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The influence of extinction coefficient on transmission in binary multilayer

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Properties

ABSTRACT

Purpose: The influence of the extinction coefficient for transmission, reflectance and absorption in multilayer binary. Reps cluster was equal to 7 It was built of two types of materials. First was a NaCl equivalent with a refractive index described by $n_A=1.544\text{-}ik$, and as second was GaAs lossless metamaterial equivalent

Design/methodology/approach: Research was carried out using the map of: transmitting, reflectance and absorption of the electromagnetic wave. Maps determined using the matrix method.

Findings: It is shown that the higher the extinction coefficient, which is responsible for the absorption of electromagnetic waves, decreases the transmittance and reflectance of the multilayer system at the same time increasing its absorption.

Research limitations/implications: Would be a reasonable correlation between the results of the transmission, reflectance and absorption obtained using numerical methods with with experiment.

Practical implications: Taking into account the extinction coefficient allows for a better representation of the real multilayer structures. Quasi one-dimensional superlattices can be used as filters or multiplexers electromagnetic waves.

Originality/value: In the literature the most frequently analyzed lossless structure. Taking into account the extinction coefficient allows for better study the properties of the tested materials.

Keywords: Transmission; Multilayers; Superlattices; Absorption; LHM; RHM

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1. Introduction

Photonic crystals are intensively studied composite materials. Extremely interesting type of photonic materials are quasi one-dimensional multilayer systems [1-5]. With the specific internal structure of these materials incident electromagnetic wave is partially reflected on each boundary. As a result of the interference occurring within the structure of the waves at given wavelengths do not propagate in the material. This effect has been called the presence of the photonic band gap. Multilayers, particularly those of the binary or aperiodic structures, are characterized by rather complicated transmission structures. When designing a multi-layer for specific purposes on the structure of the transmission can be influenced by selecting a certain type of structure, the type of materials constituting a composite material and thickness of the layers. Techniques for making multilayer structures are used to determine the arrangement of the layers and to determine their thickness [6-32]. The first theory that predict the existence of materials characterized by the presence of negative refractive index [33], and later increased interest in producing [34] and testing the properties in various research centers worldwide [35-44], tend to include metamaterials in the study of the filtration characteristics of multilayer structures.

The most frequently used two methods to analyze the filtration properties of multilayer systems. The first is to an alternating numerical iteration Maxwell equations, and therefore one can observe changes of electrical and magnetic fields in an N-dimensional space in the time domain. This method is called the finite-difference time-domain algorithm (FDTD). To analyze the properties of the selected networks filter in the wavelength range of visible light used a second algorithm - matrix method [2]. With knowledge of the angle of incidence of the electromagnetic wave of a given length in relation to the normal to the surface of the superlattice structure and the parameters of the multilayer construction can be determined characteristic matrix of structure which allows to determine the transmission map of the specific superlattice [42].

Propagation of electromagnetic waves in multilayer may be determined by the following matrix equation

$$\begin{bmatrix} E_{in}^{(+)} \\ E_{in}^{(-)} \end{bmatrix} = \Gamma \begin{bmatrix} E_{out}^{(+)} \\ E_{out}^{(-)} \end{bmatrix} \tag{1}$$

where $E_{in}^{(+)}$ is the electric field intensity of an incident electromagnetic wave, $E_{out}^{(+)}$ is the electric field intensity of an electromagnetic wave passing through the structure, $E_{in}^{(-)}$ is the electric field intensity of electromagnetic wave reflected from the multilayer, $E_{out}^{(-)}$ always equals zero, Γ is a characteristic matrix describing the construction of the superlattice defined as

$$\Gamma = \begin{bmatrix} \Gamma_{11} & \Gamma_{12} \\ \Gamma_{21} & \Gamma_{22} \end{bmatrix} = D_{in,j} \left[\prod_{j=1}^{J} P_j D_{j,j+1} \right] \tag{2}$$

The matrix of electromagnetic wave propagation in isotropic material can be defined as

$$P_j = \begin{bmatrix} e^{i\varphi_j} & 0 \\ 0 & e^{-i\varphi_j} \end{bmatrix} \tag{3}$$

Where:

$$\varphi_j = d_j n_j \frac{2\pi}{\lambda} \cos\Theta_j \tag{4}$$

for d_j - thickness of the layer j, n_j - refractive index of the layer j, λ is wavelength of the incident electromagnetic wave, and Θ_j is determined from Snell's law the angle of incidence of the electromagnetic wave to layer j.

