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Optothermodynamic Method of Diagnosis of Absorption Coefficient in the Liquids

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Abstract

Optothermodynamic method of diagnosis of absorption coefficient of waves in inhomogeneous absorbing liquids has been developed temperature influence on wave's absorption coefficient has been determined. Optothermodynamic method allows establishing relation between optic and thermophysical properties of liquid. Developed method is based on the application of energy conservation on the interaction of laser beams with inhomogeneous absorbing liquids.

In interacting of laser beam with inhomogeneous absorbing liquids optoacoustic waves which are spread in liquids in definite conditions. They contain information occur about physical characteristics of liquid. One of the important optoacoustic characteristics of liquid is the coefficient of radiation absorption. Average integral value of absorption coefficient of optoacoustic waves in the liquid is determined on the bases of Buger's law. At present some experimental research methods of average value of absorption coefficient of acoustic waves in the liquids have been developed. In inhomogeneous absorbing medium radiation absorption coefficient changes with the depth of penetration and varies from point to point. That's why diagnosis of absorption coefficient of inhomogeneous absorbing medium is of great interest. The results of experiments on restoration of distribution of absorption coefficients in model liquid are given [1]. On the basis of experiments it has been determined that restoration is possible in the order depth of optic thickness of the medium. Possibility of formation of acoustic signal of given form has been shown with the help of inhomogeneous-absorbing mediums and formula for optoacoustic diagnosis of absorption coefficient has been offered [2]. On the bases of optoacoustic signal wave front the formula on diagnosis of absorption coefficient with the depth in oil emulsion adding transformation oil into water have been given. Experiments showed that absorption coefficient with penetration depth of the wave into the liquid increases nonlinear [3,4].

Existing methods of diagnosis of absorption coefficients in inhomogeneous absorbing medium are based on the change of optoacoustic pressure with the depth [4].

Unlike abovementioned works in the given paper the optothermodynamic method of absorption coefficient is offered. The aim of the work is diagnosis of absorption coefficients in inhomogeneous absorbing medium based on the information about temperature change in two various points of the medium. According to temperature distribution in liquids of absorption coefficient distribution in inhomogeneous medium is determined on the basis of law of conversation of energy.

In linear absorption of laser beams in the liquid volume density of absorbed energy in the liquid volume density of absorbed energy $Q_1(z)$ is determine on the formula.

$$Q_1(z) = \alpha(z)\dot{I}_0 \exp\left(-\int_0^z \alpha(z)dz\right) \quad (1)$$

Where a $\alpha(z)$ is an absorption coefficient, $\dot{I}_0$ is the intensity of incident laser beam.

It is accepted that absorbed energy of laser beam is used to increase internal energy of the liquid, i.e., to the heating of liquid. Temperature field in liquid is determined from the solution of differential equation from the solution of differential equation of that conductivity. For homogeneous of liquid can be considered constants this equation has the form:

$$C_P\rho\left(\frac{\partial T}{\partial t} + \upsilon\frac{\partial T}{\partial x}\right) = \lambda\frac{\partial^2 T}{\partial x^2} + Q_1(x) \quad (2)$$

where C_p is heat capacity in the constant pressure, ρ is liquid density, υ is average volume speed of convection, λ is heat conductivity coefficient.

Thus, determination of absorption coefficient distribution leads to the solution of the inverse problem for equation (2). To simplify the solution of equation (2) let's consider stationary temperature field and accept that by the transfer energy at the expense of heat transfer it can be disregarded as small in comparison with the heat transfer at the expense of convection. In this case for determination of absorption coefficient from eqn. (2) we have Volterra integral equation of the first class:

$$\int_0^z \alpha(z)dz = -\ln(1-\xi_1)\ ,\ \xi_1 = \frac{C\rho\upsilon\Delta T_1(z)}{\dot{I}_0} \quad (3)$$

Where ΔT_1 is change of the temperature with the depth in the interval from liquid surface to the depth.

Solution of this equation is searched in the form of series. If to accept for certainty:

$$\alpha(z) = \alpha(0)\left(1+\sigma_1 z^n\right) \quad (4)$$

Where n is the level of nonlinearity of absorption coefficient distribution, σ_1 is coefficient characterizing diagnosis level than from eqn. (3) we have:

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$$\alpha(z) = \alpha(0) - \frac{n+1}{l}\left(\frac{z}{l}\right)^n \ln\left(1-\xi_1\right) \qquad (5)$$

Relative change of absorption coefficient in the medium where optoacoustic wave is determined from

$$\frac{\alpha(z)-\alpha(0)}{\alpha(0)} = 1 - \frac{n+1}{\alpha(0)l}\left(\frac{z}{l}\right)^n \ln(1-\xi_1) \qquad (6)$$

Diagram of relative change dependence of absorption coefficient with the depth of penetration in various values ξ_1 has been shown in Figure 1.

