Polarizers and Splitters on the Base of Multi-layer Systems

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Methods of calculation of polarizers and splitters for visible spectra based on a multi-layer dielectric system are considered. Practical formulas for calculation are given. For example the cases of a splitter calculation when $R_S > 70\%$ and $R_P \leq 30\%$ or $R_S = R_P$ were considered. The formulas of the effective layers method are of practical use. The optical characteristics of calculated and fabricated polarizers and splitters for 650 nm and 780 nm wavelengths are presented.

Keywords : Polarizer, Splitter, Optical communication

1. INTRODUCTION

Semiconductor lasers as GaAs, AlGaAs and InGaAsP and optical fiber devices are the major system components of optical communication systems and optical information processing. These lasers emit radiation in the red and near infrared area where the fibers on the base of a silicon dioxide have very small absorption. However, practical utilization of optical systems requires application of different optical elements: filters, mirrors, polarizers and splitters of light beams[1,2]. All these devices may be fabricated on the base of interference multi-layer coatings on a transparent substrate. Often there is a problem to output from a light stream (or to input in it) radiation of a particular wavelength and polarization at the strictly given parameters. There are some difficulties in their calculation because these devices operate in the optical systems as a rule at the large incident angles of light (45°-60°). In the present work the results of calculation and fabrication of polarizers and splitters for 650 nm and 780 nm wavelengths are presented.

2. POLARIZER

Birefringence or dichroism is used to construct polarizing systems based on crystalline substances. Polarizers based on birefringence, are fabricated from birefringent crystals, often from Iceland spar. One of the rays is eliminated as a result of a total interior reflection in this polarizer. The polarizers have a good optical characteristics, however their lack is the small aperture. Their cost strongly rises at the increase of the aperture because it requires the use of crystals with large sizes.

The operation principle of dichroism polarizers is based on a different absorption of the ordinary and extraordinary beams in some birefringent crystal. If the plate thickness of such an anisotropic crystal is sufficient, one of the beams was completely absorbed, and the light after a plate will be totally polarized. However the low transmittance of these polarizers is a disadvantage.

Multi-layer interference polarizers represent the successful compromise between the mentioned above polarizers. The polarizers based on thin films may be made with high enough transmittance in a wide spectral area and with the rather large aperture (up to 100-150 mm). The following phenomenon is the base of operation of these polarizers. There are two waves with mutually perpendicular polarization (s and p components) when the plane unpolarized wave falls at the angle on the boundary between two media with different refractive indices. In this case the reflectance and transmittance of s and p waves is different. It is possible to increase the degree of polarization of transmittance or reflectance, using the multi-layers structures.

The design of polarizing coating is usually realized on the basis of two-component periodic structures, as the most simple for the analysis and technological production. Calculation and analysis of such structures are carried out using an optical admittance. The last is defined as a relation of amplitudes of magnetic and electrical fields of a light wave in the medium. If the design of polarizer is a stack of quarter-wave layers as $(n_1\ n_2)^k n_{sub}$, the admittance of such a system is given at the normal incidence of light by[3]

$$Y = \frac{y_1^2 y_3^2 y_5^2 \ldots y_{sub}}{y_2^2 y_4^2 y_6^2 \ldots} \qquad (1)$$

Here y_i is the admittance of i-th layer and y_{sub} is the admittance of a substrate (in the numerator if number of layers is even, or in the denominator if odd). The relation of magnetic field amplitude to electric field amplitude of a light wave in non-magnetic medium ($\mu = 1$) equals numerically to a refractive index n of the medium. It follows from the Maxwell's equations for an electromagnetic field [3]. Therefore at a normal incidence of light the admittance of a multi-layer system was expressed through refractive indices of media looks like:

$$Y = \frac{n_1^2 n_3^2 n_5^2 \ldots n_{sub}}{n_2^2 n_4^2 n_6^2 \ldots} \qquad (2)$$

At the tilted incidence of light, when s and p components of a light wave are arisen, it is convenient to use the effective refractive indices.

$$u_S = n\cos\theta, \quad u_P = n/\cos\theta \qquad (3)$$

Here the indices s and p correspond to the components of a light wave, n is the refractive index of medium, and θ is the angle between the normal and the direction of propagation of light in the medium. At a normal incidence their values coincide with the true value of the refractive index of the medium. At titled incidence of light we may calculate the thickness of interference layers as at normal incidence, but use the effective refractive indices. The concept of "effective refractive index" does not have the physical sense, however its use is very fruitful in a calculation and gives correct results.

