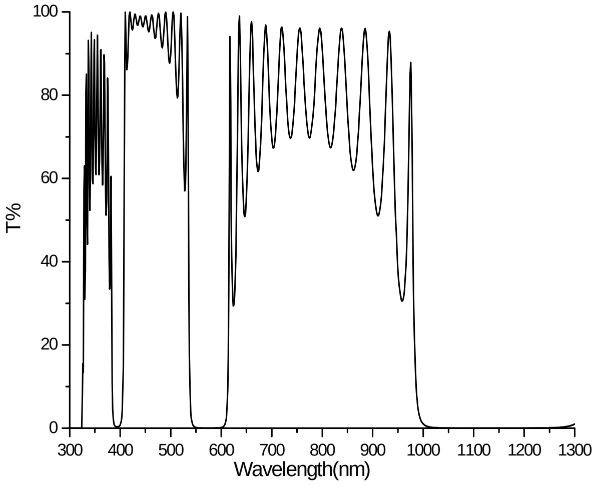

Figure 1. Transmittance spectrum for design listed in Table 1. Increasing the ratio h_L/h_H is one way for manifesting the second order central minimum in addition to enhancing T% on the short wave side of this central minimum.

Table 1. Design details for initial parameters: Start wave: 1060, ξ: 1.01, $\mathscr{M}$: 0.77, $\mathscr{N}$: 1.3 no of layers: 25. Every reference wave for every layer is the wavelength matching this layer to the next layer in the table.

Layer no.	Physical Thickness (after multiplication by $\mathscr{M}$ or $\mathscr{N}$ in nm)	Material	Reference waves λ_o (nm)
0		Air	
1	264	Cryolite	1060
2	91	ZnS	373
3	265	-	372
4	90.7	-	371
5	266	-	370
6	90.4	-	369
7	267	-	368
8	90.1	-	367
9	268	-	366
10	89.8	-	365
11	269	-	364.9
12	89.5	-	364
13	270	-	363
14	89.1	-	362
15	271	-	361
16	88.8	-	360
17	272	-	359
18	88.4	-	358
19	273	-	357
20	88.1	-	356
21	274	-	355
22	87.8		354
23	275		353
24	87.4		352
25	276		
	Substrate	Glass	

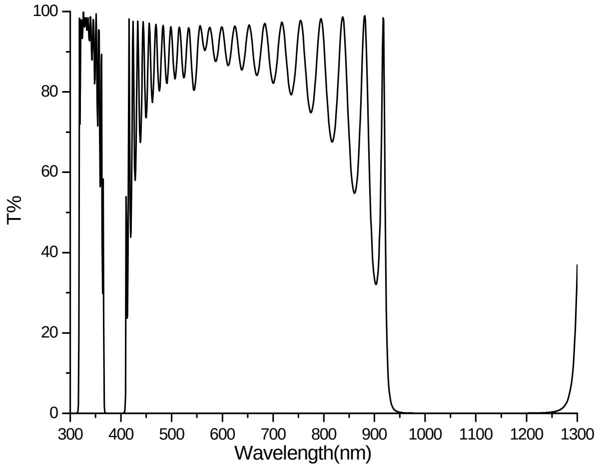

Figure 2. Transmittance spectrum for design listed in Table 2. When ξ, $\mathscr{M}$ and $\mathscr{N}$ are taken as unity the second order central minimum is suppressed.

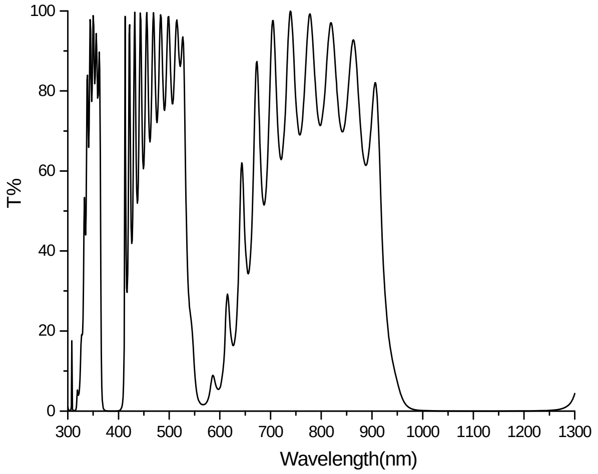

Figure 3. Transmittance spectrum for design listed in Table 3. Increasing ξ is another way for exhibiting the second order central minimum.