Diagram of relative change dependence of absorption coefficient on parameter in various values of penetration depth has been presented in Figure 2. This diagram allows evaluating influence of temperature change on the absorption coefficient.

Diagram of relative change dependence of absorption coefficient on the depth in various levels by diagnosis has been presented in Figure 3.

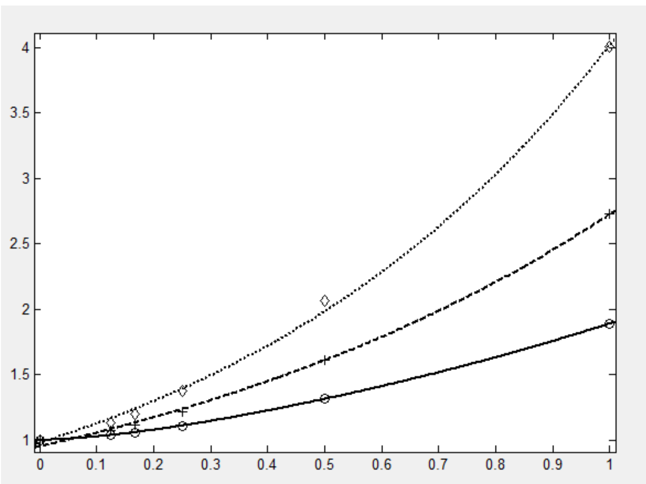
Temperature dependence of absorption coefficient can be determined on the basis of eqn. (3). If, to differentiate this equation on z we have:

$$\alpha(z) - \alpha(0) = \frac{\frac{d\xi_1}{dz}}{1-\xi_1} \qquad (7)$$

If, to consider expression for ξ_1 and consider that besides ΔT_1 the rest of the values are constant, then we have

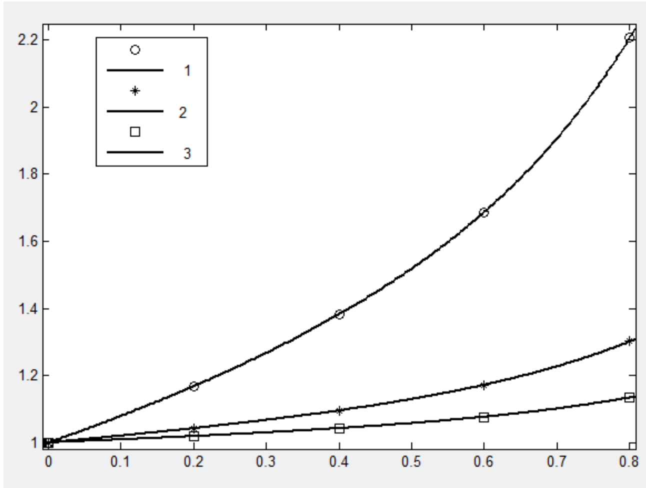
$$\alpha(z) - \alpha(0) = \frac{1}{\frac{\acute{Y}_0}{C\rho\upsilon} - \Delta T_1}\frac{d\Delta T_1}{dz} \qquad (8)$$

As it follows from this formula, absorption coefficient is directly proportional to the temperature gradient. With the increase of temperature gradient, absorption coefficient raises. Simultaneously formula eqn. (8) creates a relation between the absorption coefficient and thermophysical parameters $\left(C_P, \rho, \eta\right)$ of inhomogeneous-absorbing liquid.



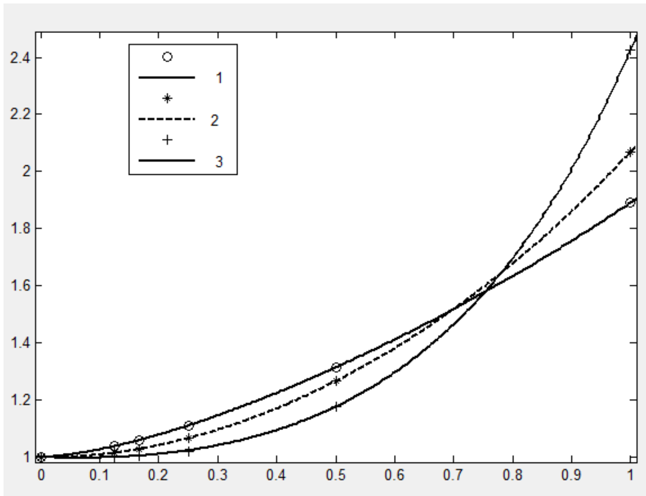
$$\frac{\alpha(z)-\alpha(0)}{\alpha(0)}$$