The concept of admittance is convenient for practice, because the reflection of a multi-layer system is determined through admittance by the formula:

$$R = \left|\frac{y_0 - Y}{y_0 + Y}\right|^2 \qquad (4)$$

Here y_0 is the admittance of a surrounding medium (for air $y_0 = 1$) and Y is the admittance of multi-layer system.

Let's calculate for example a polarizer for $\lambda = 650$ nm and transmittance $T_P > 95\%$. Let's assume that $T_S = 0$ and consequently $R_S = 1$ and $R_P < 5\%$. Let's choose as a design of polarizer the stack of eight quarter-wave layers, i.e. $(n_1\ n_2)^4 n_{sub}$. Our task is to calculate n_1 and n_2 and select the corresponding materials. In according to Eq. (2) the admittance of such a system equals

$$Y = \frac{n_1^4 n_{sub}}{n_2^4} \qquad (5)$$

At a tilted incident of light we can write the admittance for s and p polarizations using Eq. (3). In this case from the formula (5) we shall obtain:

$$Y_s = \frac{u_{1s}^4 u_{sub,s}}{u_{2s}^4} = \frac{n_1^4 \cos^4\theta_1 n_{sub}\cos\theta_{sub}}{n_2^4 \cos^4\theta_2},$$

$$Y_p = \frac{u_{1p}^4 u_{sub,p}}{u_{2p}^4} = \frac{\left(\dfrac{n_1}{\cos\theta_1}\right)^4 \dfrac{n_{sub}}{\cos\theta_{sub}}}{\left(\dfrac{n_2}{\cos\theta_2}\right)^4} \qquad (6)$$

where θ_i is angle between the normal and the direction of a propagating light ray in the media. According to the Snell's law

$$n_0 \sin\theta_0 = n_1 \sin\theta_1 = n_2 \sin\theta_2 = n_{sub} \sin\theta_{sub} \qquad (7)$$

Taking into account Eq. (7) and $n_0 = 1$ (air) the Eq. (6) may be rewritten as

$$Y_s = \frac{\left(n_1^2 - \sin^2\theta_0\right)^2 \left(n_{sub}^2 - \sin^2\theta_0\right)^{1/2}}{\left(n_2^2 - \sin^2\theta_0\right)^2},$$

$$Y_P = \left(\frac{n_1}{n_2}\right)^8 n_{sub}^2 \frac{\left(n_2^2 - \sin^2\theta_0\right)^2}{\left(n_1^2 - \sin^2\theta_0\right)^2 \left(n_{sub}^2 - \sin^2\theta_0\right)^{1/2}}. \qquad (8)$$

So far as $R_P = 0$ and $R_S = 1$, then in accordance with Eq. (4) $Y_P = 1$ and $Y_S = 0$. Let's choose MgF_2, possessing refractive index of $n = 1.38$ as a material n_1. Let's assume $n_{sub} = 1.52$ and $\theta_0 = 60^o$. Substituting in the upper equation of a system (8) $n_1 = 1.38$, $n_{sub} = 1.52$ and $\theta_0 = 60^o$ we shall obtain $n_2 \approx 1.6$. The refractive index of Al_2O_3 is the closest to this value. Thus the design of a polarizer looks like $(n_1\ n_2)^4\ n_{sub}$. Here n_{sub} is for a glass substrate, n_1 and n_2 are quarter wave layers of MgF_2 and

Al_2O_3, respectively. The calculated performance of a spectral transmittance of such a polarizer is shown in Fig.1.

