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Saturation Intensity in Excited Channel for Nonlinear Medium With Coincident Absorption and Emission Bands-Part I

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Abstract: Optical properties of nonlinear medium can be considered by using a typical three-level configuration (S_0-S_1-S_2). In this configuration the transition of molecules in principal channel (S_0-S_1) are occurred by the light fields of intensity I_{12} at frequency ω_0 and the light fields with intensity I_{23} at frequency ω transmit the excited molecules to second excited level (S_2). The absorption and other properties of dye solutions depend on the intensity of radiations and on saturation processes in excited channel, which occurred at saturation intensity I_{23}^{sat}. The saturation intensity in excited channel decreases with increasing radiation intensity in the principal channel. The saturation intensity I_{23}^{sat}, for materials with coincident absorption and emission bands, has its optimal values when the frequency of light fields in principal channel is tuned into the centre of principal absorption band. The saturation intensity in excited channel, with enough small values, achieved through effective excitation of molecules in principal channel and when the radiations in excited channel tuned into the centre of absorption and emission excited bands. The saturation intensity in excited channel affect strongly the nonlinear processes such as: four-wave mixing, holography and bistability and their control.

Key words: Nonlinear media, saturation, excited channel, coincident bands

INTRODUCTION

An optical properties of dye solutions were used to study nonlinear processes such as: four-wave mixing, amplification and holography (Shalaev, 2002; Sarychev and Shalaev, 2000; Poliakov *et al.*, 1999). The interaction of light beams with nonlinear media appears in many nonlinear processes such as refraction, interference, thin films, optical bistability, phase-conjugation and others (Poliakov *et al.*, 1998; Podolskiy *et al.*, 2003; Agishev *et al.*, 1998; Popov and Shalaev, 1980a). The three-level model were studied using averaged Einstein coefficients for different media (Bolotskikh *et al.*, 1986; Agishev *et al.*, 1998; Tichonov and Shpak, 1979).

The control of the nonlinear processes is very important to study many optical properties. The three-level model for nonlinear media gives ability to control the nonlinear processes by independent light beam (Popov *et al.*, 2000; Agishev *et al.*, 1998; Popov and Shalaev, 1980b). In this model the dye solution can be excited by light fields in which, first group of light fields acts in principal channel (S_0-S_1) and other group acts in excited channel (S_1-S_2). Light fields (with intensity I_{23} at frequency ω) can involve a nonlinear processes in excited channel and other light field (optical pumping with intensity I_{12} at frequency ω_o) acts in the principal channel (Agishev *et al.*, 1998; Rubanov *et al.*, 2000). In this case, the nonlinear processes can be controlled by independent light beam (optical pumping), acting in the principal channel.

The phase response of nonlinear media depends on the intensities and frequencies of light fields acting in each of principal and excited channels. The saturation intensity in principal channel was studied for nonlinear medium with Gaussian form of mirror-symmetric absorption and emission bands with Stokes shift (Addasi, 2005).

The aim of this theoretical study is to find an optimal conditions of saturation intensity in excited channel for nonlinear media with coincident absorption and emission bands.

THEORY

The extinction coefficient in excited channel at frequency ω can be written as follows:

$$\chi_{23}(\omega) = \frac{c}{2v} K_{23}(\omega) \qquad (1)$$

where:

$$K_{23}(\omega) = \frac{\hbar\omega}{v}(N_2 B_{23}(\omega) - N_3 B_{32}(\omega))$$

is the absorption coefficient in principal channel, N_i is the population of i-energy level; N is the number of molecules in the unit volume and v = c/n is the light velocity.

Using the balance equations under a double frequencies excitation of dye solution modeled by three-level configuration we can rewrite Eq. 1 in the form:

$$\chi_{23}(\omega) = \chi_0 (I_{12} B_{23} / vp_{21}) / K \qquad (2)$$

where:

χ_0 = $N\hbar c B_{12}(\omega_0)/2v$,
$\chi_0(\omega_0)$ = Linear extinction coefficient,
P_{ij} = Total probability of spontaneous and radiationless transitions in the i-j channel,
K = $1+JI_{12} + aI_{23} + bI_{12}I_{23}$,
a = B_{32}/vp_{32},
J = $(B_{12} + B_{21})/vp_{21}$,
b = $B_{12}B_{23} + aJ$.

The Einstein coefficients $B_{12}(\omega_0)$, $B_{21}(\omega_0)$ are determined at the frequency of radiations (ω_0) in the principal channel S_0-S_1. At the same time $B_{23}(\omega)$; $B_{32}(\omega)$ are determined at frequency of radiations (ω) in the excited channel S_1-S_2.