Transmission matrix at the border centers can be described by

$$D_{j,j+1} = \frac{1}{t_{j,j+1}} \begin{bmatrix} 1 & r_{j,j+1} \\ r_{j,j+1} & 1 \end{bmatrix} \tag{5}$$

Coefficients t and r are Fresnel amplitude transmittance and reflectance coefficients that are dependent on the type of polarization of the incident electromagnetic wave on the structure.

For a P-polarization can be defined as

$$t_{j,j+1} = \frac{2n_j \cos\Theta_j}{n_j \cos\Theta_{j+1} + n_{j+1}\cos\Theta_j} \tag{6}$$

and

$$r_{j,j+1} = \frac{n_j \cos\Theta_{j+1} - n_{j+1}\cos\Theta_j}{n_j \cos\Theta_{j+1} + n_{j+1}\cos\Theta_j} \tag{7}$$

the S-polarization can be defined as

$$t_{j,j+1} = \frac{2n_j \cos\Theta_j}{n_j \cos\Theta_j + n_{j+1}\cos\Theta_{j+1}} \tag{8}$$

and

$$r_{j,j+1} = \frac{n_j \cos\Theta_j - n_{j+1}\cos\Theta_{j+1}}{n_j \cos\Theta_j + n_{j+1}\cos\Theta_{j+1}} \tag{9}$$

Transmission for a quasi one-dimensional multi-layer structures can be calculated from the formula

$$T = \frac{n_{out}\cos\Theta_{out}}{n_{in}\cos\Theta_{in}} \left| \frac{1}{\Gamma_{11}} \right|^2 \tag{10}$$

Reflectance can be described as

$$R = \left| \frac{\Gamma_{21}}{\Gamma_{11}} \right|^2 \tag{11}$$

Absorption can be defined as

$$A = 1 - (T + R) \tag{12}$$

By providing the index of refraction as a complex number can be considered a phenomenon of absorption [2]

$$n \to n - ik = 1 + \frac{Ne^2(\omega_0^2 - \omega^2)}{2\varepsilon_0 m\left[(\omega_0^2 - \omega^2)^2 + \gamma^2\omega^2\right]} - i\frac{Ne^2\gamma\omega}{2\varepsilon_0 m\left[(\omega_0^2 - \omega^2)^2 + \gamma^2\omega^2\right]}, \tag{13}$$

where k is imaginary part of refractive index and called as extinction coefficient.

2. Research

Equivalent NaCl material with a refractive index described by $n_A = 1.544 - ik$, was used for the analysis, as the material A. As a material B was used metamaterial equivalent of GaAs with a refractive index described by $n_B = -3.4$. To investigate the effect on the absorption of coefficient k, material B was defined as isotropic, non-dispersive and lossless. The structure was surrounded by air with a refractive index $n_{in} = n_{out} = 1$. The thickness of the individual layers in the structure is $d_A = d_B = 175[nm]$, the thickness of the cluster is $d = 350[nm]$. The thickness of the entire filter is $d_f = 2.45[\mu m]$. Superlattice has a layer structure described by

$$X_7^B = ABABABABABABAB. \tag{14}$$

a)

b)