Table 2. Design details for initial parameters: Start wave: 1060, ξ: 1, $\mathscr{M}$: 1, $\mathscr{N}$: 1 no of layers: 25. Reference wavelength the same for all layers.

Layer no.	Physical Thickness (after multiplication by $\mathscr{M}$ or $\mathscr{N}$ in nm)	Material	Reference waves λ_o (nm)
0		Air	
1	203	Cryolite	1060
2	118	ZnS	-
3	203	-	-
4	118	-	-
5	203	-	-
6	118	-	-
7	203	-	-
8	118	-	-
9	203	-	-
10	118	-	-
11	203	-	-
12	118	-	-
13	203	-	-
14	118	-	-
15	203	-	-
16	118	-	-
17	203	-	-
18	118	-	-
19	203	-	-
20	118	-	-
21	203	-	-
22	118		-
23	203		-
24	118		-
25	203		
	Substrate	Glass	

Table 3. Design details for initial parameters: Start wave: 1060, ξ: 1.25, $\mathscr{M}$: 1, $\mathscr{N}$: 1 no of layers: 25. Every reference wave for every layer is the wavelength matching this layer to the next layer in the table.

Layer no.	Physical Thickness (after multiplication by $\mathscr{M}$ or $\mathscr{N}$ in nm)	Material	Reference waves λ_o (nm)
0		Air	
1	203	Cryolite	1060
2	118	ZnS	983
3	205	-	913
4	117	-	848
5	207	-	789
6	115	-	735
7	210	-	686
8	113	-	642
9	214	-	603
10	111	-	568
11	219	-	536
12	108	-	508
13	227	-	482
14	104	-	459
15	236	-	437
16	99	-	417
17	249	-	397
18	93	-	378
19	267	-	359
20	87	-	335
21	289	-	277
22	79		275
23	320		272
24	71		269
25	364		
	Substrate	Glass	

formed state. Here appears the refining effect of $\mathscr{M}$ and $\mathscr{N}$.

Increasing the ratio h_L/h_H further by way of $\mathscr{M}$ and $\mathscr{N}$ results in broadening the central minimum with respect to the spectrum. This is shown in **Figure 4**.

Concerning the transmittance fluctuations on either side [8-11] of the central minimum it is seen from **Figures 1** and **3** that ripple on the short wavelength side is less obvious than that on the long wavelength side. This is another effect of increasing the ratio h_L/h_H.

If the opposite is done by increasing the ratio h_H/h_L, ripple on the long wavelength side is greatly improved as shown in **Figure 5**. **Figure 6** is a further illustration for this last design which is extended to 35 layers as an in-

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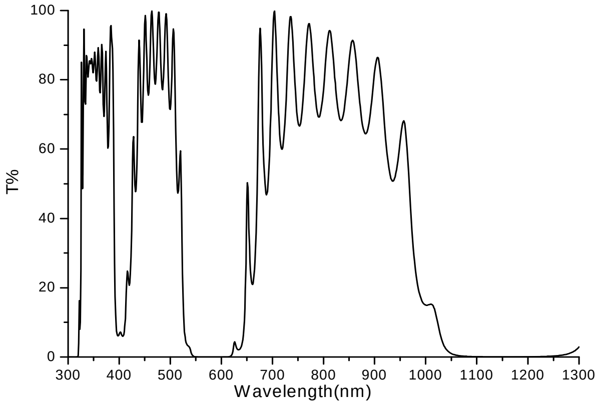

Figure 4. Transmittance spectrum for design listed in Table 4. Increasing the ratio h_L/h_H further results in broadening the central minimum with respect to the spectrum.

