THE REFLECTION OF TRANSVERSELY POLARIZED WAVE AT ITS INCIDENCE ANGULARLY ON TWO-LAYER SYSTEM: ANTIREFLECTING COATING – ABSORPTIVE SUBSTRATE

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The results of theoretical investigations of reflection characteristics of transversely polarized wave at its incidence angularly on absorptive dielectric substrate with coated layer of antireflecting non- absorptive coating, regulated on thickness, are given. The possibility of experimental observation of non-reflective wave absorption in considered two-layer system is well founded.

The conditions of effect initiation of total non-reflective absorption of transversely polarized electromagnetic wave at its incidence angularly on plane absorbing substrate of infinite thickness with the layer of non-absorptive dielectric, coated on it were investigated in the paper [1,2]. It has been established, that these conditions are fulfilled in the dispersion region of substrate at well-defined selective values of coating layer thickness, frequency and wave angle of incidence. The carrying out of investigations of wave reflection characteristics of considered two-layer system in wide change interval of regulated parameters that is technically difficultly realized for their experimental definition. Let's carry out the simplest method of experimental relieving of total wave absorbance in substrate at fixed incident radiation frequency, when wave reflection characteristics of the system are investigated only in the dependence on wave angle of incidence on it at the given thickness of coating layer.

Let's consider the relieving possibility of this effect at the passing of plane transversely polarized wave through layer of non-absorbing substance into absorbing substrate of infinite thickness. According to data of paper [1], the conditions of non-reflecting wave passing through similar two-layer system can arise in minimum point of dependence of wave reflection coefficient module ρ on thickness l of antireflecting coating layer and if condition ρ=0 in this point is fulfilled. These conditions are described by the following bond equations between the selective values of refraction coefficient of substrate n and factor dielectric loss γ of one, wave length of incident radiation λ_0, layer thickness l_0 and refraction coefficient n_1 of antireflecting coating.

$$\bar{y} = \frac{1}{\bar{n}}\sqrt{(\bar{n}-1)(\bar{n}_1^2-\bar{n})} \quad (1)$$

$$\frac{l_0}{\lambda} = \frac{1}{\bar{n}_1\sqrt{1-p}}\left[\frac{(2N_0-1)}{4} + \frac{1}{4\pi}arctg\frac{2\bar{n}\bar{n}_1\bar{y}}{\bar{n}_1^2-\bar{n}^2(1+\bar{y}^2)}\right]. \quad (2)$$

Here: $\bar{n} = \bar{\lambda}/\bar{\lambda}_d$; $\bar{n}_1 = \bar{\lambda}/\bar{\lambda}_{1d}$; $\bar{y} = tg\bar{\delta}/2$; $\bar{\delta} = arctg\bar{\varepsilon}''/\bar{\varepsilon}'$; $\bar{\lambda} = \lambda/\sqrt{1-p}$; $\bar{\lambda}_d$; $\bar{\lambda}_{d1}$ is wave length in the substance substrate and coating correspondingly at the wave propagation angularly to plane surfaces, limiting them; $p=sin^2\alpha_0$; α_0 is wave angle of incidence; N_0 is number of zero minimum of ρ dependence on l; $\bar{\varepsilon}' = (\varepsilon' - p)/(1-p)$; $\bar{\varepsilon}'' = \varepsilon''/(1-p)$; $\bar{\varepsilon}_l = \varepsilon_l/(1-p)$, where ε', ε'' and ε_l are connected with refraction coefficients n and factor of dielectric loss γ of substrate and refraction coefficient n_1 of coating by known relations correspondingly

$$\varepsilon' = n^2(1-y^2) \; ; \; \varepsilon'' = 2n^2y \; ; \; \varepsilon_1 = n_1^2 \quad . \quad (3)$$