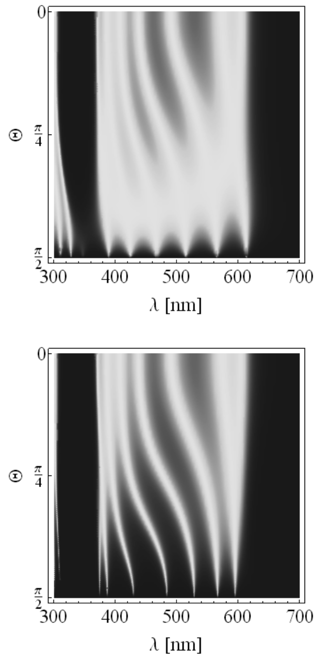

Fig. 1. Binary superlattice transmission map for L = 7, k = 0, a) polarization P, b) polarization S

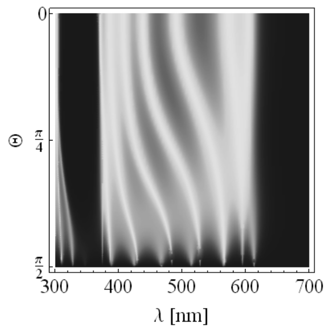

Fig. 2. Binary superlattice unpolarized transmission map for L = 7 and k = 0

a)

b)

c)

d)

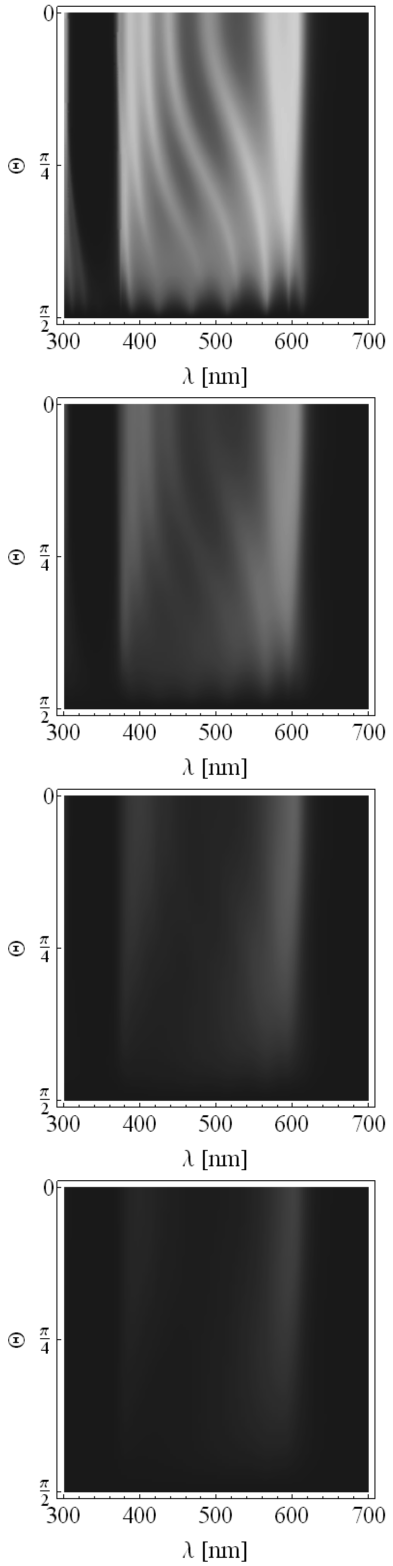

Fig. 3. Binary superlattice unpolarized transmission map for L = 7; a) k = 0.01, b) k = 0.03, c) k = 0.05, d) k = 0.07

Fig. 1 shows a map of the transmission structure of examined, depending on the type of polarization. It should be noted the occurrence of a transmission band of a different nature for different types of polarization. Shall stand out clearly band gaps for the two wavelength ranges from 300 nm to 360 nm and from about 620 nm to 700 nm.

Fig. 2 shows the unpolarized map of the transmission of tested structure. It was determined by averaging the intensity of the electromagnetic wave propagating in the system. The extinction coefficient was equal to zero.

