THE REFLECTION OF THE CROSS -POLARIZED ELECTROMAGNETIC WAVE AT ITS INCIDENCE UNDER THE ANGLE ON THE TWO-LAYER DIELECTRIC-METAL SYSTEM

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The conditions of the full reflectionless absorption origin of the cross-polarized electromagnetic wave at its incidence under the angle on the absorbing dielectric layer, applied on the metal substrate, were found. Its dependence on the cover thickness on the angle of the wave incidence, and on the dielectric properties of the cover material is under investigation.

The effect of the full or reflectionless radiation absorption occurs at the normal incidence of the plane-polarized electromagnetic wave on the absorbing cover, applied on the metal substrate [1]. The absorption has a spectral nature and manifests in the region of the cover substance dispersion at strictly fixed selective values of the incident radiation frequency and the cover layer thickness [2].

It is necessary to carry out the research of characteristics of the substance wave reflection in the wide interval of frequencies and thicknesses for the direct proof of this effect existence, what is hard to be realized. One of methods of this effect experimental detection at the fixed frequency of the incident radiation is realized by results of characteristics of the microwave radiation reflection by binary solutions of polar liquids in non-polar solvents, obtained in works [3,4].

It was established, that at the given frequency of the incident radiation the full wave absorption in polar molecule solutions occurs at strictly fixed, belonged to the given solution, layer thickness and concentrations of the polar solution component. Obviously, similar experimental proofs of this effect existence in pure substances at the given radiation frequency may be realized by research of their wave reflection characteristics with the change of the cover substance temperature or the angle of the wave incidence on it.

For the basis of the last proof, let‘s examine theoretical conditions of the full radiation absorption origin at its incidence under the angle α_0 to the surface of the plane layer of the absorbing dielectric, applied on the ideal metal substrate.

The thickness l of the layer cover is regulated, and the cover substance has the complex value of the dielectric constant $\varepsilon=\varepsilon'-i\varepsilon''$, where ε' is the dielectric constant and ε'' is dielectric losses. With regard of the vector position of the electric polarization E of the wave with respect to the plane of its incidence, we will distinguish reflection cases of the parallel-polarized (TH type wave) and cross-polarized (TE type wave) wave, respectively when the vector E is parallel and perpendicular to the plane of the wave incidence. As the initial step let‘s confine by the case of the reflection from such two-layer system of the cross-polarized wave.

For the given type of the incident wave polarization, the complex expression of the wave reflection coefficient ρ from the examined plane two-layer system is equal to:

$$\dot{\rho} = \frac{Z_{\text{âõ}}\cos\alpha_0 - Z_0\cos\alpha}{Z_{\text{âõ}}\cos\alpha_0 + Z_0\cos\alpha} \qquad (1)$$

where $Z_{bx}=Zth\gamma l$ the input resistance of the two-layer system, Z_0, Z are the wave resistances of the vacuum and the cover substance, respectively, $\cos\alpha=\sqrt{1-\sin^2\alpha_0/\varepsilon}$; α is the angle of the wave refraction in the cover layer and is simultaneously the angle of the wave incidence on the dielectric-metal interface, l is the thickness of the cover layer [5-7].

The constant of the wave distribution γ in the cover substance included in the expression for the input resistance, is equal to:

$$\gamma=\gamma_0\frac{\cos\alpha}{\cos\alpha_0} \; ; \qquad (2)$$

where $\gamma_0=i2\pi/\lambda$, λ is the constant of the wave distribution and the wave length in the vacuum, respectively.

The reflectionless wave absorption in the examined two-layer system may occur in the minimum point of the dependence of the modulus of the wave reflection coefficient ρ on the thickness l of the cover layer and at the fulfillment of the condition ρ=0 in this point. Let‘s introduce notations $r=sin2\alpha_0$ and $\lambda_b=\lambda/\sqrt{1-p}$, λ_b is the wave length in the free space in the direction of the wave spreading respectively to the normal to the layer surface. As $Z=Z_0/\sqrt{\varepsilon}$, then with regard of expressions (1) – (2) and accepted symbols, the condition of the full radiation absorption may be represented in the form:

$$th\frac{2\pi l}{\lambda_b}\sqrt{\varepsilon^{\bullet}}=\frac{Z_0\cos\alpha}{Z\cos\alpha_0}=\sqrt{\varepsilon^{\bullet}} \; ; \qquad (3)$$

where

$$\varepsilon^{\bullet}=\varepsilon_1-i\varepsilon_2 \; ; \quad \varepsilon_1=\frac{\varepsilon'-p}{1-p} \; ; \quad \varepsilon_2=\frac{\varepsilon''}{1-p} \; .$$

