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Band-pass filters based on photonic crystal

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Abstract. Multilayer photonic crystal structures with bleaching layers are being investigated. In order to calculate the characteristics of ultra-wideband filters on their basis, T-lines lossless model was used. Amplitude-frequency characteristics for the synthesized filters of 5th, 11th and 17th orders are given. It is proved that by a significant increase in filter *N* order, the difference between the connection coefficients of central resonators' layers' becomes negligible. This makes it possible to develop 27-order filter, in which almost half of the layers are realized by periodic interchange of only two identical high-contrast materials. The investigated band-pass filters, including the ones on a glass substrate, have high frequency-selective properties at a relative bandwidth of 80%.

1. Introduction

It is well known [1, 2] that unidimensional (1D) photonic crystals are dielectric structures composed of alternating layers of different materials and having radiolucent «windows» for electromagnetic waves in certain frequency range, between which there are bandgaps - photonic stop band.

Such multilayer dielectric structures are the base for the production of mirrors for laser techniques [3], which have less losses and higher reflectance coefficient in comparison with metal mirrors, besides they are the base for the development of band-pass filters and high-*Q* resonators [4].

The given paper presents the results of investigation of multilayer dielectric structures with not more than 27 layers that are ultra-wideband ones with high frequency-selective properties.

2. Modelling results

The amplitude-frequency characteristics (AFCs) of all 1D structures were calculated by means of *T*-line without loss model. It was assumed that electromagnetic waves from free space having wave resistance Z_0 = 377 Ω incident orthogonally on thin films which are under investigation. Having passed through the structures at certain frequencies electromagnetic waves propagate further in free space. Falling (P_{fal}), reflecting (P_{ref}) and passing (P_{pas}) power of electromagnetic waves are connected by the law of energy conservation:

$$P_{\mathrm{fal}} = P_{\mathrm{ref}} + P_{\mathrm{pas}} \qquad (1)$$

The tune of band-pass filters is done by «manual» parametric synthesis, during which the central frequency of passband f_0=300 GHz as well as the relative bandwidth $\Delta f/f_0$ = 80% were recorded. Meanwhile, the passband of single-dimensional structure from each dielectric layer is formed by one resonance. To improve frequency-selective filters properties, the first and the last selected layers were chosen as radiolucent ones. They are quarter-wave resonators (λ/4) with electrical length (optical film thickness) $\theta_1 = \pi/2$. The remaining layers in the structures are half-wave (λ/2) with electric length $\theta_2 = \pi$. The scheme of such photonic crystal structure with 17 dielectric layers is shown in figure 1.

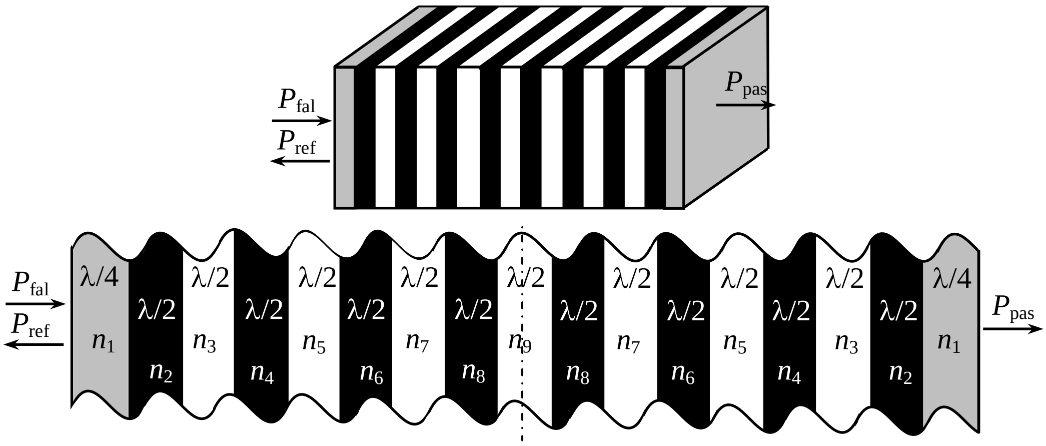

Figure 1. Schematic representation of 17-layers structure.