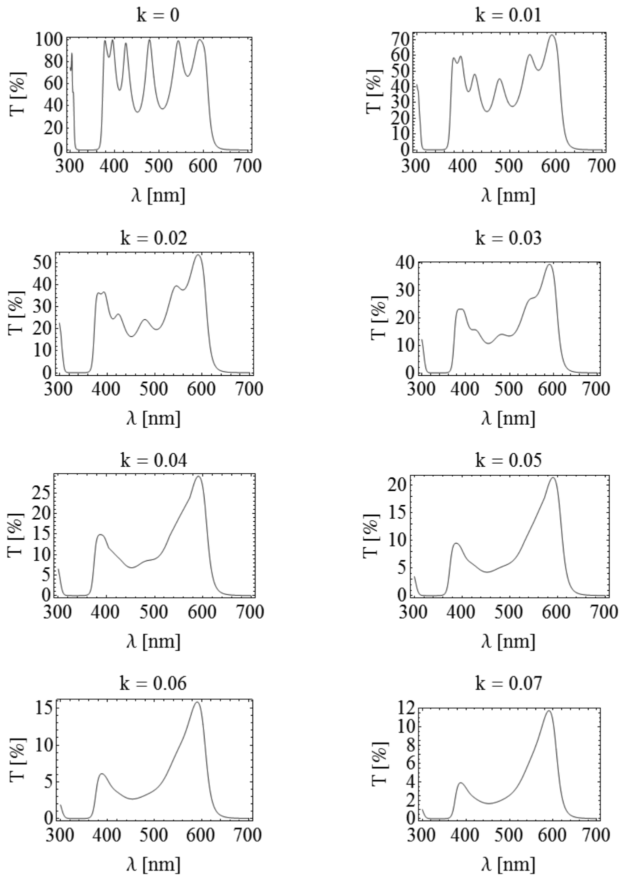

Fig. 4. The transmission of binary structure for the angle of incidence equal to $\Theta = \pi/4$ and different rates of extinction coefficient *k*