The dielectric constant ε' and dielectric losses ε'' of the cover substance are connected with the refraction coefficient n and the factor of dielectric losses of this substance by known equations:

$$\varepsilon'=n^2\left(1-y^2\right) \; ; \quad \varepsilon''=2n^2y \; ; \qquad (4)$$

where $n=\lambda/\lambda_g$; $y=tg\delta/2$; $\delta=arctg\,\varepsilon''/\varepsilon'$; λ_g is the wave length in the cover material.

For the convenience of the further examination let‘s assume, that ε_1 and ε_2 by the analogy to the expression (4) are represented in the form:

$$\varepsilon_1 = \hat{n}^2(1-\hat{y}^2)\ ;\ \varepsilon_2 = 2\hat{n}^2\hat{y}\ ; \qquad (5)$$

where $\hat{n} = \lambda_b / \lambda_g^{\bullet}$; $\hat{y} = tg\delta^{\bullet}/2$; $\delta^{\bullet} = arctg\,\varepsilon_2/\varepsilon_1$; $\lambda_g^{\bullet}$ is the wave length in the cover substance at the wave spreading under the given angle to its limiting plane surfaces.

Using this notations in equations (3), after transformations we receive:

$$th(2\pi x\hat{y} + i2\pi x) = \hat{n}(1-i\hat{y})\ ; \qquad (6)$$

where $x = l/\lambda_g^{\bullet}$.

Let‘s divide the equation (6) on imaginary and real parts. After corresponding transformations we receive two equations, which describe the condition of the reflectionless wave absorption in the examined system:

$$\hat{y}sh4\pi x\hat{y} + \sin 4\pi x = 0\ ; \qquad (7)$$

$$\hat{n}\left(1+\hat{y}^2\right) = th2\pi x\hat{y} - \hat{y}tg2\pi x\ . \qquad (8)$$

From their joint solution, we have:

$$th4\pi x\hat{y} = \frac{2\hat{n}}{\hat{n}^2\left(1+\hat{y}^2\right)+1}; \qquad (9)$$

$$tg4\pi x = \frac{2\hat{n}\hat{y}}{\hat{n}^2\left(1+\hat{y}^2\right)-1}. \qquad (10)$$

As conditions of the reflectionless wave absorption in the system are fulfilled in the minimum point of the dependence ρ on l and at cover thicknesses, close to the values multiple to $\lambda_g^{\bullet}/4$, let‘s take, that:

$$x = \frac{2N-1}{4} + \Delta; \qquad (11)$$

where *N* is a number of the zero minimum of the dependence ρ on *l*, Δ is in common case is low, but not the zero value, determined from the joint solution of equations (10) and (11):

$$\Delta = \frac{1}{4\pi} arctg \frac{2\hat{n}\hat{y}}{\hat{n}^2\left(1+\hat{y}^2\right)-1}\ . \qquad (12)$$

By substituting expression (12) in equations (9) and (10) and excluding the value Δ as the intermediate parameter, we receive:

$$\pi(2N-1) + arctg\frac{2\hat{n}\hat{y}}{\hat{n}^2\left(1+\hat{y}^2\right)-1} = \frac{1}{2\hat{y}} ln\frac{(1+\hat{n})^2 + (\hat{n}\hat{y})^2}{(1-\hat{n})^2 + (\hat{n}\hat{y})^2}\ . \qquad (13)$$