Figure 1: Diagram of relative change dependence of absorbtion coefficient with penetration depth in various values ξ_1 (1- $\xi = 0.3$, 2- $\xi = 0.5$, 3- $\xi = 0.7$).



$$\frac{\alpha(z)-\alpha(0)}{\alpha_0}$$

Figure 2: Diagram of relative change dependence of absorbtion coefficient on parameter ξ_1 in various values of penetration depth (1- $x = \frac{1}{2}$, 2- $x = \frac{1}{6}$, 3- $x = \frac{1}{6}$).



$$\frac{\alpha(z)-\alpha(0)}{\alpha(0)}$$

Figure 3: Diagram of relative change dependence of absorbtion coefficient on the depth in various levels by diagnosis (1- $n = 1.5$, 2- $n = 2$, 3- $n = 3$).

In non-linear, two-photon absorption of laser beams in the liquid, decrease of the beam intensity with the thickness is determined by formula:

$$-d\dot{I} = \gamma(z)\dot{I}^2 dz \qquad (9)$$

$\gamma(z)$ is coefficient of two-photo absorption of beam in non-linear absorbing liquid. Density of the absorbed energy of laser beams is determined by the formula

$$Q_2(z) = \gamma(z)\dot{I}_0^2\left[1 + \dot{I}_0\int_0^z \gamma(z)dz\right]^{-2} \qquad (10)$$

It is accepted that this absorbed energy completely increases internal energy of the liquid. Similarly to the abovementioned applying the law of conservation of energy

$$C_p \rho \upsilon \frac{dT_2}{dz} = \gamma(z) \dot{I}_0^2 \left[1 + \dot{I}_0 \int_0^z \gamma(z) dz \right]^{-2} \quad (11)$$

For determining of non-linear absorption distribution $\gamma(z)$ from eqn. (2) we have Volterra integral equation of the first class:

$$\int_0^z \gamma(z) dz = \frac{\xi_2}{\dot{I}_0 (1-\xi_2)}, \quad \gamma(z) = \gamma(0)\left(1+\sigma_2 z^m\right) \quad (12)$$

Solution of eqn. (12) we find in the from

$$\gamma(z) = \gamma(0)\left(1+\sigma_2 z^m\right) \quad (13)$$

And have

$$\gamma(z) = \gamma(0) + \frac{m+1}{J_0 l} \left(\frac{z}{l}\right)^m \frac{\xi_2}{1-\xi_2} \quad (14)$$

Where l is optic depth of liquid.

In definite conditions, for example in focusing laser beams multiphoton absorption can take place. In this case decrease of radiation intensity on dz thickens has the form:

$$-d\dot{I} = \delta(z) \dot{I}_0^n dz \quad (15)$$

Where $\delta(z)$ is coefficient n of photon absorption.

Absorbed energy is determined from formula:

$$Q_3(z) = \delta(z) \dot{I}_0^n \left[1 + (n-1) \dot{I}^{n-1} \int_0^z \delta(z) dz \right]^{-\frac{n}{n-1}} \quad (16)$$

As above, applying the law of conversation of energy for determination of absorption coefficient distribution has the equation:

$$\int_0^z \delta(z) dz = \frac{1}{(n-1)\dot{I}_0^{n-1}} \left[\frac{1}{(1+\xi_n)^{n-1}} - 1 \right], \quad \xi_n = \frac{C_P \rho \upsilon \Delta T_n}{\dot{I}_0} \quad (17)$$

If solution of integral eqn. (17) to find in the form

$$\delta(z) = \delta(0)\left(1+\sigma_3 z^m\right) \quad (18)$$

Then for distribution of non-linear absorption coefficient we have the formula:

$$\delta(z) = \delta(0) + \frac{m+1}{l(n-1)J_0^{n-1}} \left(\frac{z}{l}\right)^m \left[\frac{1}{(1+\xi_n)^{n-1}} - 1 \right] \quad (19)$$

From above given formula on determination of absorption coefficient distribution in inhomogeneous-absorbing medium it follows that with the depth of penetration absorption coefficient increases. It is qualitatively conformed to the experiments results carried out by Musayev [4]. On the bases of carried out researches the following conclusions can be made:

1. Optothermodynamic method of diagnosis of absorption coefficient is based on the measure of medium temperature where acoustic signal occurs and spreads.

2. Optothermodynamic method allows evaluating influence of the temperature change on absorption coefficient.

3. Optothermodynamic method of diagnosis of absorption coefficient allows to create-relation between optic and thermophysical properties of the medium.

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