Table 4. Design details for initial parameters: Start wave: 1060, ξ: 1.04, $\mathscr{M}$: 0.75, $\mathscr{N}$: 1.5 no of layers: 25. Every reference wave for every layer is the wavelength matching this layer to the next layer in the table.

Layer no.	Physical Thickness (after multiplication by $\mathscr{M}$ or $\mathscr{N}$ in nm)	Material	Reference waves λ_o (nm)
0		Air	
1	271	Cryolite	1060
2	78	ZnS	278
3	276	-	277.3
4	77	-	277.9
5	281	-	277.5
6	76	-	277.1
7	286	-	276.7
8	74	-	276.3
9	291	-	275
10	73	-	274.9
11	298	-	274.4
12	71	-	273.9
13	304	-	273.4
14	70	-	272.9
15	311	-	272.4
16	68	-	271.8
17	319	-	271.2
18	66	-	270.6
19	327	-	270
20	65	-	269
21	335	-	268.8
22	63		268.2
23	343		267
24	62		266
25	353		
	Substrate	Glass	

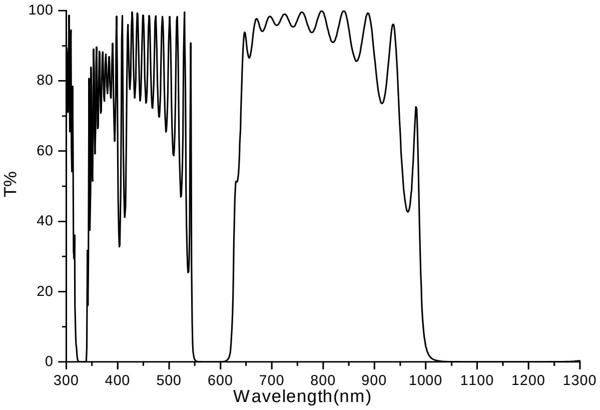

Figure 5. Transmittance spectrum for design listed in Table 5. Increasing the ratio h_H/h_L instead of h_L/h_H improves ripple on the long wavelength side of the central minimum.

Table 5. Design details for initial parameters: Start wave: 1060, ξ: 1.12, $\mathscr{M}$: 1.4, $\mathscr{N}$: 0.7 no of layers: 25. Every reference wave for every layer is the wavelength matching this layer to the next layer in the table.

Layer no.	Physical Thickness (after multiplication by $\mathscr{M}$ or $\mathscr{N}$ in nm)	Material	Reference waves λ_o (nm)
0		Air	
1	145	Cryolite	1060
2	169	ZnS	1019
3	146	-	980
4	168	-	943
5	146	-	908
6	167	-	874
7	147	-	841
8	166	-	810
9	148	-	780
10	165	-	752
11	149	-	725
12	164	-	700
13	150	-	676
14	162	-	653
15	152	-	632
16	161	-	611
17	154	-	592
18	159	-	574
19	156	-	557
20	156	-	541
21	158	-	526
22	154		512
23	161		498
24	151		485
25	164		
	Substrate	Glass	

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Table 6. Design details for initial parameters: Start wave: 1060, ξ: 1.12, $\mathscr{M}$: 1.4, $\mathscr{N}$: 0.7 no of layers: 35. Every reference wave for every layer is the wavelength matching this layer to the next layer in the table.

Layer no.	Physical Thickness (after multiplication by $\mathscr{M}$ or $\mathscr{N}$ in nm)	Material	Reference waves λ_o (nm)
0		Air	
1	145	Cryolite	1060
2	169	ZnS	1019
3	146	-	980
4	168	-	943
5	146	-	908
6	167	-	874
7	147	-	841
8	166	-	810
9	148	-	780
10	165	-	752
11	149	-	725
12	164	-	700
13	150	-	676
14	162	-	653
15	152	-	632
16	161	-	611
17	154	-	592
18	159	-	574
19	156	-	557
20	156	-	541
21	158	-	526
22	154		512
23	161		498
24	151		485
25	164		472
26	148		460
27	167		449
28	145		438
29	172		427
30	141		417
31	177		407
32	137		397
33	182		387
34	132		378
35	189		
	Substrate	Glass	

