PHOTOACOUSTIC SPECTROSCOPY OF THE GYROTROPIC SAMPLE BY INCIDENT LIGHT AT ANGLE

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Photoacoustic (PA) transformation in isotropic gyrotropic media when incident light is normal to the surface of the sample was described in the paper [1-3], where the methods of determination optical parameters using the result of measurement amplitude and phase characteristic was proposed. The objective of the paper is the research of PA effect when the incident light falls at angle of the surface of absorbing gyrotropic sample.

Let modulated by intensity elliptical polarized radiation falls at angle θ on the surface of parallel-sided plate thick l. Owing to a dissipation of energy the sample is subjected to periodical heating, thus it is placed in gas-microphone cell in such a manner that the radiation falls on its upper bound, and the registration of the variation of temperature is carried out on opposite bound. Therefore optically opaque plate should be thermally thin, that the temperature waves reached boundary a sample - detection gas.

The optical properties of the medium may be described by the material equation [4]:

$$\begin{cases} \mathbf{D} = \varepsilon \mathbf{E} + i\gamma \mathbf{H}, \\ \mathbf{B} = \mu \mathbf{H} - i\tilde{\gamma}\mathbf{E}, \end{cases}$$

where we suppose $\mu = l, \varepsilon = \varepsilon' + i\varepsilon'', \gamma = \gamma' + i\gamma''$, ε'' - characterizes usual absorption, and γ'' - characterizes circular dichraism.

Electric field strength of an incident wave can be represented as:

$$\mathbf{E} = [A_n \mathbf{e}_n + iA_p \mathbf{e}_p] e^{i(\mathbf{k}\,\mathbf{r} - \omega t)},$$

The subscript p denotes the component parallel to the plane of incident, and the subscript n denotes the component normal to the plane of incident. Here $\mathbf{k} = \frac{\omega}{c} n\mathbf{n}$, $\mathbf{n}$ - unit vector of the wave normal, n-index of refraction of the around media. Electromagnetic field inside a plate is presented as a superposition of two refracted eigen waves with the right and left circular polarization

$\mathbf{E}_+, \mathbf{E}_+$ and two waves of the same polarization reflected from a lower bound $\mathbf{E}'_+, \mathbf{E}'_-$:

$$\mathbf{E}_{\pm} = T_{\pm}[\mathbf{e}_n + i\mathbf{e}_p]e^{i(\mathbf{k}_{\pm}\cdot\mathbf{r}-\omega t)},$$
$$\mathbf{E}'_{\pm} = T'_{\pm}[\mathbf{e}'_n + i\mathbf{e}'_p]e^{i(\mathbf{k}_{\pm}\cdot\mathbf{r}-\omega t)},$$

where $\mathbf{k}_{\pm} = \frac{\omega}{c}n_{\pm}\mathbf{k}_{\pm}$, $\mathbf{k}'_{\pm} = \frac{\omega}{c}n_{\pm}\mathbf{n}'_{\pm}$, $n_{\pm} = n'_{\pm} + i\cdot n''_{\pm}$, $n'_{\pm} = \sqrt{\varepsilon'} \pm \gamma'$, $n''_{\pm} = \varepsilon''/2\sqrt{\varepsilon'} \pm \gamma''$.

Using a condition of continuity of an electromagnetic field on boundaries when $z = 0$ and $z = l$, it is possible to obtain a system of equations for finding amplitudes of eigen waves T_+, T_-, T'_+, T'_- and then to define dissipation of energy:

$$Q(z) = Q_+(z) + Q_-(z) + Q'_+(z) + Q'_-(z),$$

$$Q_{\pm}(z) = \frac{\omega}{4\pi}\left(\varepsilon'' \pm 2\sqrt{\frac{\varepsilon' + \sqrt{\varepsilon'^2 + \varepsilon''^2}}{2}}\cdot\gamma''\right)|T_{\pm}|^2 e^{-\beta_{\pm} z},$$

$$Q'_{\pm}(z) = \frac{\omega}{4\pi}\left(\varepsilon'' \pm 2\sqrt{\frac{\varepsilon' + \sqrt{\varepsilon'^2 + \varepsilon''^2}}{2}}\cdot\gamma''\right)|T'_{\pm}|^2 e^{\beta_{\pm} z},$$

where $\beta_{\pm} = 2\frac{\omega}{c}\operatorname{Im}(n_{\pm}\cdot\cos(\theta_{\pm}))$, $\cos(\theta_{\pm}) = \sqrt{1-(n\sin(\theta)/n_{\pm})^2}$, $\theta_{\pm}$ - complex angle of refraction of the eigen waves.

In order to find the temperature T on boundary a sample - detection gas ($z = l$) we must solve a system of equations of a thermal conductivity

$$\frac{\partial^2 T(z,t)}{\partial z^2} - \frac{1}{\alpha}\frac{\partial T(z,t)}{\partial t} = \begin{cases} \frac{1}{2\kappa}(1 + e^{i\Omega t})Q(z), & 0 \le z \le l \\ 0, & l \le z \le l' \end{cases},$$

subject to conditions of continuity of temperature and thermal flax on boundary a sample - detection gas. Here $\alpha = \kappa/(\rho C)$ is temperature conductivity of a plate, C- specific thermal capacity, k - coefficient of a thermal conduction, ρ - density, Ω - frequency of modulation. Then we have

$$T = -\kappa\frac{B_1 sh(\sigma l) + \sigma B_2 ch(\sigma l) - \sigma(E'_+ + E'_- + E_+ + E_-)}{\kappa_g\sigma_g sh(\sigma l) + \kappa\sigma ch(\sigma l)},$$

