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Cube Beam Splitters for Different Values of Reflectance to Transmittance Coefficients of Light

Optical properties of films cemented in cube beam splitters were investigated in unpolarized and linearly polarized light. Optical coefficients were measured in the visible range of the spectrum for the angle of incidence on films $\alpha = 45°$. Achromatic, unabsorbing beam splitters for the $R:T$ ratio from 1:5 to 1:2 were obtained by means of a double dielectric film of the type $L\left(\frac{\lambda_0}{2}\right)$, $H\left(\frac{\lambda_0}{4}\right)$, where L, H are substances with a low and high refraction coefficient, respectively, and λ_0 is the wavelength for which the film thickness was controlled during evaporation. Unabsorbing beam splitters for the ratio $R:T = 1:1$ require a five-film dielectric coating [7]. Optical thicknesses of particular films are equal: $H\left(1.13\frac{\lambda_0}{4}\right)$, $L\left(1.72\frac{\lambda_0}{4}\right)$, $H\left(1.13\frac{\lambda_0}{4}\right)$, $L\left(1.72\frac{\lambda_0}{4}\right)$, $H\left(1.18\frac{\lambda_0}{2}\right)$. Besides optical properties of a simpler beam splitter for $R:T = 1:1$ with a mixed coating i.e. double dielectric film $L\left(\frac{\lambda_0}{2}\right)$, $H\left(\frac{\lambda_0}{4}\right)$ and a thin inconel film, were presented.

I. Introduction

Cube beam splitters with a metallic film, commonly used in optical measurements, are achromatic in the visible range, but have high absorption. A cube splitter with an inconel film splitting light with $R:T = 3:2$, absorbs about 60% of light. The dependence of the optical coefficients R, T on the wavelength λ of a cube beam splitter with an inconel film is presented in Fig. 1. The reflectance and transmittance coefficients are denoted by R_p, T_p for the parallel, and R_s, T_s for the perpendicular components of linearly polarized light. As is seen from Fig. 1, cube beam splitter with an inconel film is achromatic in the visible range of the spectrum. For many years investigations were carried out on cube beam splitters with the dielectric films instead of the metallic ones. The litterature available to us consists of papers [1-9]. Recently, Sokolova [9] published a paper dealing with prism beam splitters with dielectric films, obtained by a chemical method. The results of our investigations on cube beam splitters with dielectric and mixed films evaporated in vacuum, are presented below.

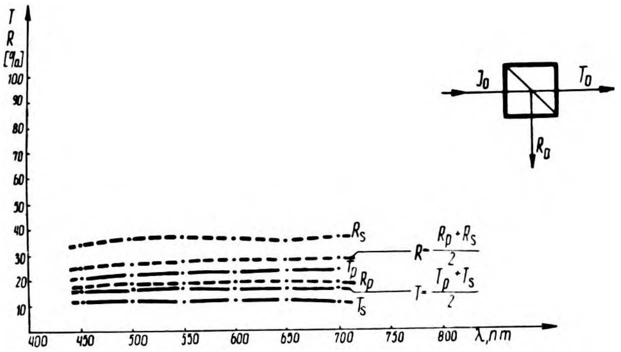

Fig. 1. Reflection (R) and transmittance (T) coefficients versus wavelength λ for beam splitter with an inconel film (light linearly polarized) $R:T = 3:2$

II. Experimental procedure

Film beam splitters were evaporated in an Edwards Vacuum Coating Unit type 19E7 under the pressure $p = 1 \times 10^{-5}$ Tr, on the rectangular prisms of BK 7 glass. During evaporation the base was not heated. After the evaporation the prisms with films were glued together with the prisms without films to make a cube. For CaF_2, MgF_2, Na_3AlF_6 and ZnS a molybdenium boat, and for inconel a tungsten filament were used as heaters. During the preparation of the

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films the following parameters were fixed in all processes: substrate preparation, ionic bombardment cleaning, substrate rotation while cleaning and pressure during the evaporation. Thickness was checked photometrically by measuring maximum or minimum of the reflected light for a given wavelength λ_0, selected by an interference filter. Two-, three-, and five-film coatings were obtained in one evaporation process.

