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Design of Broadband Optical Interference Filters Based on Six-Layer Period

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The paper proposes new approach top the design of wide-band interference filters with suppression adjacent stop-bands. The method of research of the multi-layered interference system, allowing to find the necessary of refractive indices of layers, is presented. The results described in communication open new possibilities for construction and calculation of devices based on thin film materials.

Keywords: Thin film, Wideband interference coating, Narrow-band interference coating, Refractive indicies.

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1. INTRODUCTION

Many applications need non-absorbed coatings with high coefficient of reflection or transmission in the wide spectral range. There are mirrors for re-tuned lasers, cut-off and heat-reflected filters, polarizers, etc. However, the existing film compounds make it possible to manufacture coatings with relatively low width of the high reflectivity band, especially for UV- and visible spectral ranges. The known constructions of coatings allowing to expand the range of low transmission are characterized by completeness of their practical realization due to using layers (or groups of layers) with not multiple optical thicknesses. The system of two groups of layers with periodical alignment (AB) and (2AB), where A, B are quarter-wave (0.25 λ0) layers with refraction indices nA, nB. Nevertheless, this coating has satisfactory characteristic only if the ratio of the refraction coefficients of the layers *A* and *B* is larger than 2, what can be realized in the IR spectral range.

2. RESULTS AND DISCUSSION

Authors have proposed [1, 2] coatings containing two groups of the layers with periods (*A*2*BAB*2*AB*) and (*AB*). For these periods the wide-band systems can be realized at the ratio of the layers' refractive indices equal 1.67 and more. Compounds forming thin films which provide fulfillment of this condition in visible and near-UV spectral range, are existing, what makes possible to manufacture required wide-band coatings.

The spectral dependencies of the transmission coefficient *T* of the multilayer dielectric coating are defined by the elements of its interference matrix $A_{i,k}$ (this matrix is a product of the matrices describing the layers as components of the coating) and the refraction indices n_0, n_S of environmental media are written as follows [3, 4]:

$$T = \frac{4n_0 n_S}{(A_{11}n_0 + A_{22}n_S)^2 + (A_{12}n_0 n_S + A_{21})^2} \qquad (1)$$

The interference matrix of the *j*-layer is

$$(m_{k,l})_j = \begin{pmatrix} \cos\beta_j & in_j^{-1}\sin\beta_j \\ in_j\sin\beta & \cos\beta_j \end{pmatrix} \qquad (2)$$

Where $\beta_j = 2\pi n_j t_j / \lambda = 0.5\pi\nu\alpha_j$ is the phase thickness of the layer, and n_j, t_j are the refraction index and the geometrical thickness of the layer, respectively, α_j is a relative layer thickness in the units $\lambda_0/4$, $\nu=\lambda_0/\lambda$, λ is a wavelength.

Figures (1-3) present calculated transmittance of narrowband filters with period *SN*(*AB*)2*AN*(*BA*)*S*, bilateral cut filters with period *SN*(2*AB*)2*AS* (Fig. 1, 2)

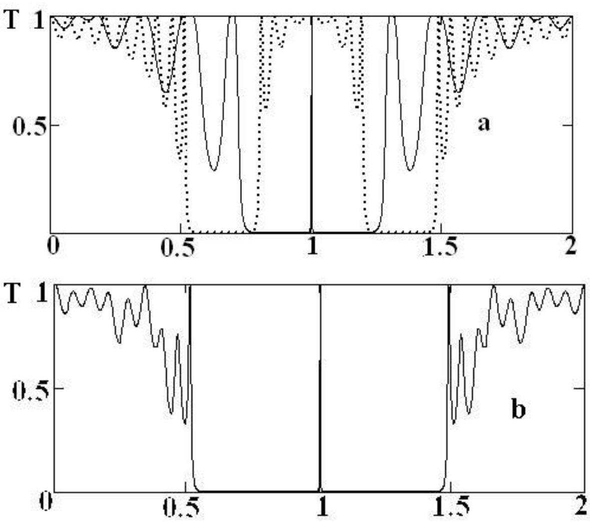

Fig. 1 – Spectral transmittance dependencies of 17-layer narrowband filter (solid line) and cut filter based on 2*AB*-period (dotted line) for $n_A = 2.7$, $n_B = 1.32$ (a) and resultant curve (b)

and with period *SN*(*A*2*BAB*2*AB*)*A*2*BAS* (Fig. 3). The resultant transmittance is also shown. Here *N* is a number of matched periods, $n_S = 1.52$, λ_0 is doubled optical thickness of basic narrowband filter period (*AB*).