The filters of 3th, 5th, 7th, 9th, 11th, 13th, 15th and 17th orders were synthesized with the same maximum level of return loss (L_R = –30 dB) in the passband. The comparison of amplitude-frequency characteristics of these band-pass filters of 5th, 11th and 17th orders is shown in figure 2.

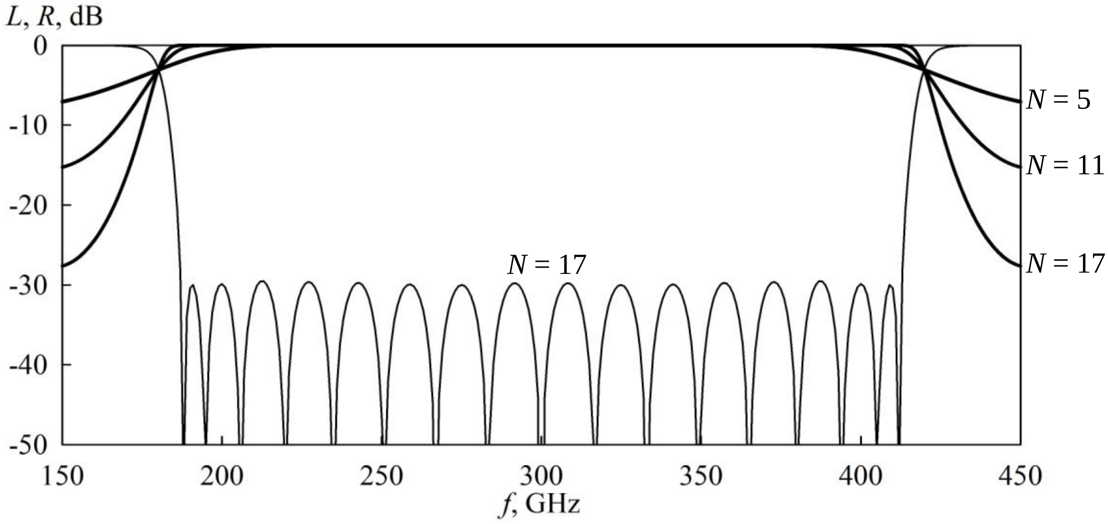

Figure 2. AFCs of the 5th, 11th and 17th orders filters.

Here for $N = 17$ is the value of relative refractive indices of dielectric layers' diffraction: $n_1 = 1.249$, $n_2 = 1.763$, $n_3 = 1.257$, $n_4 = 1.885$, $n_5 = 1.175$, $n_6 = 1.990$, $n_7 = 1.129$, $n_8 = 2.040$, $n_9 = 1.116$.

As it is seen from the above given figure, with an increase of N order of such ultra-wideband filters, the increase of power suppression in the stop bands occurs slowly. Therefore, the improvement of their frequency-selective properties requires the use of larger number of layers-resonators in the structures and, correspondingly, an increase in the number of tuning parameters. However, this significantly exaggerates «manual» parametric synthesis of filters. Therefore, another approach to develop such band-pass filters with strong suppression of parasitic power was proposed.

In this connection, for all 8 synthesized filters, the coupling coefficients between pairs of adjacent layers-resonators were calculated (figure 3). For this purpose, the formula that had been obtained by the author of the work [5] for a filter of series-connected half-wave resonators formed by line-segments with «low» Z_- and «high» Z_+ wave resistance was used:

$$|k_{+-}| = \frac{2\pi \operatorname{arctg}\sqrt{Z_-/Z_+}}{\pi^2 + \operatorname{arctg}^2\sqrt{Z_-/Z_+}}. \quad (2)$$

It is obvious that connection value between the filter and the input and the output will be determined by the difference in the wave resistance in free space (Z_0 = 377 Ω) and the extreme structure layers that the first and last resonators form. This also allows to estimate coupling coefficient k_{01} of the first resonator with the «space», using the above mentioned formula.