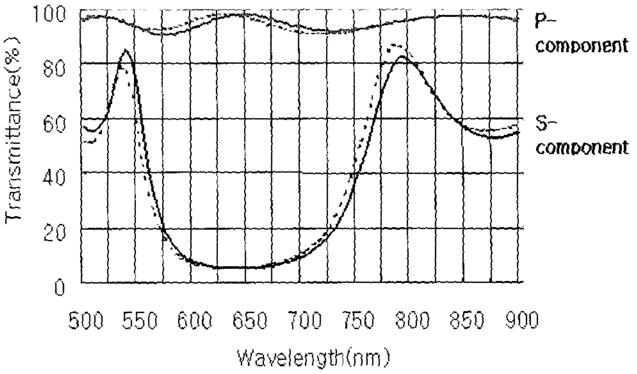

Fig. 1. Optical characteristics of a polarizer $s(n_1n_2)^5$, n_1 = 1.664, n_2 = 1.38, n_{sub} = 1.52, θ = 60° (solid line – simulation, dotted line - experiment).

The divergence of the semiconductor laser's beam is about ± 5°. Therefore the optical characteristics of polarizer should essentially not vary at the changing of the incident angle within these limits. For the polarizer calculated above at $\theta = 60^\circ \pm 5^\circ$ T_P = 95-97 % and T_S = 5-7 %. Magnification of layer number increases T_P till 98-99%, but simultaneously also T_S increases essentially achieving 9-13 %.

If it is necessary to obtain a very large degree of polarization (order $T_P/T_S \sim 10^3$ - 10^4), it is possible to make that at the tilted incidence of light on a multi-layer coating the spectral width of the high reflecting area of the *s*-component is more, than that of *p*-component. The idea of the polarizer is as follows: it is necessary to select of the layer thickness so that a working wavelength will be located in the area, where *s*–component of radiation has very high reflectance, and *p* - component has a very high transmittance.

It is well known, the width of a spectral area with high reflectance of a multi-layer coating is determined by a difference of layer refractive indices. Let's construct a polarizer for λ = 650 nm on the basis of TiO_2 (n_H = 2.274) and SiO_2 (n_L = 1.4565). The set of ten double layers $(HL)^{10}$ results in the very sharp edges of high reflecting bands for both *s*- and *p*-components. (Here H and L are TiO_2 and SiO_2 layers of the quarter wave thickness). However, the lateral minima are observed on the long wavelength side of T_P band. For example in the area of 600-670 nm the transmittance of T_S is practically zero, but T_P in this area has a deep minimum reaching 70 %. We have used the first three periods of unequal optical thickness for suppression of this minimum. Moreover we introduced the matching layer between a substrate and multi-layer system and carried out the last period as unequal thickness to achieve near flatness at a level 98% for T_P in the area of 640-660 nm. The final polarizer design was as follows S(0.88H0.52L0.48H)(0.8H1.2L)^3(HL)^{7}0.6H1.4L. Its optical characteristic is shown in Fig. 2.

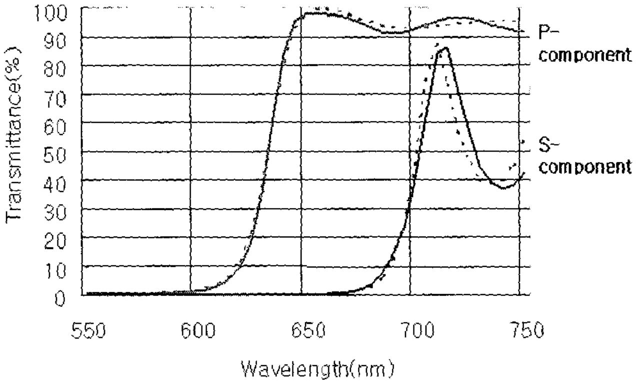

Fig. 2. Optical characteristics of a polarizer with a layer structure: s(0.88H0.52L048H)(0.8H1.2L)3(HL)7)0.6H 1.4L, nH = 2.274, nL = 1.4565, nsub = 1.52, θ = 57° ; (solid line –simulation, dotted line – experiment).

The performance was calculated at an incidence angle of θ_0 = 57°(Brewster angle for a glass substrate). However within $\Delta\theta_0 = \pm 5^\circ$ the optical characteristics of a polarizer nearly do not vary: T_P = 98 % and T_S < 0.1 %.

From Fig. 2 it is seen, the polarizer is calculated for a wavelength 650 ± 10 nm. However, it is very easy to remove a spectral characteristic along a horizontal axis by changing a characteristic wavelength λ_0 and to obtain the same polarization relation for any wavelength in a visible area.