The equation (13) determines the connection between values $\hat{n}$ and $\hat{y}$, and consequently, between ε' and ε of the cover substance of the two-layer system, at which the full absorption of the incident radiation occurs in the system. The required thickness of the cover layer is determined, as it follows from equations (11) and (12) from the expression

$$\frac{l_0}{\lambda} = \frac{1}{\hat{n}\sqrt{1-p}}\left[\frac{(2N-1)}{4} + arctg\frac{2\hat{n}\hat{y}}{\hat{n}^2\left(1+\hat{y}^2\right)-1}\right] \quad (14).$$

Obtained equations (12)-(14) were used for the dependence determination between selective values ε', ε'', l_0 of the cover substance, the length of the radiation wave λ and the angle of the wave incidence α_0, at which conditions of the full absorption of the electromagnetic radiation in the examined two-layer system is fulfilled. These dependences at N=1,2 and 3 are given on the fig.1. Dependences ε''on ε' shift to the X axis with the value α_0 growth and at α_0=90 coincide with it. At the given number of the zero minimum N of the function ρ(l) all curves of the family are placed below the limiting dependence for α_0=0, which corresponds to the case of the normal wave incidence. The similar family type of curves $\varepsilon''(\varepsilon')$ exists also at the growth of N, but with closer its position to the X axis (see fig. 1b,c).

Selective values of the cover layer thickness l_0 increase with $\varepsilon'$and α_0 growth and reduce with growth of N, but numerically they are always higher than the multiple value $\lambda_g^{\bullet}/4$. The value of these deflections Δ on the multiplicity reduces with ε' and N growth (see fig.2).

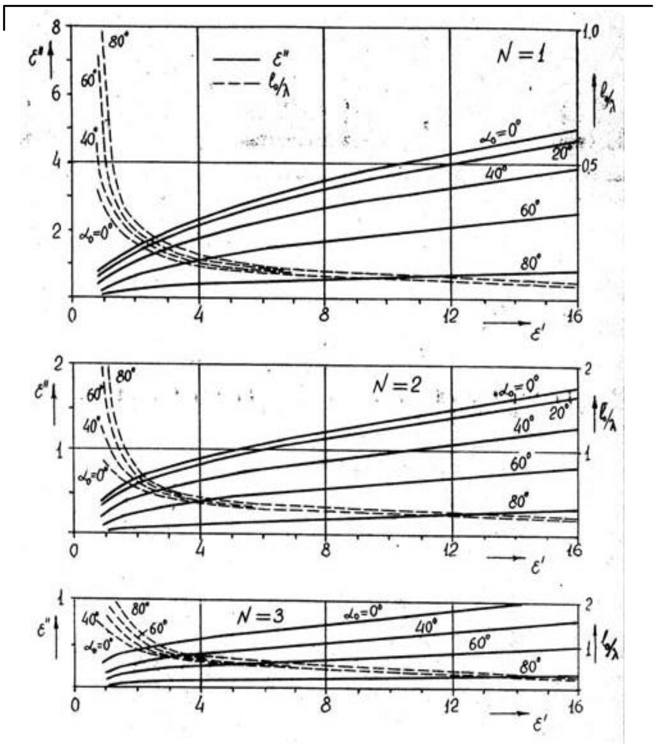

Fig.1. The dependence between the dielectric constant ε' and dielectric losses ε'' at the reflectionless absorption of the cross-polarized wave, incident under the angle α_0 on the two-layer dielectric metal system at *N*=1,2,3. *N* is the number of the zero minimum of the dependence of the modulus of the wave reflection coefficient on the thickness of the cover layer.

Selective values of the wave incidence angles and corresponding to them the cover layer thickness, at which the wave reflection is absent, may be determined by equations (12)-(14) or graphically; if values e'_0 and e''_0 of the cover substance are known for the given frequency of the incident radiation.

