TRANSMITTANCE OF A NON-LINEARLY ABSORBING TWO-CHAMBER GAS CELL

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We present here some estimates of the attenuation of ruby laser radiation in a non-linearly absorbing two-chamber gas cell. The calculations that we have made refer to the case when one of the chambers contains molecular iodine while the other one the potassium vapor as admixtures. Transmittance of such a cell is shown to depend on the succession in which the chambers are placed along the laser beam due to the differences in mechanisms of non-linear interaction between these gases and laser radiation.

INTRODUCTION

In this paper we present a theoretical study of the transmittance of resonantly absorbing media, in a two-chamber gas cell, for the case of a non-linear interaction between the radiation and media. The gas mixtures in each chamber are supposed to have different composition. In this paper we focus on the geometric factor, i.e., the succession in which the gas mixtures are placed along the propagation path of radiation, and its influence on the total transmittance of such a two-chamber gas cell.

In our earlier paper[1] we have shown that in the case of a two-level medium this factor may manifest itself, for example, in the non-linear effect of resonance absorption saturation, if the medium nonlinearity varies along the propagation path. In contrast to Ref. 1 here we assume the mechanisms of non-linear interaction between radiation and the gas mixtures in two chambers of the absorption cell to be different.

The analysis was performed for a ruby laser. Molecular iodine and alkali metal (in particular, potassium) vapor mixed with buffer gases were considered as resonantly absorbing components. In our study we have analyzed the case of a ruby-laser radiation propagation through the mixtures of buffer gases with the molecular-iodine vapor and atomic-alkali-metal (potassium) vapor (as resonantly absorbing components). The non-linearity of interaction with the molecular iodine is, in the first place, caused by the dissociation of its molecules.[2] In the case with the atomic potassium it is the absorption saturation effect.[3,4]

The initial shape of the pulse was assumed to be as follows:

$$I(\rho, 0, t) = I_0 \exp[-(t/\tau_p)^2] \{\exp[-(\rho/\rho_0)^2\}^k .$$

The radial profile of the beam changed from the Gaussian (at $k = 1$) to a quasi-rectangular (as $k \to 0$) one, here ρ is the radial coordinate and τ_p is the pulse duration.

STATEMENT OF THE PROBLEM

To estimate the transmittance of the gas mixture containing potassium vapor we made use of the known two-level model of an absorbing medium that allows for the absorption saturation effect under steady-state interaction.

Calculations of the iodine vapor transmittance were performed assuming the pulse duration to $\tau_v >> \tau_p >> \tau_r$, where τ_v is the time of vibrational relaxation and τ_r is the time of iodine atoms' recombination into the molecular state. For triple collisions $\tau_r \sim 10^{-4}$ s, according to Ref. 2.

Under the above-stated restrictions, the propagation of radiation is described by the following system of equations:

$$\frac{\partial I(\rho,z,t)}{\partial z} = -\frac{\beta I(\rho,z,t)}{1 + I(\rho,z,t)/I_s}, \tag{1}$$

$$\frac{\partial I(\rho,z,t)}{\partial z} = -\sigma N\, I(\rho,z,t), \tag{2}$$

$$\frac{\partial N}{\partial(t - z/c)} = -\frac{\sigma}{h\nu} N\, I(\rho,z,t), \tag{3}$$

where I_s is the intensity at which the absorption by an alkali metal vapor saturates; σ and N are the

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absorption cross-section and concentration of the molecular iodine; $h\nu$ is the photon energy. Note that Eq. (1) describes propagation of laser radiation in a gas mixture containing potassium, while Eqs. (2) and (3) describe that in the mixture containing iodine vapor.[5] It is the order of solving these equations that determines the succession of the absorption cell chambers placement along the beam path.