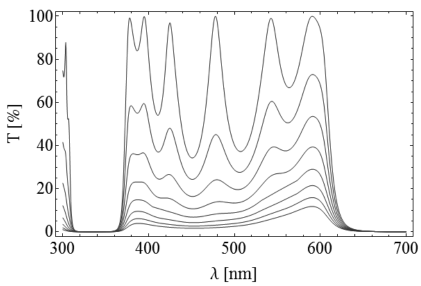

Fig. 5. The imposition of charts from Fig. 4

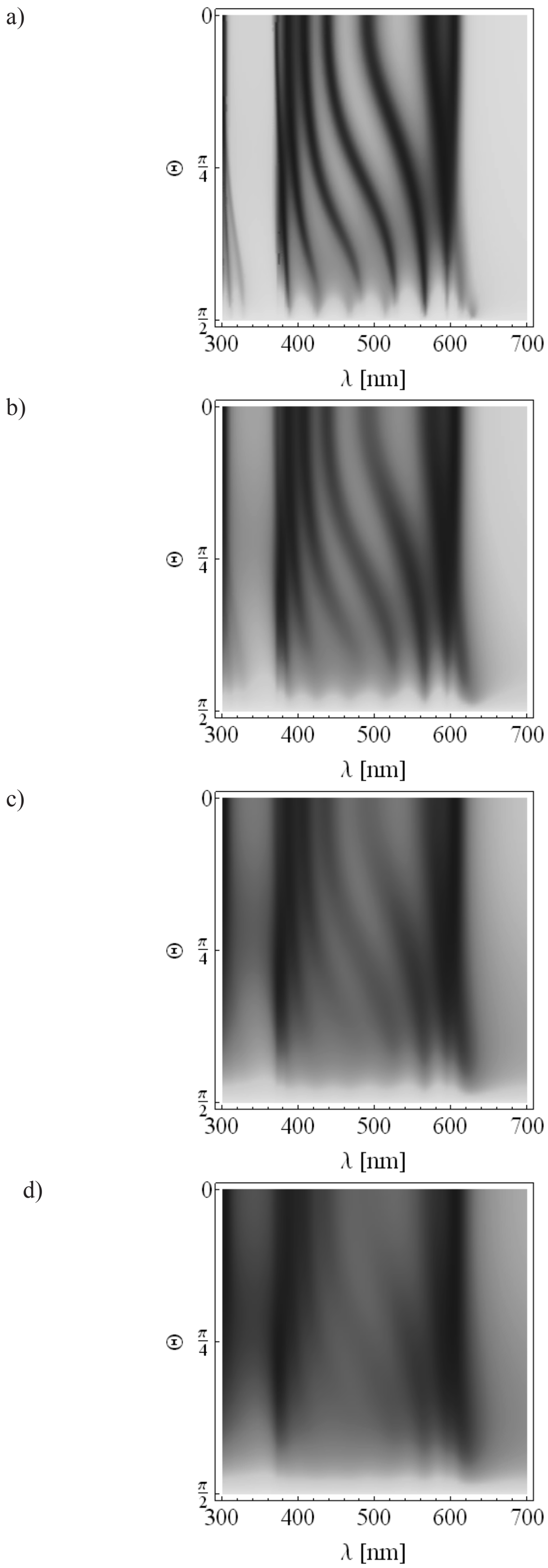

Fig. 6. Binary superlattice unpolarized reflectance map for L = 7; a) k = 0.01, b) k = 0.03, c) k = 0.05, d) k = 0.07

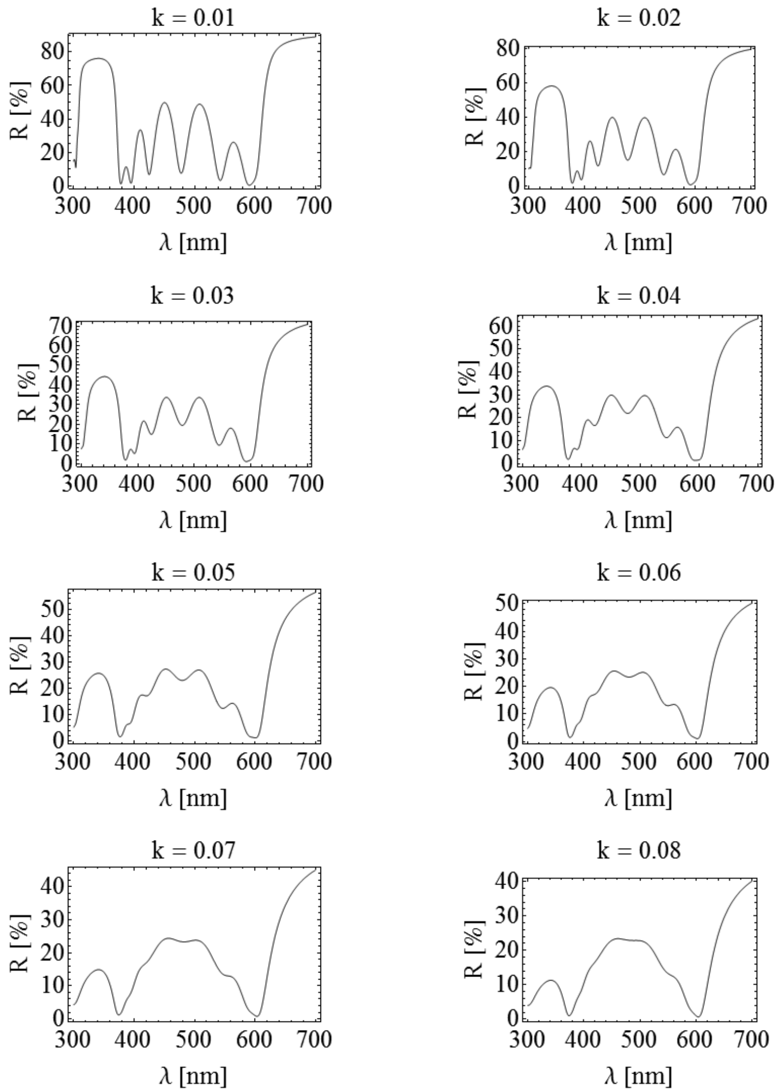

Fig. 7. The reflectance of binary structure for the angle of incidence equal to $\Theta = \pi/4$ and different rates of extinction coefficient k

