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Selective unequal-thickness thin-film filters for IR spectral region

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Abstract. A new five-layer structure of the dielectric interference filter for the infra-red region of spectrum is investigated. The main spectral parameters of such a narrow-band filter are determined. The dependence of the transmission band half-width on the thickness of a dividing layer in this system is investigated. It is shown that, in the case of the application of PbTe, GeTe, and SnTe layers with a given thickness; their number can be limited to five at providing the necessary selectivity of the filter: practically the 100-% transmission at the resonance frequency and 0.005 % outside the transmission band.

Keywords: interference filter, narrow-band filter.

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1. 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 [1, 2]. 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. As is well known, the multilayer thin-film dielectric systems including the layers with optical thickness multiple to $\lambda_0/4$ are most popular. Their structure is like to that of the Fabry-Perot standard. Parameters of such systems are studied in [1-4] in detail. Mainly, there are known the two-component systems which include the layers of materials with high and low refraction indices. Nevertheless, the two-component systems cannot practically ensure the necessary suppression of additional transmission bands. In such a way, the three-component structures are very often used [5, 6]. Recently, the film structures with unequal-thickness layers have attracted a particular interest [7, 8]. In such structures, the best parameters are achieved at a substantially simplified construction due to the decrease of the number of layers.

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. 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 [9]. 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.

This work is devoted to the synthesis and investigation of HLH_1LH-type dielectric systems, where H and L are unequal-thickness layers with high and low refraction indices, respectively, H_1 being the layer with a high refractive index. The thickness of this layer is much greater than λ_0, and it is used simultaneously as a substrate. Calculations were conducted by the matrix method [10], and the relevant software was developed by us.

2. Model of narrow-band filter

The interference filter include five layers with the following structure: the thin dielectric layers L are sputtered on the thick dielectric layer H_1 from both sides and the thin dielectric layers H are sputtered on the surface of each dielectric layer L.

For the calculation of the transmission spectra of such a system, germanium Ge ($n = 4.2$), lead telluride PbTe ($n = 5.6$), germanium telluride GeTe ($n = 6.12$), and tin telluride SnTe ($n = 7.2$) were used as materials with high refraction index, whereas strontium fluoride SrF_2 ($n = 1.44$) and sodium fluoride NaF ($n = 1.32$) were used as materials with low refraction index. These dielectrics are the most used materials for the development of practically all types of filters. Fluorides of alkaline-earth elements have high melting temperatures and sufficient resistance to the high-humidity atmospheres. It should be noted that such materials as PbTe, Ge, and SnTe are mechanically strong and water-insoluble and have a wide region of transparency and a high refraction index. These factors give them the priority in the synthesis of systems on their basis with a high transmission coefficient [11].

Thicknesses of thin dielectric layers with low and high refraction indices were chosen to be multiple to $\lambda_0/4$ (the investigations were performed for a wavelength of 5 μm) and the thickness of the dividing layer was calculated by the formula

$$d = \frac{\lambda_0}{4n}\left(2m+1\right),$$

where m is a sufficiently large integer, and n is the refraction index of the layer. The calculations of the thickness of the dividing layer were carried out for the aforementioned materials with a high refractive index at $m = 1000$.

3. Results

The results of calculations of the spectral curves of transmittance of interference filters for Ge and SrF_2, SnTe and NaF are shown in Figs. 1 and 2, respectively.

With the aim to search for the optimum composition of materials with a maximally possible difference between high and low refractive indices, the spectra of transmission of the offered filter were calculated for four different combinations of materials (see Fig. 3).

At the fixed values of transmittance of the system, the width of the transmission band can be changed by a modification of the thickness of the dividing layer. The dependence of the transmission band half-width on the thickness of the dividing layer for a five-layer structure with Ge and SrF_2 materials is shown in Fig. 4.

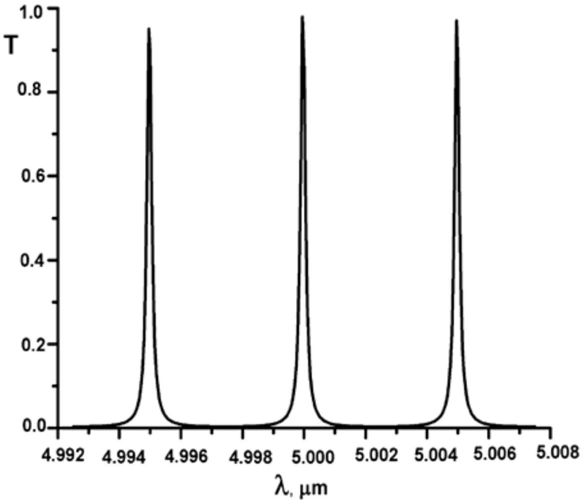

Fig. 1. Transmission spectrum of an interference filter designed for Ge and SrF_2 materials.

