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Methods of the Transmission Characteristics Shaping of Optical Filters Using Thin Films

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In paper the principle of corrective action of the transmission characteristics of thin-film optical filters guessing importation of a determined optical losses level into the chosen concrete optical layer is considered. The offered method allows at inappreciable boosting of a losses degree to receive practically planar transmission characteristic in a transmission band. Besides the principle of the corrective actions guessing variation of an index of refraction of a chosen layer is considered and allowing to change a period of the transmission characteristic.

Key words: optical filter, thin films, index of refraction, losses, correction.

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Introduction

Now most perspective technology considers technology of wave separation and multiplexing - WDM (Wavelength Division Multiplexing), which allows establishing optical, networks with practically unlimited opportunities of growth of transmission rate [1]. The fundamental sense WDM consists that in one optical fibre on different wavelengths some parallel information channels are established. Thus, the channels are located on identical distance.

The problems of creation of communication systems with wavelength division-multiplexing are immediately joined with presence of nonlinear effects in optical environment of transmission which cause to such phenomena as stimulated Brillouin scattering, stimulated Raman scattering, four-wave mixing and so on that increase error ratio of such systems [2]. Also it is necessary to mark, that the application of Erbium-Doped Fibre amplifiers in WDM and DWDM (Density Wavelength Division Multiplexing) systems drives to reduction of signal/noise ratio [3].

In this connection the development of filters having an equidistant arrangement of resonance frequencies and, accordingly, pass bands and rejection bands is of interest. The application of such filters in WDM and DWDM systems allows lowering a level of noises and level of non-linear interaction products of adjacent channels.

Among known types of devices such properties have the filters using thin films [4]. Distinctive feature of these filters is the possibility of equidistant arrangement of pass bands. However, for reduction of spectral signal degradations it is necessary to ensure enough planar characteristic in a pass bands. Thus paths of regulation of a frequency interval between bands also are of interest.

I. Principles of a statistical method of modeling

The classical methods of simulation analysis of a light transmission through stratified mediums designed in [5]. However, in them the quantum nature of light was not taken into account. In these methods the signal is represented as continuous. In an actual situation the optical signal is transmitted as group of discrete optical quantums. Thus, the interaction of quantums with an optical medium of the filter occurs according to the laws of a quantum electrodynamics [6].

The thin-film filter represents plurality of dielectric transparent films of particular thickness providing separation of an input signal on two directions. To a direction of signal transmission through the filter, and direction of reflection an input signals from the filter. From a point of view of a classical electrodynamics such filter represents multilayer dielectric medium, the propagation of electromagnetic waves in which is determined by known methods. Thus it is supposed, that the electromagnetic wave represents continuous wave process. However, according to principles of a quantum electrodynamics, the light wave consists of discrete formations - optical quantums. The process of transmission of optical quantum between optical mediums is characterized by a reflection coefficient C_r, which is determined for a continuous electromagnetic wave falling perpendicularly of a plane of the film, expression:

$$C_r = ((n_{21}-1))/((n_{21}+1))^2 \qquad (1)$$

Where n_{21} – relative index refraction of optical mediums with refraction indexes n_1 and n_2 accordingly.

As against a continuous electromagnetic wave the value of a reflectivity represents for optical quantum probability of reflection from a border [6]:

$$C_r = \lim_{N\to\infty}\frac{N_{ref}}{N}, \qquad (2)$$

Where N_{ref} – quantity of quantums, reflected from a border, and N – total quantity of quantums falling on a border of two mediums. Thus the numerical value of this probability will be matched with a value obtained from expression (1).

The process of transmission of optical quantum of the multilayer filter consists of a lot of elementary events representing transmission of layers with consequent junction through a border of optical medium or reflection from it.

As the transmission through border or reflection is process defined by an accidental sequence of events of transmission - reflection, for calculation of transmission filter responses the method of statistical tests is usable, or namely a Monte-Carlo method [7].

At simulation analysis according to a Monte-Carlo method the trajectory of each quantum driving with use of the pseudorandom numbers oscillator is determined at transmission of an optical medium border for result determination - transmission or reflection.

Thus, each quantum on an output of the filter is characterized by an own trajectory of transmission thru the filter and, accordingly, own phase shift as a result of this. The amplitude of a resulting output signal is represented as the total sum of separate quantum amplitudes in view of phase relations. As against classical computational methods, the statistical method takes into account an opportunity multiple quantum reflections between border of optical medium and, accordingly, influence of the relevant phase shift to an output signal. For determination of ratios between amplitudes falling and reflected from a thin dielectric film waves the formulas of the Fresnel were used [5]. At a choice of a small incidence angle it is possible to consider it practically normal to a film surface.

