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Gain competition effect in dual-wavelength dye lasers

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Abstract

In this paper, we present a theoretical model for the gain competition in dual-wavelength dye lasers. For this purpose the rate equations under the steady-state conditions have been used. The degree of the gain competition is shown to depend on the polarization of the two laser beams. The dependence of the gain competition on various working parameters such as pumping power, dye concentration and the reorientation rate of the molecules or solvent viscosity is studied for two different cases of parallel and orthogonal polarizations. The results of our model show dramatically different behaviors in the two proposed cases.
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Keywords: Dye laser; Dual-wavelength; Gain competition

1. Introduction

A two-wavelength tunable laser can serve as a valuable instrument in applications such as differential absorption lidar (DIAL), laser probing of the atmosphere, nonlinear frequency conversion and two-photon excitation.

Dye lasers as tunable light sources with broad tuning ranges and large stimulated emission cross sections have been used for simultaneous generation of a single laser beam at two wavelengths. In a dual-wavelength dye laser, there is gain competition between the two wavelengths because the two laser lines share a common upper level. Due to this common upper level, characteristics of the dual-wavelength laser pulses cannot be independent of each other [1]. When laser fields of both wavelengths share the same active gain medium, gain of one field can affect the gain of the other. In this case, the relative intensity of the two wavelengths cannot be controlled and the wavelength difference is very limited [2]. Also in general, the tuning range in such cases is reduced and becomes wavelength dependent [3–5]. There are some experimental studies of the gain competition in two-wavelength dye lasers for both parallel and orthogonal case polarizations but to the best of our knowledge a theoretical model for gain competition has not been presented [2–9].

As an example, Kong et al. [6] operated a two-resonator channel dye laser at dual wavelength with continuously variable polarization. They observed that the degree of gain competition depends on the cross angle of the two polarizations. Also Mcintyre et al. [7] demonstrated that gain competition between the two wavelengths is more severe at higher pumping energies.

In this work, a theoretical model describing the gain competition in two-wavelength dye lasers for two cases of parallel and orthogonal polarizations is presented. Influence of various parameters such as pumping power,dye concentration and solvent viscosity on the gain competition will also be shown for the two polarizations.

2. Two-wavelength laser system

Configuration of a two-wavelength dye laser is shown in Fig. 1 [10]. The two output beams are collinear and

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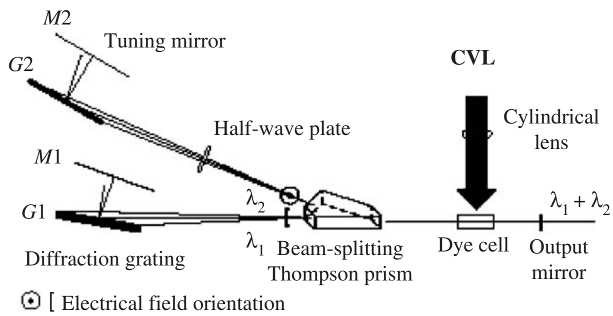

Fig. 1. Experimental configuration of dual-wavelength dye laser.

their wavelengths are continuously tunable anywhere within the optical gain region of the particular dye solution. Beam of a pulsed laser such as a copper vapor laser (CVL) is assumed to be focused by a cylindrical lens onto a dye cell in a transverse pumping configuration. The dye laser cavity consists of a Thompson prism that is used as polarizer-splitter, a pair of holographic gratings oriented at grazing incidence, tuning mirrors which are fully reflecting (the tuning mirrors are situated in the first diffraction order of the grating), the output mirror which is an uncoated plate and the half-wave plate which is used to maximize grating feedback.

The common arm of the resonator consists of an output coupler, the dye cell and a Thompson prism.

The active medium is chosen to be Rodamine (Rh 6G or Rh B) dissolved in ethanol.

3. Theoretical model

Interaction between the dye molecules, the pump and the radiation fields in the laser cavity can be shown by the rate equations suitable for a homogeneously broadened active medium. We present this model for the two cases of orthogonal and parallel polarizations, separately.