The optical coefficients R and T as functions of the wavelength λ were measured for the angle of incidence $\alpha = 45°$. The transmittance coefficients for unpolarized light were measured by a type VSU-1 Zeiss spectrophotometer The reflectance R and transmittance T coefficients for linearly polarized light were measured by means of a polarization spectrophotometer. Radiation was detected in a photomultiplier directly coupled with recorder pen $G_1 B_1$ (Zeiss made). Using the same spectrophotometer, after removing the Nicol, the optical coefficients R and T for unpolarized light were determined. The transmittance and reflection coefficients were measured with the accuracy $\Delta T = 0.5\%$ and $\Delta R = 2\%$, respectively. Besides the ratio of white light reflected (R) to transmitted (T) through the splitter, was measured.

III. Experimental results and discussion

Generally, in the case of small value of the ratio $R{:}T$ a beam splitter with one dielectric film is proposed. Optical thickness of the film is equal $n_1 d_1 \cos\varphi_1 = \frac{1}{4}\lambda_0$, where n_1 is the refraction coefficient of a substance with a high refraction coefficient, e.g. TiO_2, d_1 is the geometrical thickness of the film, φ_1 — angle of refraction in the film. It seems to us that a better achromatism of the splitter can be assured by a set of two dielectric films. The first film evaporated on glass has a low refraction coefficient and optical thickness $\left(\frac{\lambda}{2}\right)$, whereas the second one has a high refraction coefficient, and optical thickness $\left(\frac{\lambda_0}{4}\right)$. To control film thickness during the evaporation of such beam splitters in an Edwards vacuum apparatus, the interference filter for $\lambda_0 = 510$nm was used. By means of double dielectric films of the type $L\left(\frac{\lambda_0}{2}\right)$, $H\left(\frac{\lambda_0}{4}\right)$ we obtained achromatic unabsorbing beam splitters for the rations $R{:}T$ from 1:5 to 1:2. Here, L, H denote the substances with low and high refraction coefficients, respectively. In Figs 2 and 3 optical properties of beam splitters with a double dielectric film for unpolarized light are presented. In Fig. 2 the dependence of the reflectance R and transmittance T coefficients on the wavelenght λ for a beam splitter with a double film CaF_2 $\left(\frac{\lambda_0}{2}\right)$ and $ZnS\left(\frac{\lambda_0}{4}\right)$ is given. In Fig. 3 we have $R = f(\lambda), T = f(\lambda)$ for a beam splitter with the films Na_3AlF_6 $\left(\frac{\lambda_0}{2}\right)$, $ZnS\left(\frac{\lambda_0}{4}\right)$. In Fig. 4 optical properties of the same beam splitter in the linearly polarized light are presented. Measurements in the polarized light were restricted to the range 450-700 nm, because of the photomultiplier sensitivity range. Other beam splitters with double dielectric films investigated by us exhibited similar optical properties in polarized and unpolarized light. Beam splitters of this type are rather easy to obtain,

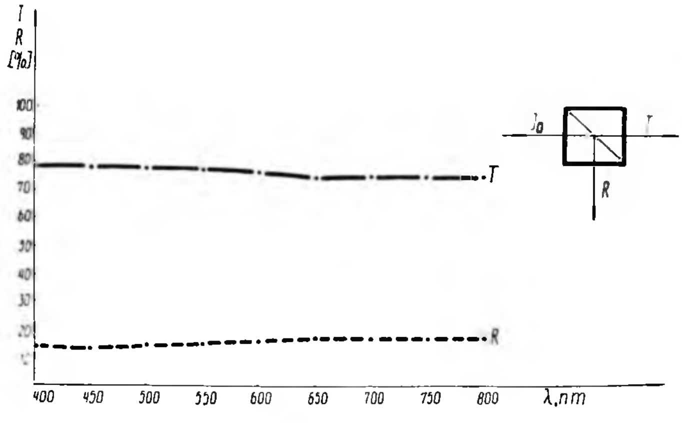

Fig. 2. $R = f(\lambda)$, $T = f(\lambda)$ for beam splitter with a double dielectric film $CaF_3\left(\frac{\lambda_0}{2}\right)$, $ZnS\left(\frac{\lambda_0}{4}\right)$, $\lambda_0 = 510$ nm, $R{:}T = 1{:}5$. Beamsplitter without antireflecting coatings. Light unpolarized