The transmission characteristic of the filtering device (insertion loss of filter) was determined as:

$$\alpha = 20\lg A_{in}/A_{out},$$

where A_{in} and A_{out} represent amplitudes of an input and output cumulative signal.

As an output signal the signal, reflected from the filter was considered. In more detail principles of calculation were described in [8].

II. Influence to the transmission characteristic of an index of refraction

In introduced report the numerical modelling of the filter construction which uses two films is carried out (fig.1).

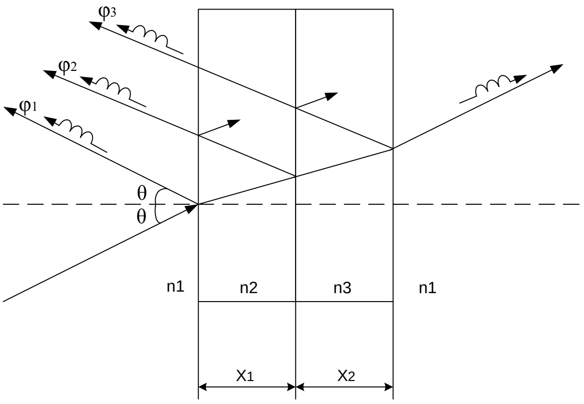


Fig. 1. The optical filter using two films.

Thus, between indexes of refraction of layers n_2 and n_3 the ratio $n_2 > n_3$ is carried out. Here n_2 – is index of refraction of the first layer, n_3 - is index of refraction of the second layer, n_1 - is index of refraction of an environment. Here x_1 and x_2 - thickness of the first and second film accordingly.

The important factor at modeling the multilayer optical filter is the account of change of a signal phase at reflection from border between two optical mediums with indexes of refraction n_1 and n_2. In this case phase shift of the reflected beam, at perpendicular falling on border of the medium is π, if $n_2 > n_1$ and 0, if $n_1 > n_2$.

On fig. 2 characteristics of insertion loss for the two-layer filter are submitted at change of value of the phase shift inserted by single layers. Thus the index of refraction of the second layer n_3 has the constant value equal 1,5, and an index of refraction of the first layer n_2 accepts values: 1,8; 2,2; 2,5; 2,8. Between indexes of refraction of layers and their thickness the ratio was carried out:

$$(n_2/n_3)(x_2/x_3) = 1.$$

Thus equality of phase shifts in each layer for quantums with identical wavelengths was provided. Apparently from results of calculations, at rather small values n_2 in the center of a passband of the filter $(\varphi = \pi/2 + \pi n)$ the local increase in attenuation is observed. It is possible to explain this phenomenon of influence of a total signal of the quantums reflected from back border of the second layer of the filter. Their phase differs on π from a phase of the quantums reflected from the first layer. And it results in reduction of a level of a total signal. With increase in value of an index of refraction of the first layer n_2 the number of the quantums reflected from it increases. Thus influence of the second layer decreases also the characteristic in a passband becomes flat. In a backward case the attenuation in a transmission band is boosted in such manner that the period of the characteristic diminishes twice.

And so, by a choice of refraction ratio indexes between layers of the filter it is possible to operate a view of the transmission characteristic. Thus it is possible to change a period between transmission bands.

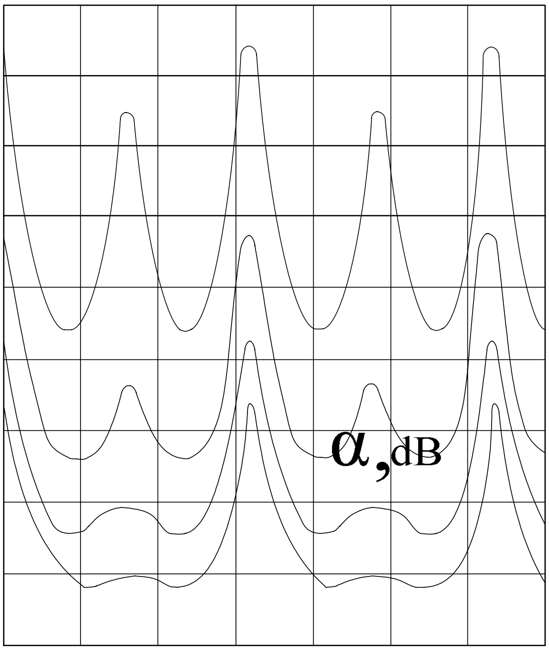


Fig. 2. Transmission filters response at n_2=1,8(1); 2,2(2); 2,5(3); 2,8(4).

III. Influence to the transmission characteristic of an insertion loss

In the article the different principles of forming of the transmission characteristics of thin-film optical filters are considered. The principles guess a choice not only real but also imaginary part of indexes of refraction of concrete optical layers.