We use the equation (1-3) for the finding of dependencies between selective values of dielectric constant ε' and dielectric loss ε'' of substrate substance, layer thickness l_0 and wave refraction coefficient n_1 of substance of antireflecting coating, wave length λ_0 and angle of incidence of electromagnetic radiation α_0, at which the conditions of non-reflecting radiation passing in the considered system coating-substrate are fulfilled The dependencies of ε'' on ε' and l_0/λ_0 on ε' at N_0=1 and n_1=1.5, calculated on these equations are given on the fig.1 as illustration. At α_0=0 the dependence of ε'' on ε' looks like the semicircle, which crosses the absciss axis at the values ε', which are equal to 1 and ε_l^2 correspondingly. The radius of similar circle increases with α_0 increase and becomes the infinite one on the value at α_0=90°.

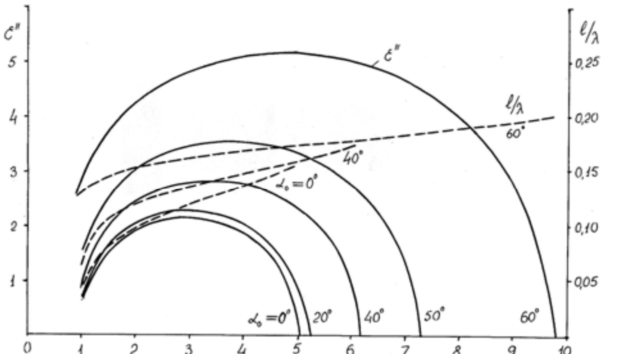

Fig.1. The dependencies between selective values of layer thickness of antireflecting coating l, dielectric constant ε' and dielectric loss ε'' of the substance of absorptive substrate at antireflecting absorption of transversely polarized incident wave at the angle α_0. The wave refraction coefficient of coating substance n_1=1.5; λ is wave length of incident radiation.

The selective values of wave angles of incident and layer thicknesses of antireflecting coating, corresponding to them, at which the wave reflection is totally absent for substances of substrate and coating with the known values ε', ε'' and n_1 for the given frequency of the incident radiation can be found graphically or on the equations (1)-(3). From the figure it is followed, that if at the given n_1 the operating point with such values ε' and ε'' is situated in [ε', ε''] coordinate plane inside the limiting dependence ε'' on ε' for α_0 =0, then the antireflecting radiation absorption is impossible with such substrate in two-layer system. If the operating point with such values ε', ε'' is situated higher, than limiting dependence ε' (ε'') for α_0=0, then in such substrate substance should observe the antireflecting absorption of incident radiation at well-defined wave angle of incidence and layer thickness of antireflecting coating, corresponding to it.

The selective values of wave angles of incidence α_0 and thicknesses of coating layer l_0, at which the conditions for antireflecting absorption of incident radiation of the given frequency in it, calculated on the base of equations (1)-(3) are given in the table. The different polar liquids, having the wave dispersion in microwave range were used as the substrate material [3].

The investigations of wave reflection characteristics from two-layer system coating-substrate, in which polar liquids were used as substrate substance, and non-absorptive substance with n_1=1.5 were used as coating. The dependencies of wave reflection coefficient module ρ of similar systems on the wave angle of incidence α_0 in interval (0,90°) and at coating thicknesses by close or equal selective values, obtained from equation (2) were defined. The complex expression for reflection coefficient of transversely polarized wave $\dot{\rho}$ of considered two-layer system was used for finding of these dependencies:

$$\dot{\rho} = \frac{Z_d \cos\alpha_0 - Z_0 \cos\alpha_1}{Z_d \cos\alpha_0 + Z_0 \cos\alpha_1}, \qquad (4)$$

where

$$Z_d = Z_1 \frac{Z \cos\alpha_1 + Z_1 \cos\alpha_2 th(\gamma l \cos\alpha_1)}{Z_1 \cos\alpha_2 + Z \cos\alpha_1 th(\gamma l \cos\alpha_1)}$$

$\cos\alpha_0 = \sqrt{1-p}$; $\cos\alpha_1 = \sqrt{1-p/\varepsilon_1}$; $\cos\alpha_2 = \sqrt{1-p/\varepsilon}$; $\gamma = i2\pi\sqrt{\varepsilon_1}/\lambda$ is wave propagation constant in material coating; Z_0, Z_1, Z are wave resistances relatively vacuum, coating and substrate materials correspondingly; α_1, α_2 are wave refraction angles in coating and substrate materials; l is thickness of coating layer; λ is wave length of incident radiation [4].