The saturation intensity in excited channel (I_{23}^{sat}) is defined as the value of radiation intensity, for which the absorption in this channel is decreasing to half of its maximum value:

$$\chi_{23}(I_{23}^{sat}) = \frac{1}{2}\chi_{23}^{max} \qquad (3)$$

$$\chi_{23}^{max} = \chi_{23}^{o} = \chi_o (B_{23} I_{12} / vp_{21})/(1 + JI_{12}) \qquad (4)$$

where, χ_{23}^{o} is the extinction coefficient for excited channel in absence of radiations in this channel. Simply we can consider the nonlinear processes in excited channel as a processes in two-level model (S_1-S_2) with varies population of first energy level and with linear extinction coefficient χ_{23}^{o}, depending on optical pumping with intensity I_{12} at frequency ω_o as an external factor.

The saturation intensity in the excited channel has the value:

$$I_{23}^{sat} = \frac{1 + JI_{12}}{a + bI_{12}} \qquad (5)$$

ANALYSIS AND RESULTS

Equation (5) shows that, the saturation intensity in excited channel I_{23}^{sat} has a monotonic dependence on radiation intensity in principal channel (I_{12}) and for effective excitation in principal channel, the saturation intensity has enough small value. The saturation intensity in excited channel (I_{23}^{sat}) has an optimum values as a function of frequency.

Using Eq. 5 we can obtain numerical analysis for dependence of saturation intensity I_{23}^{sat} on intensity in principal channel (I_{12}) and on frequency tuning of radiations in both principal and excited channels (η_{12}, η_{23}). For this dependence, nonlinear medium with a Gaussian form of coincident mirror-symmetric absorption and emission bands ($\omega_{ij} = \omega_{ji}$, $\eta_{ij} = \eta_{ji}$) is taken into consideration. Where, the frequency tuning of radiations in principal ($\eta_{12} = (\omega_0 - \omega_{12})/\Delta_{12}$) and excited ($\eta_{23} = (\omega - \omega_{23})/\Delta_{22}$) channels are used to find Einstein coefficients B_{ij} and Δ_{ij}, ω_{ij}. Where, Δ_{ij}, ω_{ij} are the profile halfwidth and the centre of i-j channel.

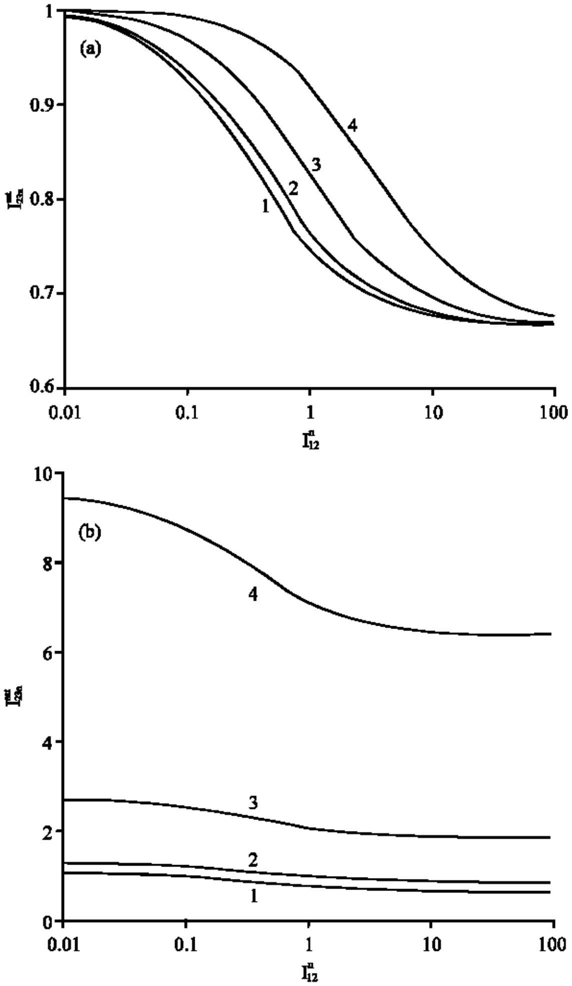

Fig. 1: Dependence of saturation intensity in excited channel I_{23n}^{sat} on radiation intensity in principal channel I_{12}^{n} for $\eta_{23} = 0$ (a) and $\eta_{12} = 0$ (b). Curves: 1, 2, 3 and 4 are at η_{12}: 0, ±0.5, ±1 and ±1.5, respectively (a) η_{23}: 0, ±0.5, ±1 and ±1.5, respectively (b)

Equation 5 and Fig. 1a and b show the monotonic dependence of saturation intensity in excited channel I_{23}^{sat} on radiation intensity in the principal channel I_{12}. Figure 1a shows the dependence for different frequency tuning of radiations in principal channel $\eta_{12} = 0$ (curve 1),