3. SPLITTERS

Very often it is necessary to separate a part of laser radiation to form the reference beam or to create a synchronizing pulse in systems of an optical information processing. For these purposes the multi-layer systems are irreplaceable, because the semitransparent metal mirrors introduce considerable losses. In this case the polarizing properties of a multi-layer system are undesirable and cause some difficulties in the splitter calculation. Since the reflectance of *s*-component is always more, than that of *p*-component, it changes the resulting polarization and may lead to particular light losses. At the same time very often it is necessary to obtain the *s*- and *p*- components of the different intensities.

The calculation of a splitter design is carried out with the help of the same formulas as a polarizer. If the splitter design is picked out as a system of layers $(n_1 n_2)^k n_{sub}$ on a glass substrate, it is necessary to decide jointly the equation system (8) for determination n_1 and n_2, in the same as a polarizer. For this purpose first of all Y_S and Y_P should be defined from Eq. (4) with the data of R_S and R_P. However, it is impossible to obtain in practice the precise analytical solution of Eq. (8), because a system of Eq. (8) has very high order. Therefore we should consider approximate magnitudes as the numerical values of n_1 and n_2. They can make it difficult to choose the suitable materials. At the same time, it is necessary to carry out the optimization of a layer thickness after picking out suitable materials and creating the splitter design.

For example we shall show the calculation of a splitter with parameters: $R_P = 30 \pm 3\%$, $R_S \geq 70\%$, angle of incidence $\theta_0 = 45^\circ$, spectral region $\lambda = 750\text{-}800$ nm. Let's pick out the splitter design as the stack of layers $(n_1 n_2)^4 n_{sub}$, where n_1 is a layer of quarter wave thickness of material with high refractive index and n_2 is the same thickness layer of material with low refractive index, $n_{sub} = 1.52$ is refractive index of glass.

Knowing $R_P = 0.3$ and $R_S = 0.7$ we can obtain from Eq. (4) $Y_P = 3.4$ and $Y_S = 18$. Then it is necessary to solve an equation system (8) to define the values of n_1 and n_2. It is seen from (8) that $Y_P = (n_1/n_2)^8 n_{sub}\ (1/Y_S)$. Substituting Y_P and Y_S by their values we will find: $n_1/n_2 = 1.5$. Let's pick out material MgF_2 with refractive index 1.38 as n_2. Then we will obtain $n_1 = 2.07$. Sb_2O_3 has refractive index near this value. Thus the design of a splitter with above mentioned specification is $(n_H n_L)^4 n_{sub}$, where n_H and n_L are quarter wave layers of Sb_2O_3 and MgF_2, respectively.

It may be happen that material n_1 is not real in nature or this material is undesired in technological process. Our technology equipment set up on operating with MgF_2 and TiO_2, so Sb_2O_3 is undesired. In this case we can use the method of effective layers [4] for simulation of the desirable material. This method allows the exchange layer with refractive index N_E and phase thickness F_E by the combination from three layers (ABA) with refractive indices of n_A and n_B and phase thicknesses of F_A and F_B. (Phase thickness $F = (2\pi/\lambda) \cdot nh$, where n is the refractive index and h is the thickness of a layer). The magnitudes N_E and F_E are defined by parameters n_A, n_B, F_A and F_B:

$$N_E = n_A \left[\frac{\sin 2F_A \cos F_B + A_0 \cos 2F_A \sin F_B - B_0 \sin F_B}{\sin 2F_A \cos F_B + A_0 \cos 2F_A \sin F_B + B_0 \sin F_B} \right]^{1/2} \tag{9}$$

$$\cos F_E = \cos 2F_A \cos F_B - A_0 \sin 2F_A \sin F_B \tag{10}$$

$$A_0 = \frac{1}{2}\left(\frac{n_A}{n_B} + \frac{n_B}{n_A} \right), \quad B_0 = \frac{1}{2}\left(\frac{n_A}{n_B} - \frac{n_B}{n_A} \right) \tag{11}$$