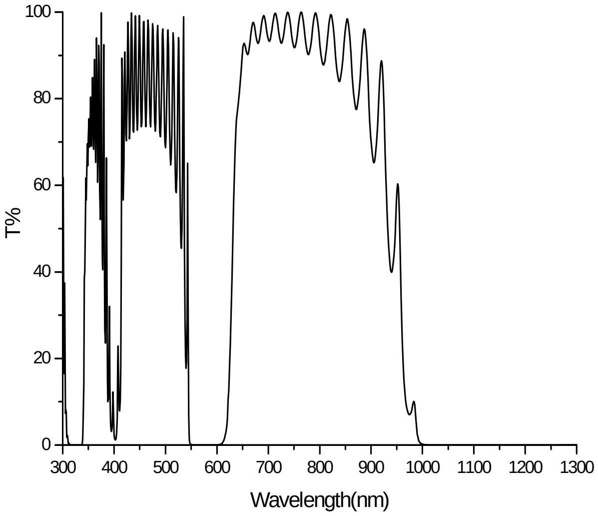

Figure 6. Transmittance spectrum for design listed in Table 6. Increasing no. of layers in the previous design affects the low transmittance bands rather than the high ones.

vestigation for the effect of increasing no. of layers. Although the reflection bands are got more defined the transmittance ones are seriously affected.

4. Conclusions

A new approach for synthesizing optical multilayer structures is presented. The resulting transmittance spectrum is also studied. The essential modifications to the basic theory introduced effective elements which revealed valuable control on the transmittance spectral characteristics of the variety of systems under study. Those control actions also unveiled useful applications for the systems presented.

5. References

[1] M. Medhat and S. S. Farag, "The Effect of the Group Propagation of Waves on the Spectral Behavior of a Multilayer Ar Coating," *Optics & Laser Technology*, Vol. 30, No. 1, 1998, pp. 57-61.

[2] M. Medhat and S. S. Farag, "Achromatic Layers Applied to Dielectric Filters," *Journal of Optics A*: *Pure and Applied Optics*, Vol. 2, No. 6, 2000, pp. 529-533. doi:10.1088/1464-4258/2/6/305

[3] M. Medhat and S. S. Farag, "Broad-Band Dielectric Multilayer Mirrors by Period Staggering," *Journal of Optics A*: *Pure and Applied Optics*, Vol. 3, No. 3, 2001, pp. 178-182. doi:10.1088/1464-4258/3/3/304

[4] M. Medhat, "Interferometric Comparison of Optical Pathlengths: Rings of Equal Chromatic Order," *Optik*, Vol. 84, No. 3, 1990, pp. 77-82

[5] R. W. Ditchburn, "Light," Academic Press Inc., London, 1976, p. 65.

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[6] A. Thelen, “Multilayer Filters with Wide Transmittance Bands,” *Journal of the Optical Society of America*, Vol. 53, No. 11, 1963, pp. 1266-1270. doi:10.1364/JOSA.53.001266

[7] H. M. Liddell, “Computer-Aided Techniques for the Design of Multilayer Filters,” Adam Hilger, Bristol, 1981.

[8] W. T. Welford, “Computations in Thin Film Optics,” *Vacuum*, Vol. 4, No. 1, 1954, pp. 3-19.

[9] P. W. Baumeister, “Design of Multilayer Filters by Successive Approximations,” *Journal of the Optical Society of America*, Vol. 48, No. 12, 1958, pp. 955-958. doi:10.1364/JOSA.48.000955

[10] R. Jacobsson, “Matching a Multilayer Stack to a High-Refractive-Index Substrate by Means of an Inhomogeneous Layer,” *Journal of the Optical Society of America*, Vol. 54, No. 3, 1964, pp. 422-423. doi:10.1364/JOSA.54.0422_1

[11] L. Young and E. G. Cristal, “On a Dielectric Fiber by Baumeister,” *Applied Optics*, Vol. 5, 1966, pp. 77-80. doi:10.1364/AO.5.000077

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