As was shown above by results of calculations, at variation of an refraction index of the first layer n_2 from 1,8 up to 2,8 period of the transmission characteristic is magnified twice. Thus values of attenuation in transmission and stop bands also vary.

Besides in this work the method of forming of transmission filter responses guessing variation of an imaginary part value of an refraction index of its films components, namely in losses importation into a concrete optical layer is offered.

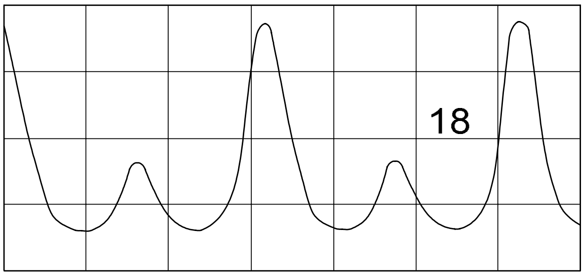
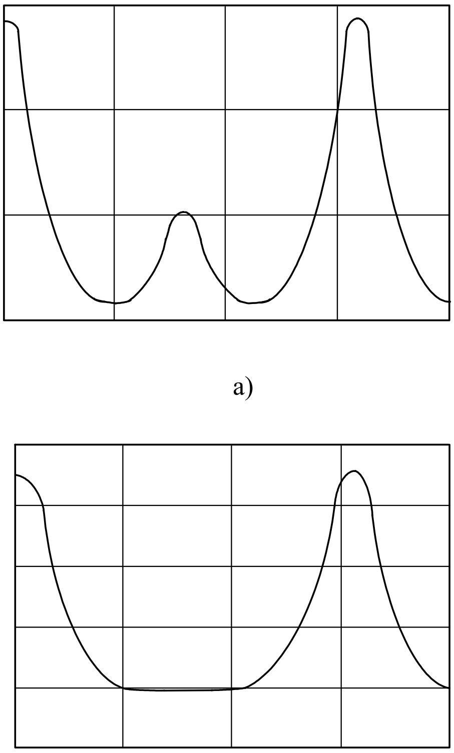


Fig. 3. Transmission filters response at n_2 = 2,2, n_3= 1,5.

With the purpose of the characteristic non-uniformity reduction in a transmission band in this work probing influence on the transmission characteristics was carried out at the expense of importation into optical layers of a particular degree of losses. The indexes of refraction of the first and second layer were equal 2,2 and 1,5 accordingly. The transmission characteristic of such filter is figured in a fig.3.



a)

b)

Fig. 4. Transmission filters response at importation of losses with a level of 3 dB in the first layer (a), and in the second layer (b).

At importation of losses (the value of losses is 3 dB) into the first layer in accordance with magnifying of attenuation the considerable deterioration of characteristics was watched. Thus the relative non-uniformity of the transmission characteristic in a transmission band practically remained constant.

At importation of losses into the second layer (the value of losses is 3 dB), the deterioration also took place, but its level was appreciably less, than in the first case. Thus the inappreciable non-uniformity of the transmission characteristic in a transmission band (no more than 0,02 dB) was reached practically. The obtained result is possible to explain by corrective action of an influence degree of quantums, reflected from an outer boundary of the second layer, on non-uniformity of the transmission characteristic in a transmission band. The importation of losses into the second layer and selection of their value allows reducing a level of a reflected stream of quantums enough to smooth a course of the transmission characteristic in a transmission band, having made a value of insertion attenuation in this band practically constant. Thus it is possible to cancel probability some magnifying of attenuation in a transmission band by application of optical amplifiers in a communication line.

Conclusion

In the article the numerical modeling of decreasing conditions of the transmission characteristics non-uniformity of the thin-film filter in a transmission band up to value about 0,02 dB is carried out at the expense of importation of a particular degree of losses into a concrete optical layer.

Thus, at designing of thin-film optical filters it is possible to reach corrective action of the transmission characteristic in the necessary direction. It is possible to cancel possible some magnifying of attenuation in a transmission band at it by application optical amplifiers in a communication line.

Besides in this work the method of forming of transmission filter responses by a choice of refraction indexes of the particular layers of the filter is described. Thus it is possible to change a period between transmission bands.

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Методи формування передаточних характеристик оптичних фільтрів, які використовують тонкі плівки

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В статті розглядаються методи формування та корекції передаточних характеристик оптичних фільтрів на тонких плівках, які передбачають внесення певного рівня оптичних втрат у визначений конкретний оптичний шар та зміну показника заломлення вибраного оптичного шару. Запропоновані методи дозволяють при незначному підвищенні рівня втрат отримати практично плоску передаточну характеристику в смузі пропускання, а також змінити період передаточної характеристики в потрібну сторону.