Formulas (9)-(11) allow us to calculate N_E and F_E for given parameters n_A, n_B, F_A and F_B. However in practice very often the problem is reversed. Knowing N_E and F_E, it is necessary to calculate the thicknesses of the A and B layers, which comprise the effective structure (ABA) at the data n_A and n_B. The theory gives the following expression for F_A and F_B [5]:

$$\sin F_B = \frac{n_A / N_E - N_E / n_A}{n_A / n_B - n_B / n_A} \sin F_E \tag{12}$$

$$\sin 2F_A = \frac{ac \pm b\left(a^2 + b^2 - c^2\right)^{1/2}}{a^2 + b^2} \tag{13}$$

where

$$a = -\frac{1}{2}\left(\frac{n_B}{n_A} + \frac{n_A}{n_B} \right) \sin F_B, \quad b = \cos F_B, \quad c = \cos F_E \tag{14}$$

For our case let's calculate the (ABA) structure instead of the quarter wave layer of Sb_2O_3, using MgF_2 as A-material and TiO_2 as B-material. We will assume $n_A = 1.38$ (MgF_2) and $n_B = 2.35$ (TiO_2), $N_E = 2.07$ (Sb_2O_3).

From Eq. (12) we will obtain $\sin F_B = 0.747$ ($\sin F_E = 1$, because $F_E = \pi/2$ is the phase corresponding to the layer thickness of a quarter wave). Thus $F_B = 48^\circ$ or 0.26π. It corresponds to optical thickness of 0.134λ of TiO_2 layer. Now it is necessary to calculate the optical thickness of the A(MgF_2) layer from Eq. (13). From Eq.(14) we will find $a = -0.8554$, $b = \cos 48^\circ = 0.6691$, $c = \cos F_E = 0$.

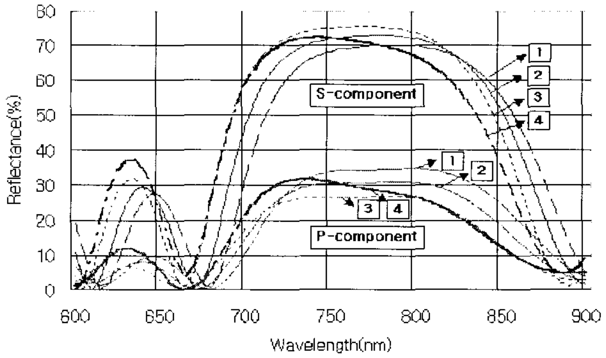

Fig. 3. Optical characteristics of a splitter with layer structure: s[(0.212L0.536H0.212L) L]^4, $n_H = 2.274$, $n_L = 1.38$, $n_S = 1.52$; (1, 2, 3 – simulation, 4 – experiment , 45°). Incident angle is: 1 – 41.5°, 2 – 45°, 3 – 48.5°.

Using these values of a, b, c we will have from Eq. (13) $\sin 2F_A = 0.6162$ and $F_A = 19^\circ$ or 0.1π. It corresponds to the 0.053λ optical thickness of MgF_2 layer. Thus the combination of (0.212L 0.536H 0.212L), where L and H are the quarter wave layers of MgF_2 and

TiO_2 respectively, plays the same role as a quarter wave layer of Sb_2O_3.

The final splitter design is S[(0.212L 0.536H 0.212L) L]^4, and its optical characteristic is shown in Fig.3.

The discrepancy between transmittance of the simulated and fabricated splitter is evidently due to monitoring errors of layer thickness. The accuracy of the latter was ±2 nm. It should be noticed that the system is very sensitive to the change of the incident angle. $\Delta R = \pm 5\%$ when the incident angle is varied within ± (3^o-4^o).

Very often it is necessary to obtain *s*- and *p*-components of the same intensities. In this case the polarizing properties of a coating due to a tilted light incidence are highly undesirable. The splitter calculation (definition of n_1 and n_2) is carried out with the help of formulas (8), taking in account correlation $Y_S = Y_P$.

As it is seen from (4), the reflectance *s*- and *p*-components is identical, if corresponding admittances (2) are equal. If we shall enter value $\Delta = u_p/u_s$, this condition corresponds to a requirement

$$\frac{\Delta_1^2\Delta_3^2\Delta_5^2\ldots\Delta_{sub}^2}{\Delta_2^2\Delta_4^2\Delta_6^2} = 1 \qquad (15)$$

The procedure is used to find a combination of materials such that condition (15) is satisfied and the value of admittance is achieved. In principle this procedure is the same as it was described above, i.e. it is the method of trial and error.