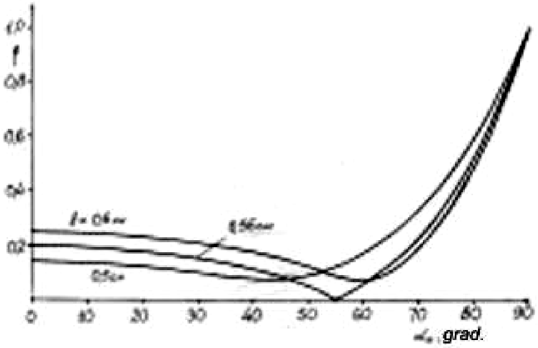

Fig.2. The dependencies of module of wave refraction coefficient ρ on the angle of incidence of transversely polarized wave on the two-layer system coating-substrate at and near selective thickness of coating layer, the material of which has the refraction coefficient n_1=1.5. The substrate is 4-ethylpyridine, wave length of radiation is λ=3.22cm.

The dependencies of module of wave refraction coefficient ρ of considered two-layer system on radiation angle of incidence α_0 on it at the values of thickness of coating layer, which is equal or close to its first selective value, calculated on the equation (4) are given on the fig. 2 for the illustration of the obtained results. The 4-ethylpyridine is chosen as substrate material. The calculation data confirm that antireflecting wave absorption in the given liquid is expected at the of polarized incident wave at the angle 54.6° and at first minimal possible thickness of coating antireflecting layer, which is equal to 0,557 cm. The dependencies of ρ on α_0 of two-layer systems, in which the methyl alcohol and cyclohexanon are correspondingly used as substrate, are presented on the fig. 3. At that the l_{01} thicknesses of first selective antireflecting layers of these coatings, which are smallest on the value, are chosen correspondingly 0,137 and 0.637 cm. The same effect can be obtained at the use of second l_{02} and following selective thicknesses of antireflecting layer, which are bigger, than first ones on the values, which are multiple to of wave half-length $\bar{\lambda}_d$ in coating substance. However, its appearance will take place in narrowest region of α_0 change. The last one is proved by data of fig. 4, on which the dependencies of ρ on α for three first selective coating thicknesses of antireflecting system with methyl alcohol as substrate material.

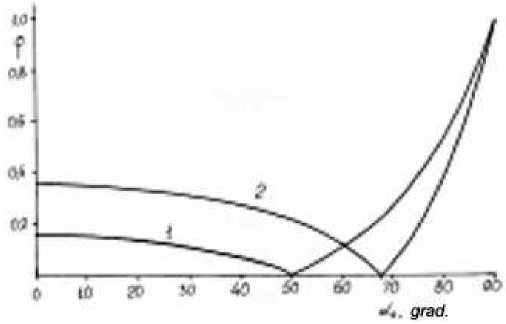

Fig.3. The dependencies of module of wave refraction coefficient ρ on the angle of incidence α_0 of transversely polarized wave on the two-layer system coating-substrate.

1. Substrate is methyl alcohol; refraction coefficient and layer thickness of coating are correspondingly 1.5 and 0.137 cm; wave length is 0,818cm.
2. Substrate is cyclohexanon; refraction coefficient and layer thickness of coating are correspondingly 1.5 and 0.637cm; wave length is 3.2cm.