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As one can see, bilateral cut filter based on (2*AB*)-period can be used on condition that n_A / $n_B \geq 2$. But if n_A / $n_B < 2$ it is better to use cut filter based on period (*A*2*BAB*2*AB*).

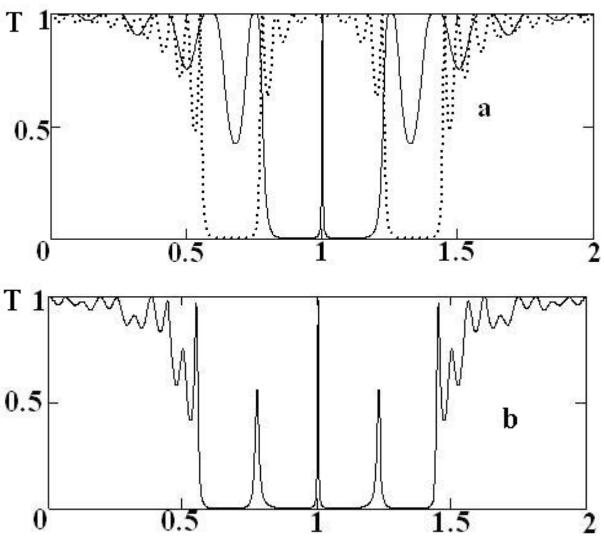

Fig. 2 – Spectral transmittance dependencies of 19-layer narrowband filter (solid line) and cut filter based on 2*AB*-period (dotted line) for $n_A = 2.2$, $n_B = 1.32$ (a) and resultant curve (b)

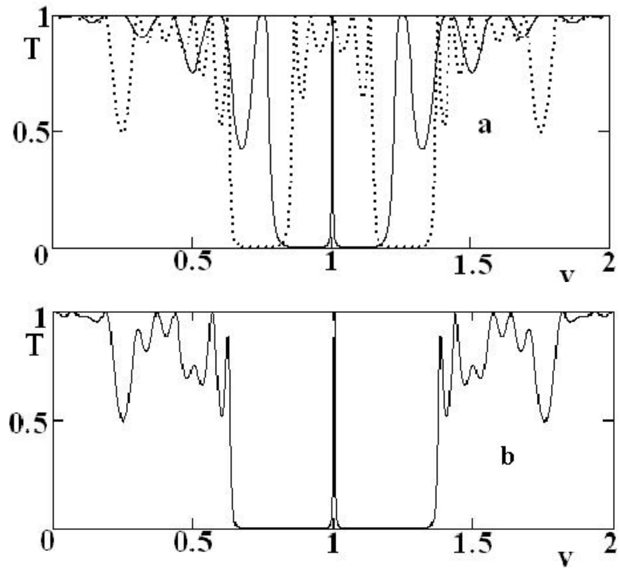

Fig. 3 – Spectral transmittance dependencies of 19-layer narrowband filter (solid line) and 21-layer cut filter based on *A*2*BAB*2*AB*-period (dotted line) for $n_A = 2.2$, $n_B = 1.32$ (a) and resultant curve (b)

On the other hand, if the six-fold period (A2BAB2AB) is considered as a principal one, and the value λ0 is determined as its double optical thickness, we obtain the transmission spectra with only uneven suppressed frequency bands, and the function $T(\nu)$ has a period equal 8. In this case the corresponding change of the refraction indices of the layers included in the filter structure leads to removing some bands. Then one can obtain a wide band filter with suppressed adjacent frequency bands. For this purpose we will consider the six-layer period consisting of two symmetrical three-layer structures: (*A*2*XA*)(*B*2*YB*) (*).

The homogeneous layer with equivalent refraction index N_E can be associated with each of these layers [4]. For the left part of the period (*):

$$N_E = n_A \cdot \sqrt{\frac{\cos\beta - \dfrac{n_A - n_X}{n_A + n_X}}{\cos\beta + \dfrac{n_A - n_X}{n_A + n_X}}} \qquad (3)$$

The equivalent thickness Γ_E is determined as follows:

$$\cos\Gamma_E = 1 - \frac{(n_A + n_X)^2}{2 \cdot n_A \cdot n_X} \cdot \sin^2\beta \qquad (4)$$

For the second subsystem from (*) the expressions are analogous. Here β is a phase thickness of the center layer.

