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THERMODIFFUSION BLEACHING MECHANISM OF TWO-COMPONENT MEDIUM BY LASER RADIATION

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Thermodiffusion bleaching mechanism of liquid-phase medium with absorbing particles under the influence of laser radiation has been analyzed. Bleaching of carbon particle aqueous suspension under the influence of He-Ne laser radiation is studied experimentally. The efficiency of recording amplitude dynamic holograms in two-component mediums with thermodiffusion mechanism of absorption coefficient modulation is researched.

Introduction

Thermodiffusion mechanism of optical nonlinearity in multicomponent liquid-phase media is specified by redistribution of component concentration in inhomogeneous light field and proper change of medium refractive index. In some cases (for example in microemulsions near critical point) the given mechanism supports rather high cube nonlinearity factor of the medium than general thermal nonlinearity based on the phenomenon of medium heat expansion [1, 2]. Except experimental works in studying thermodiffusion radiation self-interaction the applications of the given nonlinearity for recording phase dynamic holograms are known [3, 4]. In the case of differentiating absorption coefficients of the component the change of their concentration also results in change of medium absorption coefficient (bleaching or darkening) that may be used for recording amplitude (transmission) dynamic holograms.

The aim of the given work is theoretical and experimental investigation of thermodiffusion mechanism of two-component medium bleaching in the field of laser radiation as well as the analysis of efficiency of recording amplitude dynamic holograms on basis of the given mechanism.

1. Model of thermodiffusion medium bleaching

Let us consider two-component liquid-phase medium the absorption coefficient of which α is completely determined by one component with concentration C ($\alpha=\beta C$, where $\beta=\partial\alpha/\partial C$ – medium constant). For Gaussian beam the distribution of incident radiation intensity in the plane of layer $I=I_0\exp(-r^2/\omega^2)$, where ω is the beam radius, r is the distance from beam axis, Fig. 1.

The system of balanced equations for concentration C and thermal flow is written down in the following way:

$$c_p,\rho\partial T/\partial t=-\operatorname{div}J_1+\alpha I_0\exp(-r^2/\omega^2), \qquad (1)$$

$$\partial C/\partial t=-\operatorname{div}J_2, \qquad (2)$$

where c_p, ρ are specific heat capacity and medium density, T is the medium temperature, J_1 and J_2 are thermal and concentration flows respectively:

$$J_1=-D_{11}\operatorname{grad}T, \qquad (3)$$

$$J_2=-D_{21}\operatorname{grad}T-D_{22}\operatorname{grad}C, \qquad (4)$$

where D_{11}, D_{22} and D_{21} are the coefficients of medium thermal conductivity, absorbing particles diffusion and thermodiffusion.

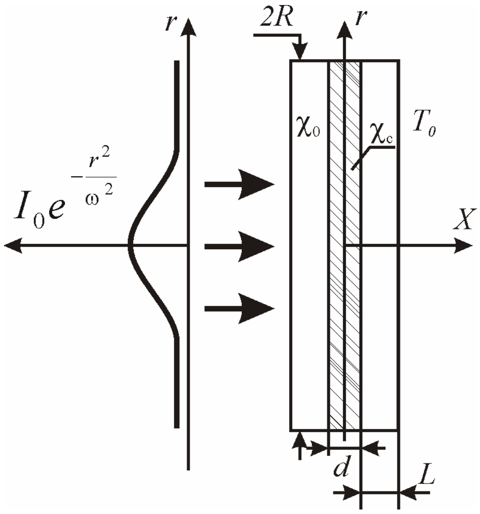

Fig. 1. *For calculation of thermodiffusion bleaching of two-component medium in thin-layer cylindrical cell*

In steady-state condition, considering that for small thickness of the layer of medium d and cell window L ($d,L<<\omega$) the radial (along r) thermal flow may be neglected, we obtain one-dimensional thermal problem from (1, 3):

$$0=D_{11}\partial^2T/\partial x^2+\alpha I_0\exp(-r^2/\omega^2). \qquad (5)$$

Boundary conditions confirm to convective heat transfer on the boundary of cell window-air:

$$J_2(\pm L)=\gamma(T_г-T_0), \qquad (6)$$

where γ, T_0 are respectively the coefficient of convective heat transfer and environment temperature, $T_г=T(L+d/2)$. For the environment temperature in cell centre we obtain:

$$T(r)=T_0+$$
$$+\alpha dI_0(L\chi_0^{-1}+\gamma^{-1}+d\chi_c^{-1}/2)\exp(-r^2/\omega^2), \qquad (7)$$

from (5, 6), where χ_0, χ_c are the coefficients of heat conductivity of cell windows material and two-component medium respectively. For the thickness of layer $d<<L$ the temperature change in medium layer on cell thickness may be neglected and take it equal $T(0)$. In steady-state conditions $((\partial T/\partial t)=(\partial C/\partial t)=0)$ from (2, 4) we have for the stationary value of concentration C_s:

$$-D_{21}\,\mathrm{grad}\,T - D_{22}\,\mathrm{grad}\,C_s = 0. \qquad (8)$$

Integrating (8) subject to preserving a number of particles we obtain for:

$$C_s = C_0\{1+\omega^2 R^{-2}\ln[1+FI_0\exp(-R^2/\omega^2)]\}^{-1}\times$$
$$\times(1+FI_0\exp(-r^2/\omega^2))^{-1}, \qquad (9)$$

where $F=\beta d(L\chi_0^{-1}+\gamma^{-1}+d\chi_c^{-1}/2)D_{21}D_{22}^{-1}$, C_0 is the initial particle concentration, R is the radius of cylindrical cell.

The obtained expressions allow defining medium kinetic coefficients from the experimental data on the parameters of bleaching (or absorption depending on a sign of coefficient D_{21}) induced by radiation.

2. Experimental investigation of two-component medium bleaching

In the experiment the carbon particle suspension (with the diameter 0,1...0,3 mkm) in water was used as the two-component medium and He-Ne laser with the power of 60 mWt was used as the source of radiation. The experiments were carried out with two types of cells: thick-walled with wall thickness 2,25 mm and thin-walled with wall thickness 0,125 mm. In both cases the thickness of medium layer was 30 mkm. Space temperature distribution was recorded by thermograph «IRTIS 200» with an error ±1 °C (frame scanning time is 1,5 sec). Cell transmission was recorded by photodiode PHD-24K.

When lighting horizontal cell with suspension by radiation beam with radius 1,8 mm the decrease of dispersed phase concentration and respectively the medium absorption coefficient occurred as a result of thermodiffusion influence in the field of beam. The dependence of integral transmission coefficient for thin- (1) and thick-walled (2) cells on time is shown in Fig. 2. Temperature space distribution in steady-state conditions is given in Fig. 3. It is seen that thick cell is warmed up weaker in the centre of the beam due to its low thermal resistance that results in lower temperature gradient in the plane of medium layer and respectively to the minor change of transmission coefficient.

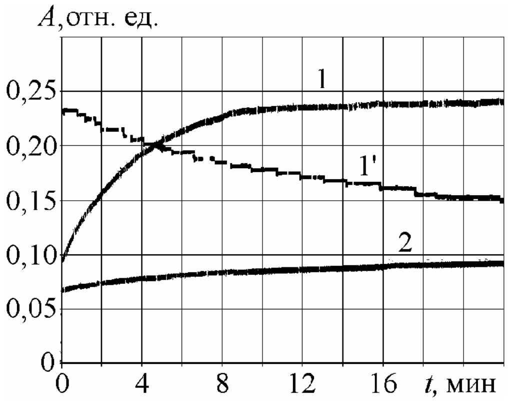

Fig. 2. *Dependence of cell transmission coefficient (beam diameter is 1 mm, power 60 mWt) on time, cell wall thickness: 1) 2,25, 2) 0,125 mm, (1) is the transmission coefficient reduction at beam power increasing in 20 times*

Renewal process of transmission coefficient of thin cell at decreasing laser beam power in 20 times is shown in Fig. 2 (curve 1`). The recovery time confirms to the diffuse one ($\tau\approx\omega^2 D_{22}^{-1}$), bleaching time (for curve 1) is several times less due to the difference of bleaching and recovery mechanisms as well as due to negative feedback occurrence of the absorbed power decreasing bleaching time. The dependence of medium temperature in the centre of laser beam on time is given in Fig. 4. It is seen that medium bleaching in beam centre results in decreasing its temperature.

Formula (9) allows defining thermodiffusion constant:

$$\alpha_T = (\nabla C/C)(\nabla T/T)^{-1}.$$

The estimate $\alpha_T\approx 0,8$ may be obtained from the experimental data (Fig. 2, 3) that corresponds to the characteristic quantities for liquid-phase media [5].