3.1. Orthogonal polarizations

The rate equations governing the simultaneous two-wavelength oscillation for the case of orthogonal polarizations (Fig. 1 setup) can be expressed as [11]

$$\frac{\mathrm{d}N_1}{\mathrm{d}t} = \frac{1}{3}\frac{W}{h\nu_\mathrm{p}V} - N_1 c\sigma_1 Q_1 + 2K(N_3 - N_1) + 2K(N_2 - N_1) - K_f N_1, \quad (1)$$

$$\frac{\mathrm{d}N_2}{\mathrm{d}t} = \frac{1}{3}\frac{W}{h\nu_\mathrm{p}V} - N_2 c\sigma_2 Q_2 + 2K(N_3 - N_2) + 2K(N_1 - N_2) - K_f N_2, \quad (2)$$

$$\frac{\mathrm{d}N_3}{\mathrm{d}t} = \frac{1}{3}\frac{W}{h\nu_\mathrm{p}V} + 2K(N_1 - N_3) + 2K(N_2 - N_3) - K_f N_3, \quad (3)$$

$$\frac{\mathrm{d}Q_1}{\mathrm{d}t} = N_1 c\sigma_1 Q_1 \frac{l}{L_1} - \frac{Q_1}{t_1}, \quad (4)$$

$$\frac{\mathrm{d}Q_2}{\mathrm{d}t} = N_2 c\sigma_2 Q_2 \frac{l}{L_2} - \frac{Q_2}{t_2}, \quad (5)$$

where N_1, N_2, N_3 are the upper level populations for the molecules with dipole moments parallel to the x, y, and z axes, respectively (the z-axis is taken to be in the direction of the dye laser beam propagation) and Q_1, Q_2 are the photon numbers for the two orthogonal S and P components, respectively. K is the reorientation rate for isotropic rotation of the dye molecules ($K_{ij} = K\ i,j = 1,2,3, i \neq j$), K_f is the rate of spontaneous emission, σ_i ($i = 1, 2$) is the emission cross section for the two polarizations and c is the light velocity in the active medium. Also, W is the pump pulse peak power, $h\nu_\mathrm{p}$ is quanta of the pumping energy, V is the volume of the cylindrical-shaped active medium with length l and radius of ω_0 ($V = lw_0^2\pi$), L_i is the ith cavity length and t_i is the ith cavity's lifetime ($i = 1, 2$), given by

$$(t_i)^{-1} = -\frac{c}{2L_i}\ln(R_i), \quad (6)$$

where R_i is the effective reflectivity determined by optical elements in the cavity-i.

In this setup (Fig. 1) R_i is given as $R_i = (R_0 T_\mathrm{d}^2 T_\mathrm{p}^2 R_{\mathrm{G-M}})$ where T_d, T_p, R_0, $R_{\mathrm{G-M}}$ are transmissions of the dye cell and Thompson prism and reflectivities of the output mirror and the grating mirrors, respectively. Relaxation times and cavity lifetimes are much smaller than the pump pulse duration (30 ns at FWHM) so the steady-state solution is applicable in this case.

The steady-state solutions for N_1, N_2, N_3 and Q_1, Q_2 can be obtained by setting $(\mathrm{d}N_3/\mathrm{d}t) = 0$ in Eq. (3),

$$\frac{\mathrm{d}Q_1}{\mathrm{d}t} = 0 \quad \text{and} \quad \frac{\mathrm{d}Q_2}{\mathrm{d}t} = 0$$

in Eqs. (4) and (5);

$$N_1 = \frac{L_1}{c\sigma_1 t_1 l}, \quad (7)$$

$$N_2 = \frac{L_2}{c\sigma_2 t_2 l}, \quad (8)$$

$$N_3 = \frac{\frac{1}{3}\frac{W}{h\nu_\mathrm{p}V} + 2K\left(\frac{L_1}{c\sigma_1 t_1 l} + \frac{L_2}{c\sigma_1 t_1 l}\right)}{4K + K_f} \quad (9)$$

Substituting these into Eq. (1) while setting $(\mathrm{d}N_1/\mathrm{d}t) = 0$ (or into Eq. (2) by setting $(\mathrm{d}N_2/\mathrm{d}t) = 0$) and after

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