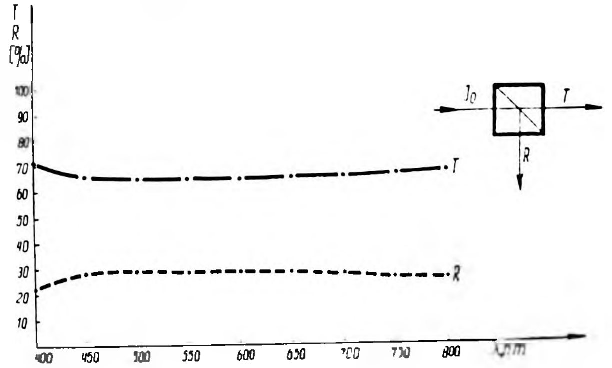

Fig. 3. $R = f(\lambda)$, $T = f(\lambda)$ for beam splitter with a double film $Na_3AlF_6\left(\frac{\lambda_0}{2}\right)$, $ZnS\left(\frac{\lambda_0}{4}\right)$, $\lambda_0 = 510$ nm, $R{:}T = 1{:}2$. Beam splitter without antireflecting coatings. Light unpolarized

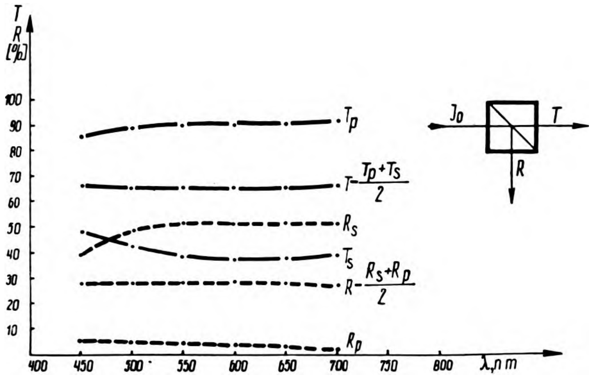

Fig. 4. Reflectance (R) and transmittance (T) coefficients as functions of λ in a linearly polarized light. Beam splitters with a double film $Na_3AlF_6\left(\frac{\lambda_0}{2}\right)$, $ZnS\left(\frac{\lambda_0}{4}\right)$, R_p, T_p and R_s T_s parallel and perpendicular components of the polarized light. Beam splitter without antireflecting coatings

as we control the thickness of evaporated films for integer multiplicity of $\left(\frac{\lambda_0}{4}\right)$. Using different substances for films with low and high refraction coefficients we can get different ratios $R:T$ from 1:5 to 1:2. It is more difficult to get unabsorbing cube beam splitters with the ratio 1:1.

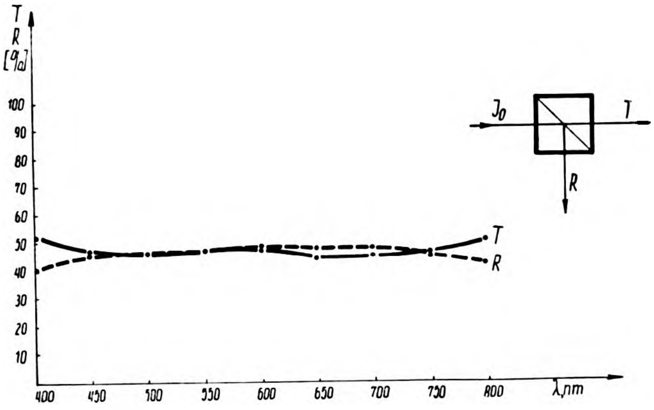

Fig. 5. $R = f(\lambda)$, $T = f(\lambda)$ for a beam splitter with a five-film dielectric coating. $R:T = 1:1$. Beam splitter without antireflecting coatings. Light unpolarized

The optical properties of five-film beam splitters were presented by Anders [7]. Optical thickness of particular films should fulfil the following conditions:

$$n_1 d_1 \cos\varphi_1 = \frac{\lambda_0}{4}, n_2 d_2 \cos\varphi_2 = \frac{\lambda_0}{4}, n_3 d_3 \cos\varphi_3 = \frac{\lambda_0}{4},$$

$$n_4 d_4 \cos\varphi_4 = \frac{\lambda_0}{4}, n_5 d_5 \cos\varphi_5 = \frac{\lambda_0}{2}.$$