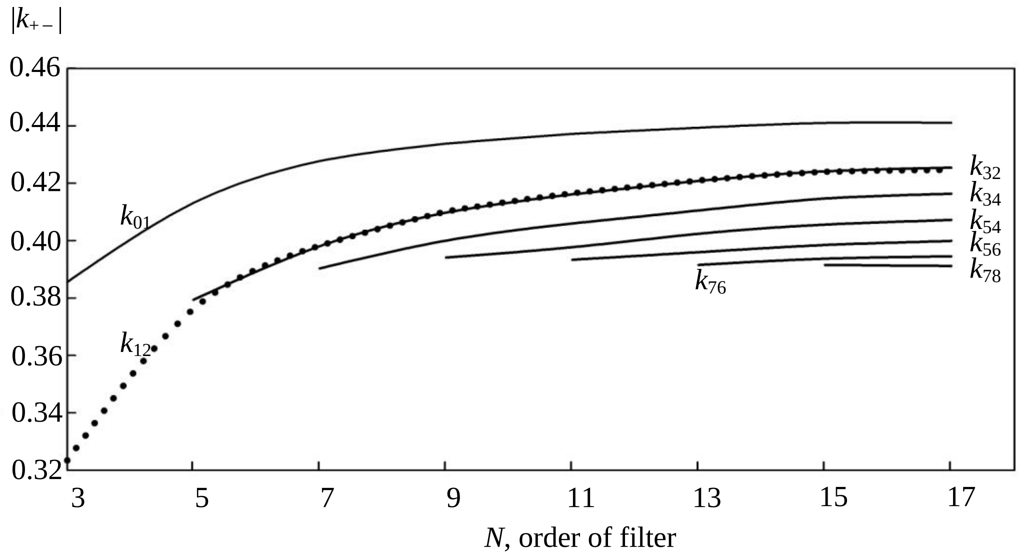

Figure 3. The dependence of coupling coefficients between the adjacent layers on the basis of filter order.

It is seen that during significant increase in filter N order, the difference between coupling coefficients of central resonator layers becomes negligible. Therefore, thirteen inner layers can be realized in the form of periodic interchange of only two high-contrast materials with the refractive index n_8 and n_9 (figure 4).

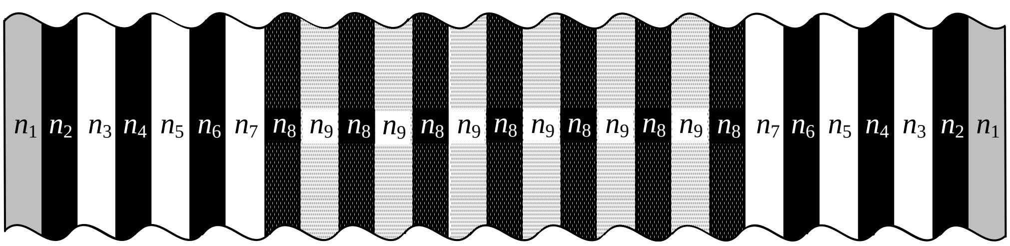

Figure 4. Schematic representation of 27-layers structures.

This improves structure manufacturability and reduces its cost in mass production, but, meanwhile, the filter with a relative bandwidth of 80% realised on its base has high frequency-selective properties (figure 5).

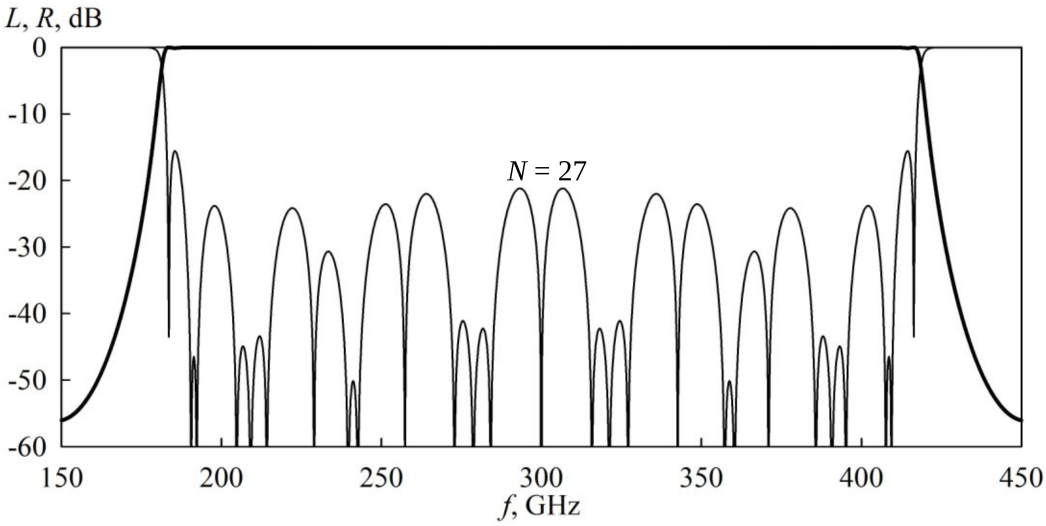

Figure 5. AFCs of 27-layers 1D structure.