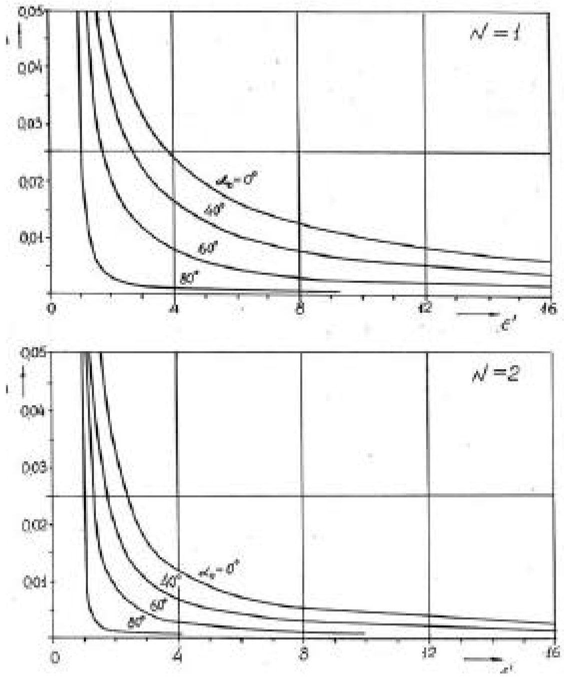

Fig.2. The deflection value *D* of the cover layer thickness on multiple values of wave length quarter in the cover substance versus its dielectric constant and the incidence angle $á_0$ at *N*=1,2; N is the number of the zero minimum of the dependence of the modulus of the wave reflection coefficient on the thickness of the cover layer.

It follows from the fig.1, that if the working point with such values e'_0 and e''_0 is placed in the coordinate plane [e', e''] at N=1, which is higher than the limiting dependence for $á_0$=0, then the manifestation of the reflectionless radiation absorption is impossible in the two-layer system with such cover. If the working point with such values e'_0, e''_0 is placed between two limiting dependences with N=1 and N=k, then in such cover substance k-1 of strictly fixed angles of the wave incidence and corresponding to them the thickness of the cover layer, at which the full absorption of the incident radiation occurs, are observed. The lesser selected thickness of the cover layer will correspond to the greater angle of the reflectionless wave incidence.

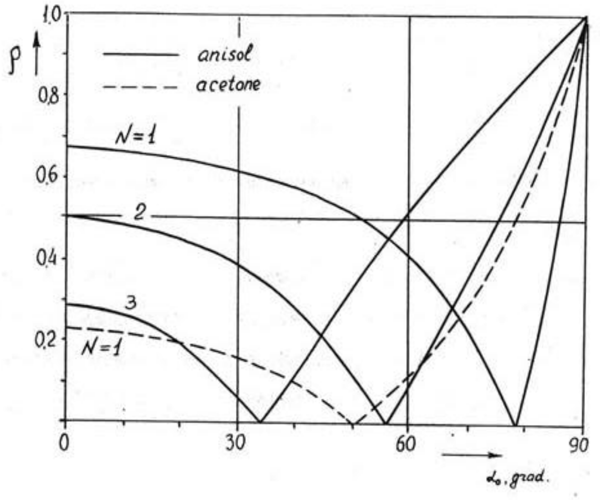

Fig.3. The dependence of the modulus of the cross-polarized wave reflection coefficient ρ on its incidence angle α_0 on the two-layer dielectric-metal system.

Dependences of the modulus of the wave reflection coefficient of the two layer system on the angle of the radiation incidence on the cover layer at the calculated selective values of its thicknesses at the wave length of the incident radiation ë=3.2 cm are presented on fig.3. The polar liquids with known values e' and e'' were used as the cover substance at this wave length and the temperature 20° C [8]. At ë=3.2 cm for acetone e' =20.5, e''=3.55 and its working point in the coordinate plane [e', e''] is placed between limiting curves 1 and 2 for the case $á_0$=0. Therefore, for acetone the reflectionless absorption of the incident radiation is expected only at $á_0$=51.1° (N=1) and at the relative cover thickness *l/ë*=0.056. Unlike the acetone, for anizole e' =3.04, e'' =0.38, and its working point is placed between limiting curves 1 and 4. In accordance with conducted calculations, the reflectionless radiation absorption should exist for the anizole at incidence angles 78.0°(N=1), 55.7°(N=2); 33.8°(N=3), respectively, and at the corresponding relative thickness *l/ë* of the cover layer: 0.174, 0.49 and 0.76.

Obtained results allow to express the supposition on possibilities of the experimental observation of the reflectionless absorption of the electromagnetic radiation, incident under the angle on the absorbing cover, applied on the metal substrate.

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