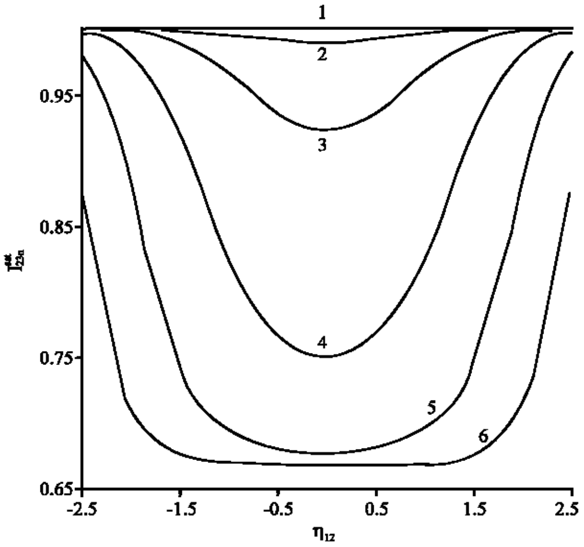

Fig. 2: Dependence of saturation intensity in excited channel I_{23n}^{sat} on frequency tuning of radiations η_{12} in principal channel for $\eta_{23} = 0$. Curves: 1, 2, 3, 4, 5 and 6 are at intensity in principal channel I_{12}^{n}: 0, 0.01, 0.1, 1, 10 and 100, respectively.

±0.5 (curve 2), ±1.0 (curve 3) and ±1.5 (curve 4) at radiations in excited channel tuned in the centre of absorption band $\eta_{23} = 0$. The dependence of saturation intensity in excited channel I_{23}^{sat} on radiation intensity in the principal channel I_{12} is shown in Fig. 1b, at frequency tuning in principal channel $\eta_{12} = 0$, for different values of frequency tuning in excited channel $\eta_{23} = 0$ (curve 1); ±0.5 (curve 2), ±1.0 (curve 3) and ±1.5 (curve 4).

Figure 1 shows that, for enough large intensity of radiations in principal channel $(I_{12}B_{12}^{max}/vp_{21}>1)$, the saturation intensity in excited channel reaches a small values ($I_{23}^{sat}B_{23}^{max}/vp_{32} \approx 0.8$).

From Eq. 5 the saturation intensity in excited channel (I_{23}^{sat}), for coincident absorption and emission bands, has optimum values (minimum) at radiations frequency tuned into the centre of principal absorption and emission bands $\eta_{12} = \eta_{21} \approx 0$, (Fig. 2). In addition, the optimum of I_{23}^{sat} is occurred at frequency of radiations, in excited channel, tuned into the centre of excited absorption and emission bands ($\eta_{23} = \eta_{32} \approx 0$,) (Fig. 3).

Figure 2 and 3 show that, the saturation intensity in excited channel I_{23}^{sat} depends strongly on the intensity of radiations in principal channel (I_{12}) for different frequency tuning in principal channel (η_{12}) and weekly depends on the intensity of radiations in principal channel (I_{12}) for different frequency tuning in excited channel (η_{23}).

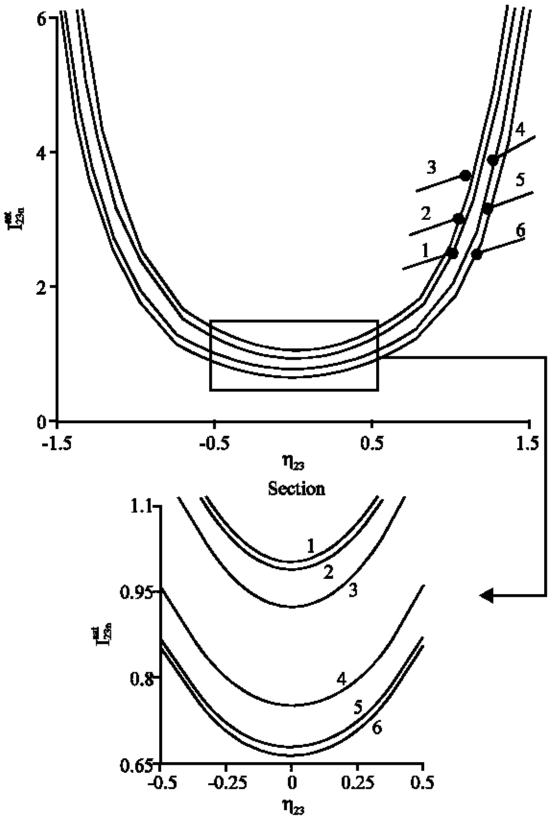

Fig. 3: Dependence of saturation intensity in excited channel I_{23n}^{sat} on frequency tuning of radiations η_{23} in excited channel for $\eta_{12} = 0$. Curves: 1, 2, 3, 4, 5 and 6 are at intensity in principal channel I_{12}^{n}: 0, 0.01, 0.1, 1, 10 and 100, respectively

CONCLUSIONS

The saturation processes in excited channel are achieved with small enough intensity ($I_{23}^{sat}B_{23}^{max}/vp_{32} \approx 0.8$), when an effective excitation of molecules occurs in principal channel $(I_{12}B_{12}^{max}/vp_{21}>1;-1<\eta_{12}<1)$). The radiations in excited channel must have a frequency tuned near the centre of excited absorption and emission bands ($-0.5<\eta_{23(32)}<0.5$), to achieve the saturation processes. The control of nonlinear effects in excited channel can simply reach by external independent radiation in principal channel.

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