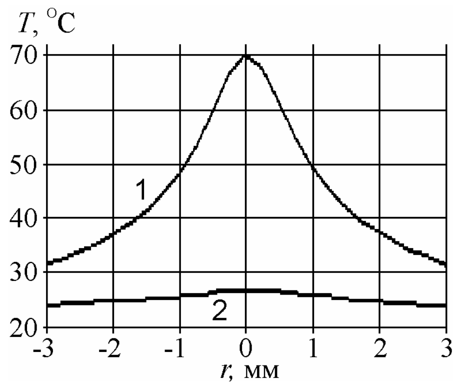

Fig. 3. *Medium temperature profile*

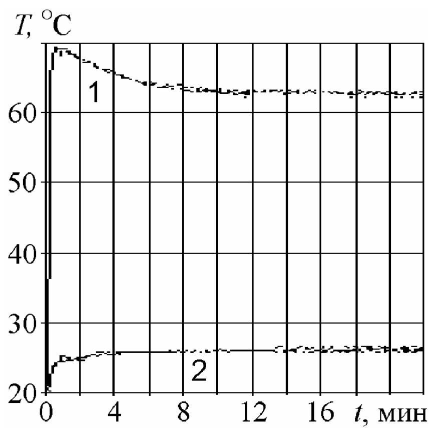

Fig. 4. *Dependence of medium temperature in beam centre on time*

3. Amplitude dynamic holograms in two-component medium

Dynamic hologram is recorded by two plane waves interfering in medium layer. Distribution of incident radiation intensity in layer plane determining the efficiency of dynamic hologram has the form $I=(I_0+I_1\sin Ky)$, where $I_1=2(I_0I_s)^{1/2}$, I_0 and I_s are the intensities of reference and signal waves recording hologram respectively

(I_0>>I_s), $\Lambda=2\pi K^{-1}$ is the period of interference pattern, y is the coordinate being in medium layer plane. Taking into account the fact that characteristic settling time of particle concentration exceeds significantly the time of temperature settling (at the same assumptions as in 1) we may accept that medium temperature is determined by local values of radiation intensity and absorbing particle concentration. Then, considering the problem being one-dimensional the solution of equations (1, 2) is tried in the form:

$$C(x,t) = C_0 + C_1(t)\sin Ky, \qquad (10)$$

$$T(x,t) = T_0(t) + T_1(t)\sin Ky. \qquad (11)$$

Here C_0 and T_0 are the average values of particle concentration and medium temperature, the amplitudes of thermal and concentration lattices are supposed to be minor (C_1/C_0)<<1, (T_1/T_0)<<1.

The solution of equation (1, 2) subject to (10, 11) and initial conditions ($T_1(0)=0$, $C_1(0)=0$):

$$C_1 = FC_0I_1(FI_0+1)^{-1}(1-\exp(-t/\tau_1)), \qquad (12)$$

$$\tau = K^{-2}(FI_0+1)^{-1}. \qquad (13)$$

The peculiarity of the considered nonlinearity mechanism is explicit dependence of hologram recording time τ_1 on reference wave intensity (13). Subject to (12) in steady-state condition the diffraction efficiency η for amplitude hologram at minor amplitude of space modulation of absorption coefficient (α_1<<α_0) equals [6]:

$$\eta = (\alpha FI_1 d/4)^2 (FI_0+1)^{-2}. \qquad (14)$$

It is seen from (14) that depending on a sign of thermodiffusion coefficient the efficiency of dynamic hologram recording may both decrease (at D_{21}<0), and increase (at D_{21}>0) at increasing the reference wave intensity.

Conclusion

As a result of analyzing thermodiffusion bleaching (darkening) of liquid-phase two-component medium with absorbing particles in the field of Gaussian radiation beam the expression for set profile of particle concentration is obtained. It is shown that experimentally observed bleaching of aqueous suspension of carbonic microparticles under the influence of He-Ne laser radiation confirms to the thermodiffusion model, the value of thermodiffusion constant is determined. The efficiency of recording amplitude dynamic holograms in thin-walled cell with two-component liquid-phase medium is studied. The obtained expressions allow calculating the characteristics of holographic recording by known kinetic medium coefficients and may be used at experimental determination of these coefficients values by the methods of dynamic holography.

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