Sokolova [9] proposes a ten-film prism beam splitter, i.e. two rectangular prisms with five-film dielectric coating obtained by a chemical method, glued up a cube beam splitter. We dealt with a five-film beam splitter of the Anders type. The following substances were chosen: zinc sulphide (films 1 and 3), cryolit (films 2 and 4), cerium oxide (film 5). Optical thickness of the respective films was: $n_1 d_1 = n_3 d_3 = 1.13\frac{\lambda_0}{4}$, $n_2 d_2 = n_4 d_4 = 1.72\frac{\lambda_0}{4}$, $n_5 d_5 = 1.18\frac{\lambda_0}{2}$. During the evaporation thickness of the film was controlled by an interference filter for $\lambda_0 = 553$ nm. In Figs 5 and 6 the optical properties of a five-film cube beam splitter are presented. As can be seen in the Fig. 5 such a beam splitter is achromatic in the range 450-750 nm. Optical properties of a beam splitter of this type in the linearly polarized light are presented in Fig. 6. The beam splitter investigated by us shows similar optical properties to those reported by Anders. The weak points of this beam splitter are the low values of the coefficients R_p and T_s. The beam splitter with mixed dielectric and metallic films may be regarded as a substitutional solution. Pohlack [6] has proposed a ZnS film of optical thickness $\left(\frac{\lambda_0}{4}\right)$ and a thin chro-

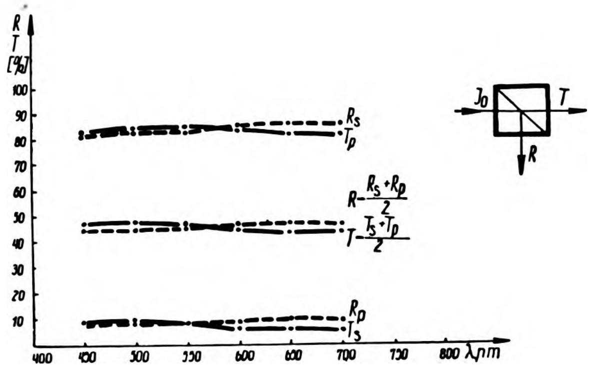

Fig. 6. Reflection (R_p, R_s) and transmittance (T_p, T_s) coefficients versus wavelength λ for a beam splitter with five-film dielectric coating. $R:T = 1:1$. Beam splitter without antireflecting coatings

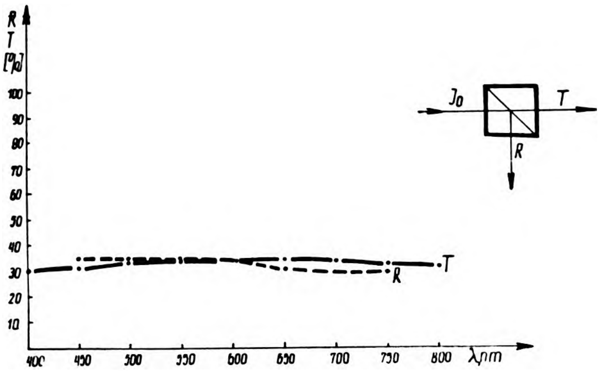

Fig. 7. $R = f(\lambda)$, $T = f(\lambda)$ for a beam splitter with films $Na_3AlF_6\left(\frac{\lambda_0}{2}\right)$, $ZnS\left(\frac{\lambda_0}{4}\right)$ and inconel. $R:T = 1:1$. Light unpolarized

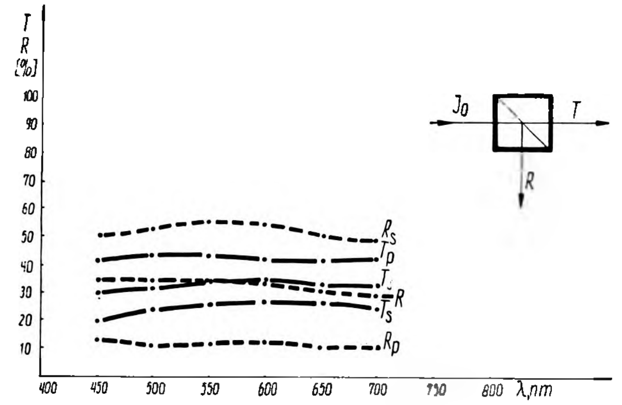

Fig. 8. Reflection (R_p, R_s) and transmittance (T_p, T_s) coefficients versus wavelength λ for a beam splitter with dielectric-metallic films $Na_3AlF_6\left(\frac{\lambda_0}{2}\right)$, $ZnS\left(\frac{\lambda_0}{4}\right)$ and inconel. Light linearly polarized. Beam splitter without antireflecting coatings

mium film. We employed a double dielectric film of the type $L\left(\frac{\lambda_0}{2}\right)$, $H\left(\frac{\lambda_0}{4}\right)$ and a thin inconel film. Optical properties of the beam splitter of this type are presented in Figs 7 and 8 in unpolarized and polarized light, respectively. As seen from Figs 7 and 8 this beam splitter is achromatic for the visible light, and has a lower absorption than a beam splitter with the inconel film, only.