The problem is essentially facilitated by picking out an intermediate material with a refractive index obeying to following requirement [3]

$$\Delta_H\Delta_L = \Delta_M^2 \qquad (16)$$

In this case the multi-layer structure looks like as...HMLMHMLMH..., so the form of the admittance is

$$Y = \frac{u_H^2 u_L^2 u_H^2\ldots}{u_M^2 u_M^2 u_M^2\ldots} \qquad (17)$$

The quantity of layers is picked out so that the necessary magnitude of reflectance is achieved.

Since the splitters operate at the large angle with respect to incident radiation, the multi-layer coating can be used in various glass prisms to decrease losses. In this case splitter represents a glass cube with a coating deposited on its interior diagonal. This system was object of many *theoretical investigations.*

Costich [6] has shown that the combination of three layers such as (H/2)L(H/2) has no polarization effect at the wavelength λ, for which the total optical thickness of the combination equals one full wave (i.e. $\lambda_0 / \lambda = 2$, λ_0 is the wavelength where L has an optical thickness of a quarter wave) whenever,

$$\Delta n_H(\Delta n_H / \Delta n_L)^{1/2} = 1 \qquad (18)$$

where

$$\Delta n = n_P / n_S = 1/\left[1 - (n_G \sin\theta_G / n)^2\right] \qquad (19)$$

Here n_G is the refractive index of a surrounding medium (glass) and θ_G is an incidence angle of radiation on the coating surface in this medium. Combining (18) and (19) we shall obtain a relation between n_L and n_H

$$n_L = (n_G \sin\theta_G)/\left\{1 - \left[1 - (n_G \sin\theta_G / n_H)^2\right]^3\right\}^{1/2} \qquad (20)$$

Assuming that the surrounding medium is a glass with refractive index $n_G = 1.52$ and $\theta_G = 45^0$ from Eq. (20) at $n_H = 2.35$ we shall obtain $n_L = 1.51$. Choosing $n_H = 2.05$ we can find from Eq. (20) another corresponding low index material with $n_L = 1.37$. These two combinations, corresponding to pairs of materials (TiO_2, YbF_3) and (Sb_2O_3, MgF_2) have two different equivalent indices *N*, which means that we could construct a periodic multi-layer system with them.

However the multi-layer system with the equivalent thickness of full wave period is not suitable for constructing reflecting systems. A.Thelen has used Costich's theory and has developed it further on a stack from the quarter wave layers [7]. The transmittance of quarter wave stack at the quarter wave point (for example, $\lambda_0 / \lambda = 1.5$) can be calculated under the formula [8]

$$T = T(x) = 4/\left(2 + x^2 + x^{-2}\right) \qquad (21)$$

with

$$x = (n_G / n_{sub})^{1/2}(n_2n_4n_6\ldots / n_1n_3n_5\ldots) \qquad (22)$$

for even number of layers and

$$x = (n_G n_{sub})^{1/2}(n_2n_4n_6\ldots / n_1n_3n_5\ldots) \qquad (23)$$

for odd numbers of layers. In the case of films cemented inside a glass cube, $n_G = n_{sub}$. T_S will be equal T_P when x_S equals x_P. This requirement reduces in the equation

$$(n_{G,S} / n_{sub,S})^{1/2} (n_{2S} n_{4S} n_{6S} \ldots / n_{1S} n_{3S} n_{5S} \ldots) =$$

$$(n_{G,P} / n_{sub,P})^{1/2} (n_{2P} n_{4P} n_{6P} \ldots / n_{1P} n_{3P} n_{5P} \ldots) \qquad (24)$$

Taking into account that $\Delta n = n_P / n_S$ we shall obtain

$$(\Delta n_G / \Delta n_{Sub})^{1/2} \Delta n_2 \Delta n_4 \Delta n_6 \ldots = \Delta n_1 \Delta n_3 \Delta n_5 \ldots \qquad (25)$$

for an even number of layers, and correspondingly,

$$(\Delta n_G \Delta n_S)^{1/2} \Delta n_2 \Delta n_4 \Delta n_6 \ldots = \Delta n_1 \Delta n_3 \Delta n_5 \ldots \qquad (26)$$

for an odd number of layers.