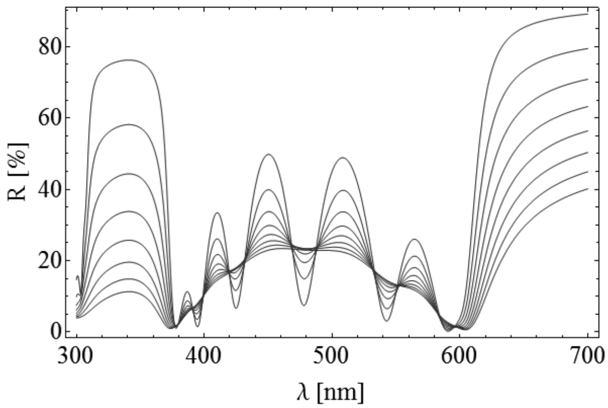

Fig. 8. The imposition of charts from Fig. 7

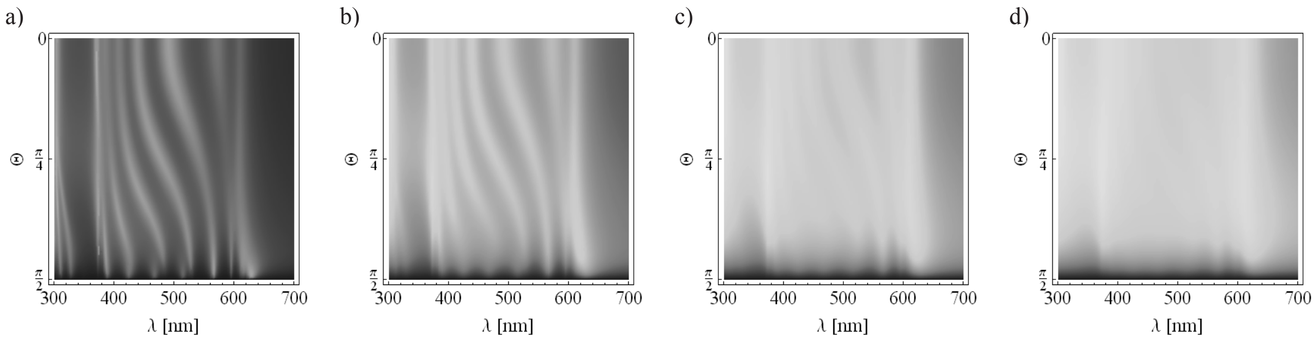

Fig. 9. Binary superlattice unpolarized absorption map for L = 7; a) k = 0.01, b) k = 0.03, c) k = 0.05, d) k = 0.07