IV. Conclusions

On the basis of the above presented investigations with cube beam splitters with dielectric and dielectric-metallic films, the following conclusions can be drawn:

a) by means of double dielectric films of the type $L\left(\frac{\lambda_0}{2}\right)H\left(\frac{\lambda_0}{4}\right)$ unabsorbing and achromatic cube beam splitters can be obtained. Using different substances with low and high refraction coefficients, different ratios $R{:}T$ from 1:5 to 1:2 in the visible range can be obtained. Beam splitters of this type are obtained by means of a simple technology,

b) the cube beam splitters with five-film dielectric coating are achromatic, and unabsorbing for $R{:}T = 1{:}1$ in the visible range of the spectrum. The weak point of such beam splitters is their strong polarization of light, which may produce uneven illumination of the field of vision in certain optical nstruments, despite the achromatism of the beam splitter. The beam splitter with dielectric-metallic films may serve as a substitutional solution.

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Cube diviseurs optiques pour de differentes valeurs de coefficients de réflexion de transmission de lumière

On a etudié des propriétés optiques des couches minces, collés en cubes diviseurs optiques, pour la lumière polarisée et nonpolarisée. On a mesuré des coefficients optiques pour l'angle d'incidence sur la couche $\alpha = 45°$. À l'aide du revêtement à deux couches diélectriques du type $L\left(\frac{\lambda_0}{2}\right)$, $H\left(\frac{\lambda_0}{4}\right)$ où L, H sont des substances à bas et haut indice de refraction, et λ_0 est longueur d'onde de contrôle de l'epaisseur de la couche sous vide, on a reçu des cubes diviseurs optiques acromatiques, nonabsorbants pour differentes valeurs R:T comprises entre 1:5 à 1:2. If faut un revêtement de cinq couches diélectriques aux épaisseurs optiques des couches particulières: $H\left(1,13\frac{\lambda_0}{4}\right)$, $L\left(1,72\frac{\lambda_0}{4}\right)$, $H\left((1,13\frac{\lambda_0}{4}\right)$, $L\left(1,72\frac{\lambda_0}{4}\right)$ $H\left(1,18\frac{\lambda_0}{2}\right)$ pour obtenir des cubes diviseurs optiques nonabsorbants pour des valeurs $R{:}T = 1{:}1$. On a présenté ainsi les propriétés optiques d'un simple cube diviseur pour $R{:}T = 1{:}1$ avec un revêtement mixte une double couche diélectrique $L\left(\frac{\lambda_0}{2}\right)$, $H\left(\frac{\lambda_0}{4}\right)$ et une couche mince d'inconel.

Светоделящие кубики для различных значений коэффициентов отражения и пропускания света

Для естественного, а также линейно — поляризованного света исследованы оптические свойства светоделящих плёнок, заклеенных в светоделящие кубики. Измерены оптические коэффициенты в видимой области спектра для угла падения на плёнку $\alpha = 45°$ С помощью двойного диэлектрического покрытия типа $L\left(\frac{\lambda_0}{2}\right)$, $H\left(\frac{\lambda_0}{4}\right)$ (L, H обозначают вещества с ниским и высоким коэффициентом преломления, λ_0 является той длиной волны, при которой во время возгонки производился контроль толщины) получены безабсорпционные, ахроматические светоделящие кубики для соотношений $R:T = 1:5$, $1:3$, $1:2$. Безабсорционные светоделители для соотношений $R:T = 1:1$ требуют 5-слойного диэлектрического покрытия о оптической толщине отдельных плёнок $H\left(1,13\frac{\lambda_0}{4}\right)$, $L\left(1,72\frac{\lambda_0}{4}\right)$, $H\left(1,13\frac{\lambda_0}{4}\right)$, $L\left(1,72\frac{\lambda_0}{4}\right)$, $H\left(1,18\frac{\lambda_0}{2}\right)$. Приводятся также оптические свойства простого светоделителя для соотношений $R{:}T = 1{:}1$ со смешанным покрытием — двойная диэлектричекая плёнка типа $L\left(\frac{\lambda_0}{2}\right)$, $H\left(\frac{\lambda_0}{4}\right)$ и тонкая плёнка инконеля.

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