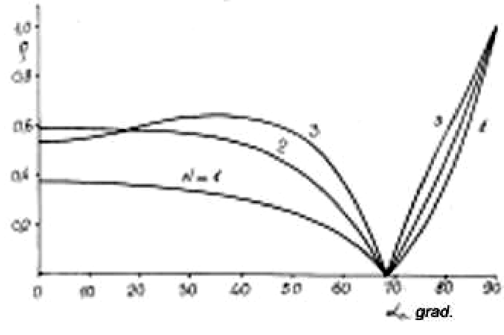

Fig.4. The dependencies of module of wave refraction coefficient ρ on the angle of incidence α_0 of transversely polarized wave on the two-layer system coating-substrate at refraction coefficient n_1=1.5 and selective thicknesses of coating layer 0.137(1), 0454(2) and 0.770 cm(3). The substrate material is methyl alcohol, wave length is 3.2 cm.

The obtained results are unambiguously put out on the possibility of experimental observation of antireflecting absorption of transversely polarized electromagnetic radiation of the given frequency at its incidence angularly on the antireflecting absorptive dielectric substrate. This effect is expected at well-defined selective values of wave angle of incidence and layer thickness of antireflecting coating at known values of dielectric properties of substrate and coating.

Table

The table of selective values of angle of incidence α_0 of transversely polarized wave, thickness of coating layer l_{01}, l_{02}, l_{03} of antireflecting system coating –absorptive substrate at value of coating refraction coefficient n_1=1.5. ε' , ε'' , n, γ are dielectric and optic parameters of liquids, used as substrate at the temperature 20°C; λ and λ_d is wave length in vacuum and in the substance of antireflecting layer correspondingly.

Liquid	λ, cm	ε'	ε''	n	γ	α_0,grad	l_{01},cm	l_{02},cm	l_{03},cm	λ_d, cm
Methyl alcohol	3.20	8.03	8.80	3.16	0.441	68.6	0.608	1.969	3.30	2.721
Methyl alcohol	0.818	5.35	3.20	2.41	0.276	49.7	0.137	0.454	0.770	0.633
Cyclohexanon	3.20	11.67	5.84	3.52	0.236	67.4	0.637	1.990	3.344	2.706
2-ethylpyridine	3.22	5.732	2.65	2.45	0.220	47.7	0.549	1.783	3.016	2.467
4-ethylpyridine	3.22	5.757	3.95	2.52	0.310	54.6	0.557	2.246	4.134	2.377

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UDAN ALTLIQ-ŞƏFFAFLANDIRICI ÖRTÜK: İKİLAYLI SİSTEMƏ BUCAQ ALTINDA DÜŞƏN ŞAQULİ POLYARİZASİYALI DALĞANIN ƏKSİ

Udan dielektrik altlıqa çəkilmiş şəffaflanmış udmayan, qalınlıqlı dəyişkən örtüyə bucaq altında düşən şaquli polarizasiyalı dalğanın əks olunma xarakteristikalarının nəzəri tədqiqatının nəticələri verilmişdir. Baxılan ikilaylı sistemdə dalğanın əks olunmadan udulmasının təcrübi öyrənilməsinin mümkünlüyü əsaslandırılmışdır.

С.Р. Касимова

ОТРАЖЕНИЕ ПОПЕРЕЧНО-ПОЛЯРИЗОВАННОЙ ВОЛНЫ ПРИ ЕЕ ПАДЕНИИ ПОД УГЛОМ НА ДВУХСЛОЙНУЮ СИСТЕМУ: ПРОСВЕТЛЯЮЩЕЕ ПОКРЫТИЕ-ПОГЛОЩАЮЩАЯ ПОДЛОЖКА

Приведены результаты теоретических исследований характеристик отражения поперечно-поляризованной волны при ее падении под углом на поглощающую диэлектрическую подложку с нанесенным на нее регулируемого по толщине слоя просветляющего непоглощающего покрытия. Обоснована возможность экспериментального наблюдения безотражательного поглощения волны в рассматриваемой двухслойной системе.

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