The use of equations (1)–(3) is restricted by the case when the change of the radial profile of a beam is caused mainly by the effect of non-linear absorption. This restriction is valid for the exact resonance and small geometric size of the medium.[6]

Let us now introduce the parameter $q = \sigma I_s \tau_p / h\nu$. This quantity is the ratio of thresholds of non-linear interactions of radiation with potassium and molecular iodine. From literature one may find that the absorption saturation intensity for potassium at $\lambda = 0.694$ μm is of the order of 10^5–10^6 W/cm^2, (see Ref. 3 and 4), while the absorption cross-section of molecular iodine being $1.5{\cdot}10^{-19}$ cm^2 (Ref. 5). The value q varies between 0.1 and 0.001 for typical duration of a ruby laser pulse of 10^{-7} to 10^{-8} s. In other words, the non-linearity of radiation interaction with potassium is significantly stronger, for the above-used parameters, than that for the iodine.

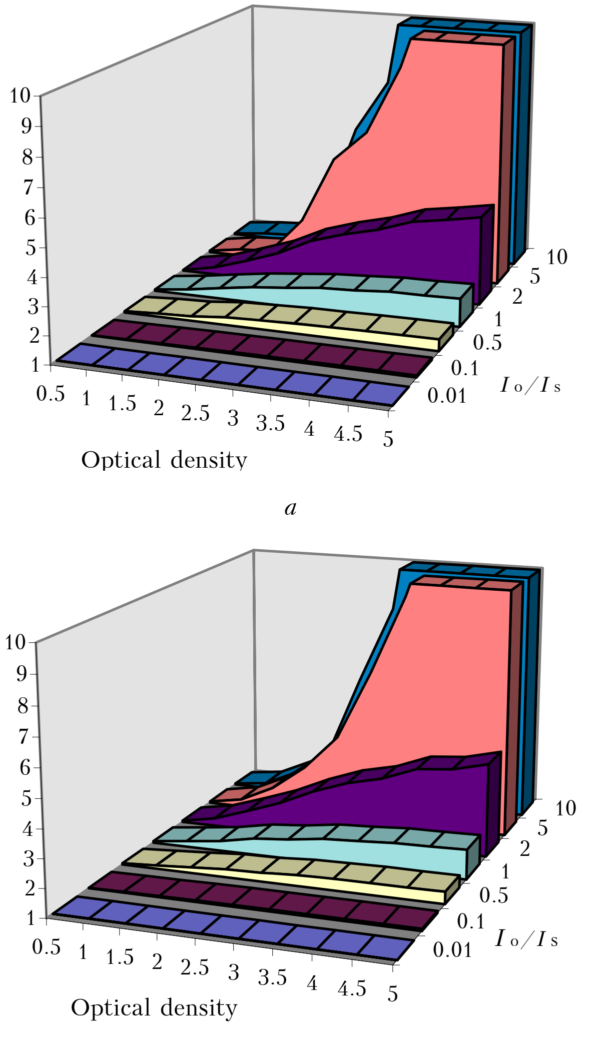
The equations (1) to (3) were analyzed by methods of numerical simulations. The solution of Eq. (1) has been represented by the known implicit function that is determined numerically by the dichotomy technique. The equations (2) and (3) were preliminarily reduced to a single integro-differential equation. Inversion of its discrete analog, in an implicit form, with respect to the spatial coordinate was performed by the iteration method.

RESULTS OF NUMERICAL SIMULATION

To make comparisons easier, all the results below have been obtained under conditions when optical thickness of potassium vapor, τ, was equal to that of the molecular iodine.

The calculations made show that, at a non-linear interaction, transmittance of the above-mentioned two-chamber cell depends on the direction of laser radiation propagation. In particular, a change in the transmittance is observed if the propagation direction is changed for the opposite one. We characterize that change in the cell transmittance, depending on the direction of radiation propagation, by the ratio of energies W_{12}/W_{21} of the same laser pulse passed through the cell in opposite directions.

From the calculations made it follows that the ratio W_{12}/W_{21} only weakly depends on the q factor characterizing the ratio of the non-linearity degrees (Fig. 1). This happens because the interaction with the molecular iodine is, in fact, linear under conditions presented by the initial data involved.



a

b

FIG. 1. The value W_{12}/W_{21} as a function of the initial intensity of the pulse for different optical thicknesses of the medium, $k = 1$; $q = 0.1$ (a) and 0.001 (b).

