OPTICS AND SPECTROSCOPY

ANISOTROPY OF INHOMOGENEOUS RESONANT MEDIA
DURING TRANSIENT INTERACTION WITH OPTICAL PULSES

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This study predicts the manifestation of anisotropic properties in linearly isotropic inhomogeneous resonant media during the propagation of optical pulses through them with pulse durations comparable to the phase memory of the medium. For examples, the energy of an obliquely incident pulse propagating through a layered inhomogeneous medium, varies with inversion of the propagation direction. This effect results from phase modulation of the pulse due to variation in refraction in a region of transient coherent processes in the medium. This study analyzes the most favorable conditions for observing anisotropic effects.

The transformation of the characteristics of optical radiation in inhomogeneous media depends to a large degree on the experimental geometry. In particular, there are many varied effects results from phase memory in the medium. For example, there are characteristics of superluminescence, light echo, refraction, and reflection which are manifested at the surface of a resonant medium [1, 2].

The primary emphasis of this study is devoted to volume effects associated with the propagation of short optical pulses through an inhomogeneous, isotropic, resonant medium with an optical thickness τ > 1.

The process of propagation will be described by the Maxwell–Bloch system of equations for quasi-planar waves in pulses with small cross-section. Analysis is limited to the case of a plane-layered inhomogeneous medium. In this case, the equations for the i-th layer of the medium takes the form

\[ \cos \theta_i \frac{\partial}{\partial h} + \frac{n_{ni}}{c} \frac{\partial}{\partial t} \int_{-\infty}^{\infty} P(\Delta') \kappa (\Delta - \Delta') d\Delta', \]  
\[ \frac{\partial P}{\partial t} = -\gamma P + i\omega \epsilon, \]  
\[ \psi_i = \psi_{i-1} + \omega t - K_i/h, \]  

where \( \epsilon \) is the complex, slowly varying amplitude, and \( \psi_i \) is the quickly varying phase of the optical wave, \( P \) is the complex polarization which depends on the inhomogeneous line broadening of the resonant transition, \( \theta_i \) is the angle between the direction of propagation of the wave in the i-th layer and the normal to the boundary between layers, \( h \) is the coordinate along this normal, \( n_{ni} \) is the nonresonant part of the refractive index for the layer, \( N_i \) is the concentration of resonant molecule, \( d \) is the dipole moment of the transition, \( \kappa = 2d/h, \kappa = \omega/c, \gamma = 1/T_2 - i(\Delta - \partial K_i/\partial t), K_i = n_{bi}/\kappa \cos \theta_i, T_2 \) is the duration of phase memory in the medium which ignores the mechanism for inhomogeneous line broadening, \( \Delta \) is the amount of detuning from resonance; \( \omega \) is the equilibrium difference in populations for the resonant transition levels.

The system of equation (1) required the addition of initial conditions and the conditions for continuity at the boundary between layers. In particular, one of the following takes the form
Fig. 1. Anisotropy in a two-layer resonantly absorbing medium as a function of the optical thickness of the layers, $\tau_1$ and $\tau_2$. Here, $W_{12}$ and $W_{21}$ are the energies of the pulse propagating forward and backward through the medium, respectively. The calculational conditions are: $\theta_0 = 40^\circ$; $T_2/\tau_p = 0.3$; $q = 4$; $\Delta_1 = 1/T_2$; $\Delta_2 = 1/T_2$ (a) and 0 (b).

\[ [n_{0,i-1} + n_{r,i-1}(t)] \sin \theta_{i-1}(t) = [n_{0i} + n_{ri}(t)] \sin \theta_i(t), \]

where $n_{ri}$ is the resonant part of the refractive index for the medium, and is proportional to the imaginary part of the ratio of induced polarization to the optical field voltage.

Let's examine the refractive characteristics for optical radiation at the boundary between layers. For simplicity, we let the pulse assume a stepped shape and ignore inhomogeneous broadening of the resonant transition. Then, from (1) and (2) and assuming that as a rule $n_{0i} >> n_{ri}$, it follows that

\[ \frac{\sin \theta_i}{\sin \theta_{i-1}} = \frac{n_{0,i-1}}{n_{0i}} \left[ 1 + \left( \frac{n_{r,i-1}}{n_{0,i-1}} - \frac{n_{r,i}}{n_{0i}} \right) f(t, t_0) \right], \]

where $t_0$ is the moment that the pulse enters the boundary between layers, $n_{ri}$ is the magnitude of the resonant part of the refractive index for the layer, which varies under the effect of monochromatic radiation, and the function

\[ f(t, t_0) = 1 - \exp \left[ -(t - t_0) T_2 \right] \left\{ \cos \left[ \Delta (t - t_0) \right] + \frac{\sin \left[ \Delta (t - t_0) \right]}{\Delta T_2} \right\} \]

describes the transient coherent processes in the medium. From (3) it follows that in the region $t - t_0 \leq T_2$ the angle of refraction can vary in time, even with a constant angle of incidence. Note that this variation changes sign with a reveal of propagation direction.

With the propagation of waves in a homogeneous medium layer, the time-varying angle of refraction leads to different angles of divergence and phase modulation in accordance with (1.3). In most layers this divergence can be ignored, but the phase distortions of the pulse can be significant, due to $K_{th} >> 1$. An evaluation of the deviation in pulse frequency $\delta \omega$ resulting from refractive variations can be obtained from (1), (3):

\[ \delta \omega (t) = n_{0i} \frac{\partial f}{\partial t} \frac{\partial \theta_i}{\partial t} \left[ \frac{n_{r,i-1}}{n_{0,i-1}} - \frac{n_{r,i}}{n_{0i}} \right]. \]

Here $\theta_{0i}$ is the angle of refraction, calculated without taking the resonant component of the medium into account. As a result of collisional line broadening $n_{si} = \Delta T_2 N_{i} \sigma(\Delta)/\kappa$, where $\sigma(\Delta)$ is the cross-section for interaction, the frequency shift in the medium layer is proportional to the difference in optical thickness of the neighboring layers under conditions of identical