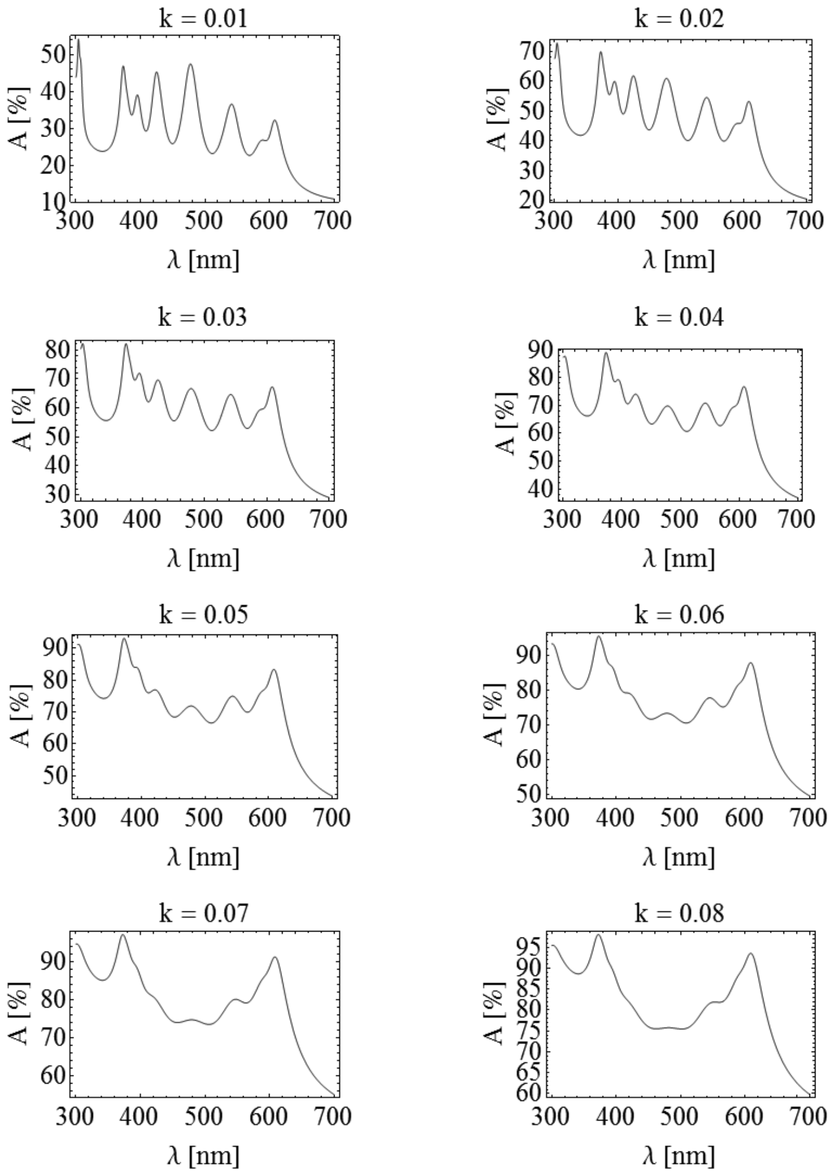

Fig. 10. The absorption of binary structure for the angle of incidence equal to $\Theta = \pi/4$ and different rates of extinction coefficient k

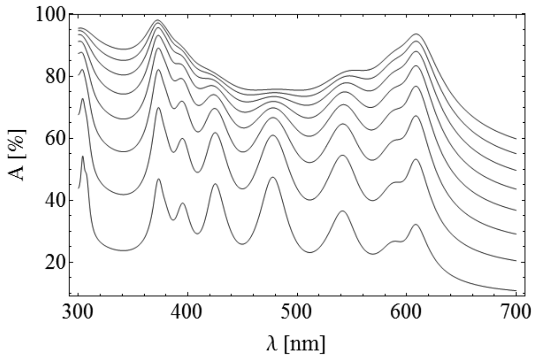

Fig. 11. The imposition of charts from Fig. 10

Fig. 3 shows the structure of the transmission of Fig. 2, after taking into account extinction coefficient *k*. It should be noted a marked reduction in transmission for increasing the coefficient *k*. More specifically, this phenomenon is shown in Figs. 4 and 5.

The increase in the extinction coefficient also reduces the reflectance and decrease its value fluctuations (Figs. 6-8).

In Figs. 9-11 can be noted how absorption of the electromagnetic wave propagating in the multilayer structure depends upon the extinction coefficient.

3. Conclusions

The study demonstrated the nature of the transmission band for binary superlattice, which depends on the polarization. It is shown that the higher the extinction coefficient, which is responsible for the absorption of electromagnetic waves, decreases the transmittance and reflectance of the multilayer system at the same time increasing its absorption. Complex refractive index form can be used to describe the lossy material in multilayer systems.

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