We used Thelen's formulas described above for calculation of a splitter design intended for operation in the air environment in a concrete optical scheme. The splitter should have the following parameters:

-angle between the normal of surface and the axis of an incident laser radiation 45° ± 5°,

-transmittance for λ = 780 nm 70 % $\leq T_S \approx T_P <$ 75 %, and $|T_S - T_P| \leq 5$ %,

- transmittance for λ = 655 nm 96 % $< T_P$.

Table 1. The layer structure of the splitter with $T_s = T_p$ for λ_0 at the incident angle of 45°.

NN of layer	Material	Refractive index	Optical thickness, in λ_0
	Air		
1	LaF$_3$	1,576	0,343
2	TiO$_2$	2,348	0,345
3	LaF$_3$	1,576	0,345
4	MgF$_2$	1,384	0,413
5	LaF$_3$	1,576	0,343
6	TiO$_2$	2,348	0,340
7	LaF$_3$	1,576	0,340
8	MgF$_2$	1,384	0,413
9	LaF$_3$	1,576	0,343
10	TiO$_2$	2,348	0,340
Substrate	Glass	1,52	

Taking TiO_2 (n = 2.35) as n_H, we selected other materials LaF_3 (n = 1.576) as n_L and MgF_2 (n = 1.384) as $n_{L'}$ so that to satisfy Eq. (25). Besides, since in our case a surrounding medium is air, we have entered in addition last two layers of n_H and n_L to achieve the desirable result. Then the optimization of layer thickness was carried out and their magnitudes are shown in Table 1.

Finally the splitter looks like S(1.652L'1.36L1.36H1.36L)^{2}1.2H1.372L, where S is the substrate, H, L and L' mean quarter wave layers TiO_2, LaF_3 and MgF_2, respectively.

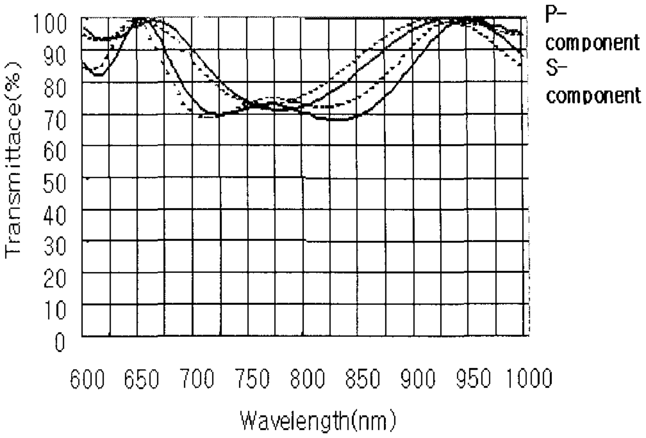

Fig. 4. Optical characteristics of a splitter with layer structure: s(1.652L'1.36L1.36H1.36L)^{2}1.2H1.372L, n_H = 2.328 (TiO_2), n_L = 1.576 (LaF_3), $n_{L'}$ = 1.384 (MgF_2), n_S = 1.52 for $T_S = T_P$ at the angle 45°, (solid line – simulation, dotted line – experiment).

The transmittance of this splitter is shown in Fig. 4. It can be seen that the splitter completely obeys the mentioned above parameters on a wavelength 780 nm. Simultaneously transmittance T_P on a wavelength 655 nm is more than 96%. It is necessary to notice, that the system is sensitive enough to a variation of incident angle, however within ± 5° the indicated above parameters are saved. Varying λ_0, the relation $T_S \cong T_P$ can be obtained at any wavelength in the visible area of a spectrum. This construction of a splitter is simpler, than one in a glass cube. It is compact enough and contains rather small number of layers. A substitution LaF_3 on Al_2O_3, Sb_2O_3 on ZrO_2, and MgF_2 on SiO_2 allows to obtain values $T_S = T_P$ with a tolerance $|T_S - T_P| \leq 5$ % in limits T = (40-80) %, that quite satisfies all practical necessities.

4. CONCLUSION

The practice formulas for the calculation of multi-layer polarizers and splitters are described. The examples of their use are shown to achieve particular parameters of polarizers and splitters. The good agreement of experimental results and simulation confirm that formulas may be of use for practical applications. A simulation that can be applied to any material with needed refractive index by the effective layer method is shown.

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