where $B_1 = E_+\beta_+e^{-\beta_+ l} + E_-\beta_-e^{-\beta_- l} - E'_+\beta_+e^{\beta_+ l} - E'_-\beta_-e^{\beta_- l}$, $E'_{\pm} = Q'_{\pm}e^{-\beta_{\pm} z}/2\kappa(\beta_{\pm}^{\,2} - \sigma^2)$
$B_2 = E_+e^{-\beta_+ l} + E_-e^{-\beta_- l} + E'_+e^{\beta_+ l} + E'_-e^{\beta_- l}$, $E_{\pm} = Q_{\pm}e^{\beta_{\pm} z}/2\kappa(\beta_{\pm}^{\,2} - \sigma^2)$, $\sigma = (1 + i)\alpha$,
parameters with subscript g belong to gas.

From now on we shall confine ourselves to the analysis variation of temperature T, which agrees Rosencwaig [5], is proportional to a variable part of pressure in the cell.

The F value that equal to a difference of amplitudes of FA signal $|q_+| - |q_-|$ with a falling on a sample only right and only left handed circularly polarized light, provides the information about the parameter of circular dichroism of the medium. Therefore greatest interest for us is dependence F on optical properties of the investigated sample and parameters of an incident light. The numerical analysis is carried out for a crystal germanate bismuth with parameters $C =$ 356,15*Дж/кг·К*, ρ =9200*кг/м*^{3}, κ=0.6285*Вт/м·К*, $\varepsilon' = 6{,}53$, $\varepsilon'' = 1 \cdot 10^{-3}$, $\gamma' = 5 \cdot 10^{-5}$ with wavelength λ=5,5·10^{-7}*м*, $\Omega = 100 Hz$. The dependence *F* on an angle of incidence θ (fig.1) when $l \approx 15 \cdot \lambda$ maps interference appearances where the decrease *F* happens to increase angle of incidence at the expense of decreasing radiant intensity into the sample. The dependence *F* on thickness of a sample *l* with $\theta = 20^\circ$ and $\theta = 45^\circ$ (fig.2) illustrates offset of an interference picture with change of an angle of incidence. It is clear from fig.3 that the increasing of absorption coefficient or thickness of the sample tends to reducing the *F* sign. Owing to circular dichroism the absorption of right handed circularly polarized light into the upper layer of the plate exceeds absorption of light with the left handed circular polarization, therefore *F> 0*. Light with the left handed circular polarization, more poorly being absorbed, penetrates into the plate deeper. As a result the dissipation of the left handed circularly polarized light in depth of the plate can exceed dissipation of the right handed circular polarized light, thus of *F < 0*. The magnitude *F* linearly depends on ellipticity *τ*, parameter of circular dichroism γ'' (fig. 4), and decreases with the growth of modulation frequency.

For a case of optically opaque thermal thin sample, if determining *F* experimentally, it is possible to find the parameter of circular dichroism γ'' by formula

$$F = \frac{c^2 \sqrt{\varepsilon'}(n^2 \sin^2(\theta) - \varepsilon')|\mathbf{E}|^2}{4\pi\kappa\omega\varepsilon''^2}\gamma'', \tag{1}$$

where the quadrate of the electric field absolute value of the wave that propagates into the sample $|\mathrm{E}|^2$ is considered approximately identical with a falling on a sample of both right and left handed circular polarized light, and is found with solution of the boundary task for the semi-infinite environment [6]. In this case the value

$$(|q_+| - |q_-|)/(|q_+| + |q_-|) = \frac{2\sqrt{\varepsilon'}}{\varepsilon''}\gamma'' \tag{2}$$

does not depend on an angle of incidence.

Thus, experimental measurement of the value PA signals for various polarization of an incident light in case of optically opaque thermal thin sample, according to obtained expressions (1) and (2) enables to decide the task of definition of the parameter circular dichraism and absorption coefficient ε" of the medium.

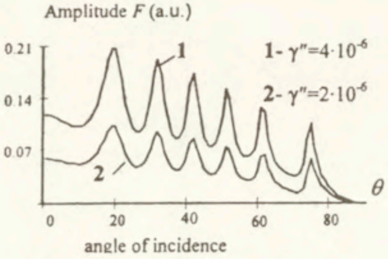

Fig.1 Variation F with angle of incidence

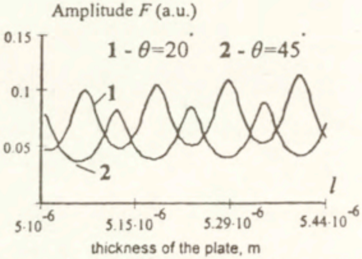

Fig.2 Variation F with thickness of the plate

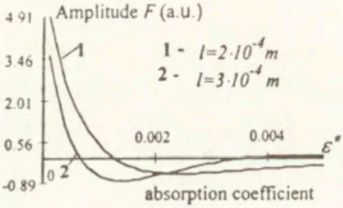

Fig.3 Variation F with absorption coefficient

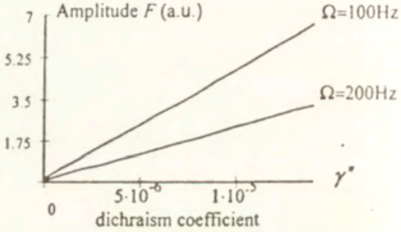

Fig.4 Variation F with dichraism coefficient

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