In the case of strong saturation ($I_0/I_s >> 1$), at a moderate optical thickness, a complete clearing up of potassium vapor occurs regardless of the propagation direction, and the value W_{12}/W_{21} is close to unity (Fig. 2*a*). Then, the value W_{12}/W_{21} ruration ($I_0/I_s \sim 1$), no qualitative distinctions are observeapidly increases with increasing τ. At a moderate satd in this function at medium and high τ values. In this case the ratio W_{12}/W_{21} monotonically grows with the increasing τ (Fig. 2*b*).

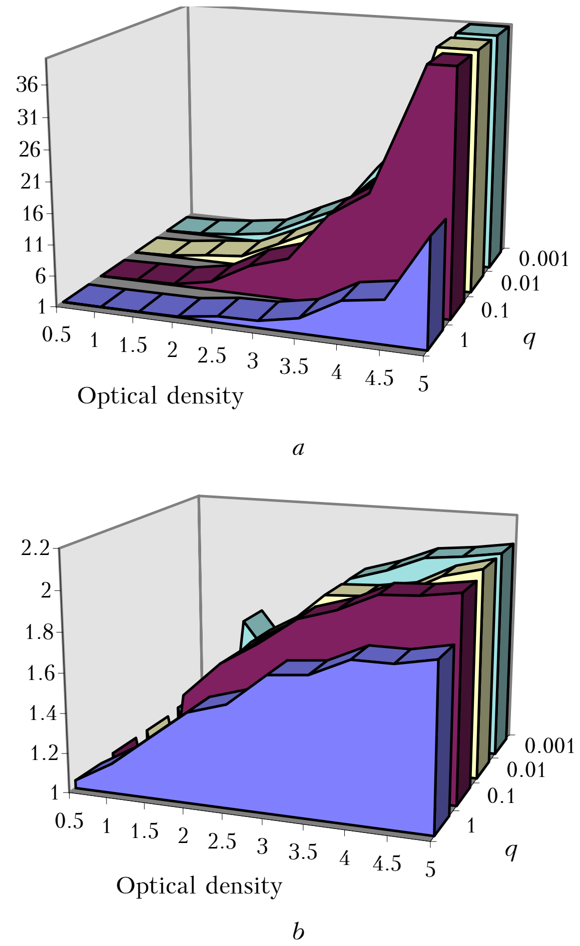


FIG. 2. The value W_{12}/W_{21} as a function of the parameter q for different optical thicknesses of the medium, $k = 1$; $I_0/I_s = 10$ (a), and 1 (b).

CONCLUSION

The results presented can be explained on the base of the following simple model. Let the incident radiation be of such intensity that the interaction of radiation with the potassium vapor is only weakly non-linear. The interaction with the molecular iodine, for the parameters of the problem used, is in fact linear. In this case, one obtains the following solution to Eqs. (1)–(3):

$$I_{12}(\rho, t) = I_0(\rho, t)\, \mathrm{e}^{-2\tau} \,[1 + I_0(\rho, t)/I_s\,(1 - \mathrm{e}^{-\tau})], \quad (4)$$

$$I_{21}(\rho, t) = I_0(\rho, t)\, \mathrm{e}^{-2\tau} \,[1 + (I_0(\rho, t)/I_s)\, \mathrm{e}^{-\tau} (1 - \mathrm{e}^{-\tau})], \quad (5)$$

where I_{12} is the intensity of a laser pulse propagated successively through the chambers with potassium vapor and vapor of molecular iodine; I_{21} is the intensity of the laser pulse propagated through the media in the counter direction.

The following relation can be obtained for pulses of a rectangular shape in time ($I_0(\rho, t) = I_0$):

$$W_{12}/W_{21} = \frac{1 + \dfrac{I_0(\rho, t)}{I_s}(1 - \mathrm{e}^{-\tau})}{1 + \dfrac{I_0(\rho, t)}{I_s}\mathrm{e}^{-\tau}(1 - \mathrm{e}^{-\tau})} .$$

It is seen from this expression that the ratio exceeds 1 under conditions of non-linear interaction.

These results are similar to those obtained for the case with a inhomogeneous, one-component, resonantly absorbing medium with the non-linearity parameter of the interaction varying along the propagation path.

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