As one sees from the expression (4), at the same phase thicknesses of the center layers the spectral dependencies of the equivalent thicknesses for tri-layer structures will be identical under conditions:

$$n_A \times n_B = n_X \times n_Y \qquad (5)$$

or

$$n_A \times n_Y = n_X \times n_B \qquad (6)$$

Now we require that for some β the equivalent thicknesses of every tri-layer structure from (*) satisfied the condition $\cos(\Gamma_E) = 0$, and for the same β the refraction indices of the tri-layers were also equal:

$$N_E(A2XA) = N_E(B2YB) \qquad (7)$$

Then, for the corresponding ν all the period (*) may be considered as a half-wave layer. At the same time, the conditions (6), (7) give physically unreliable solutions, and (5) and (7) produce two solutions for

$$n_{X1} = \frac{(n_A + n_B)^2 + (n_A - n_B) \cdot \sqrt{(n_A^2 + 6n_A n_B + n_B^2)}}{4n_B} \qquad (8)$$

and

$$n_{X2} = \frac{(n_A + n_B)^2 - (n_A - n_B) \cdot \sqrt{(n_A^2 + 6n_A n_B + n_B^2)}}{4n_B} \qquad (9)$$

The expression (5) gives the corresponding values for n_Y.

Figures (4) and (5) show spectral functions of the transmission $T(\nu)$ and the envelope curve of stray extremums $E(\nu)$ of wide-band filters

$$SN(A2XAB2YB)S \qquad (10)$$

for the solutions of (8) and (9), respectively. Here N is a number of periods.

As one can see from these figures, for refraction indices from (5) and (8) there are only suppressed frequency bands 1 and 7 in the spectra (at the period 8), and for the solution (5) and (9) there are only bands 3 and 5.

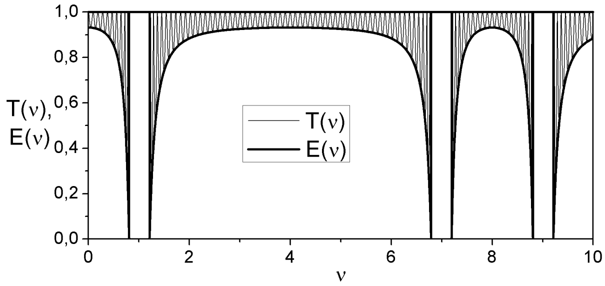

Fig. 4 - Spectral dependencies $T(\nu)$ and $E(\nu)$ of the filter (8) at $n_A = 2.3$, $n_X = 2.89$, $n_B = 1.67$, $n_Y = 1.338$, $n_S = 1.5$, $N = 10$

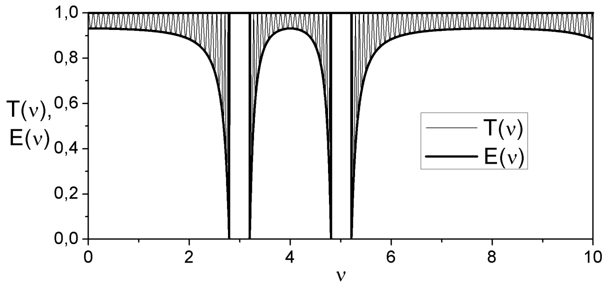

Fig. 5 - Spectral dependencies $T(\nu)$ and $E(\nu)$ of the filter (8) at $n_A = 2.3$, $n_X = 1.83$, $n_B = 1.67$, $n_Y = 2.1$, $n_S = 1.5$, $N = 10$

The spectral dependencies of $T(\nu)$ are similar with those described in [4] for a period (*ABCDDCBA*), which can be represented analogically to (*): (*B*2*ABC*2*DC*). However, authors [4] do not use the joint solution (3) and (4), the condition (5) is rather postulated, but is not proved. Such a postulation leads to a large equation binding parameters n_B / n_C and n_A / n_B.

3. CONCLUSIONS

Thereby the cyclic rearrangement of the layers in the period (10) does not lead to change of position and number of suppressed frequency bands, but at the same time, the depth of extremum in the ranges of transparency can be drastically changed. This depth also strongly depends on the refractive index n_S of the environmental media.

REFERENCES

1. A.P. Ovcharenko, E.A. Lupashko, Intern. *Conf. of OPTDIM'95*, 202 (Kiev: 1995).
2. A.P. Ovcharenko, E.A. Lupashko, *International workshop on advanced technologies of multicomponent solid films and structures and their application in photonics, 77* (Uzhgorod: 1996).
3. H.A. Macleod, *Thin-Film Optical Filters* (Bristol: Adam Hilger Ltd.: 1986).
4. A. Thelen, *Design of Optical Interference Coatings* (New York: McGraw-Hill: 1988).