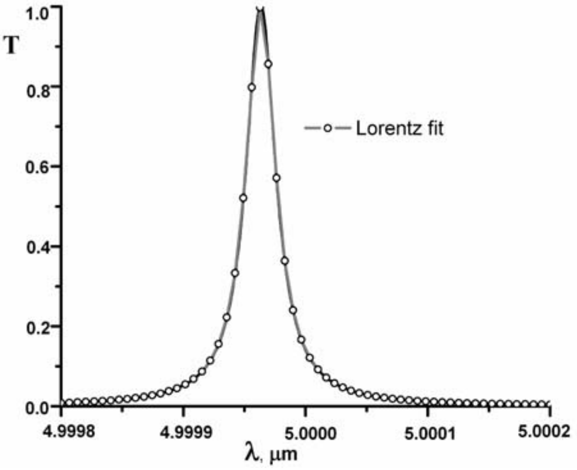

Fig. 2. Transmission spectrum of an interference filter designed for SnTe and NaF materials (the curve corresponds to the Lorentz fit).

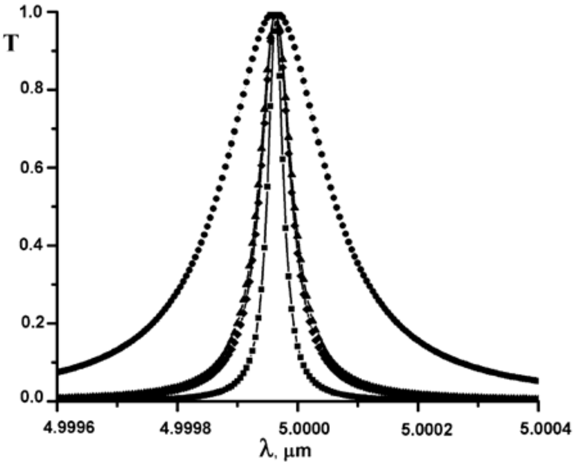

Fig. 3. Transmission spectra of interference filters designed for ● Ge and SrF_2, ■ SnTe and NaF, ♦ GeTe and SrF_2, ▲ PbTe and NaF materials.

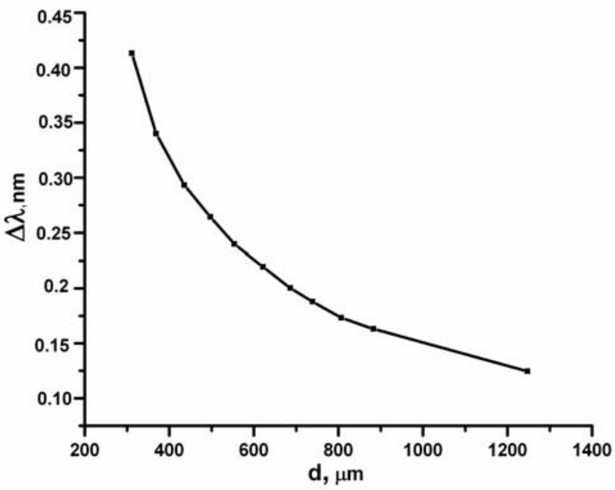

Fig. 4. Dependence of the half-width of the band transmission on the thickness of the dividing layer.

One of the main optical parameters of narrow-band filters is the contrast which is characterized by the ratio of the maximal transmittance to the average minimum transmittance.

In this case, the filtering ability (the characteristic of energy contrast of a filter) is a derived parameter [3]. For the proposed filter, the contrast is 168.73 and filtering ability is 2.49, which testifies to the high selective properties of the system.

The values of maximum transmittance as well as the half-width of the transmission band are one of the main characteristics. It is shown (see Figs. 1-2) that the maximum coefficient of transmission for a filter sintered from Ge and SrF_2 materials is 0.98, and the minimum transmission coefficient is 0.005, whereas the maximum and minimum transmission coefficients for a filter sintered from SnTe and NaF materials are 0.99 and 0.005, respectively.

As seen from Fig. 4, the values of transmittance is practically identical, however these filters have different half-widths of the transmission band (0.221 nm in the first case and 0.031 nm in the second case). In addition, with the use of GeTe and SiF_2 materials for the design of the proposed structure, we can obtain the minimum value of transmission coefficient equal to 0.003. The narrow transmission band is a result of resonance phenomena in the structure. This fact is in agreement with the fitting of this spectral characteristic with the well-known Lorenz function (see Fig. 2).

4. Conclusions

In the present work, we have calculated the spectral characteristics of five-layer structures for various materials. In these structures, the dividing layer with a high refraction index is used, which decreases the dependence of the coefficients of transmission and reflection on the angle of incidence of a light wave. The application of such a layer as the substrate casts aside the problem of the choice of a material of the substrate, which would be responded to the request of synthesis and the use of this filter, as well. In addition, such structures are enough technological due to the small number of layers. It should be noted that filters based on the optical interference phenomenon are highly universal and can be designed in all optical ranges, and the spectral characteristics of this system are like to those of a Fabry-Perot interferometer.

Consequently, in the case of the application of Ge, PbTe, GeTe, and SnTe layers as materials with a high refraction index and a given thickness, their number can be limited to five at providing the necessary selectivity of a filter: practically the 100-% transmittance at the resonance frequency and 0.005 % outside the transmission band.

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