Here for $N = 27$ is the value of relative refractive indices of dielectric layers' diffraction: $n_1 = 1.255$, $n_2 = 1.760$, $n_3 = 1.252$, $n_4 = 1.888$, $n_5 = 1.170$, $n_6 = 1.982$, $n_7 = 1.105$, $n_8 = 1.964$, $n_9 = 1.031$. It is worth noting, the initial filters investigation can be performed notwithstanding the substrate in the models. Further the substrate of infinite thickness with a certain refractive index, for example $n_s = 1.300$ (glass is the material) is added to model of *T*-lines (figure 6).

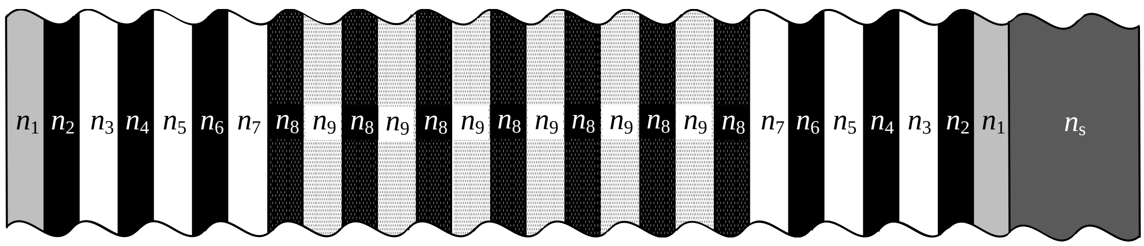

Figure 6. Schematic representation of 27-layers structures with the use of glass substrate.

Frequency-selective properties of the ultra-wideband filter of the twenty seventh order based on one-dimensional dielectric photonic crystal change slightly (figure 7).

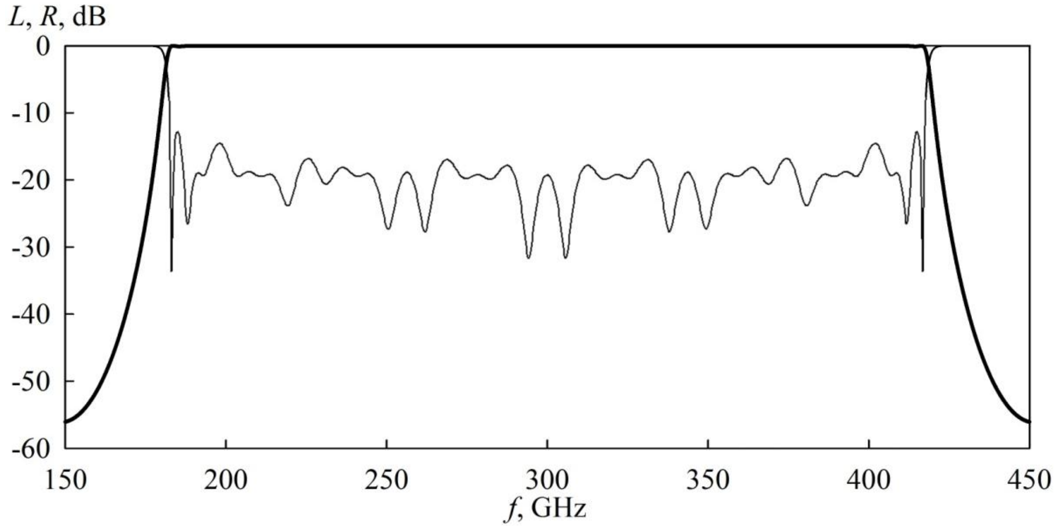

Figure 7. AFCs of 27-layers 1D structure with the use of glass substrate.

3. Conclusions

Therefore, the proposed ultra-wideband filters based on one-dimensional photonic crystal are manufacturable and have high frequency-selective properties including a strong suppression of power at frequencies of the stop bands.

Acknowledgments

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