Wave competition effects in a two-mode gas ring laser

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A method of obtaining very narrow and contrasty resonances in a two-mode gas ring laser is proposed and realized. The resonances result from the jumplike change in the lasing regime on passing through the symmetrical position of the modes relative to the line center. Their possible applications are discussed.

1. The effect of formation of very narrow contrasty resonances in a two-mode gas ring laser, which determines with high accuracy the position of the center of the Doppler line of the active medium, has been investigated theoretically and experimentally. Physically, the effect is connected with the competition between the traveling waves when their positions are symmetrical about the center of the Doppler line, and becomes manifest in the form of a rapid (abrupt) change in the generation regimes of the standing and traveling waves.[1] The effect can be used to increase the stability and reproducibility of an optical frequency standard and the resolving power in nonlinear laser spectroscopy.[2,3]

2. The system of equations describing the generation regimes of the two-mode gas ring laser can be expressed in the form

$$\dot{I}_n = 2a_n I_n (a_n - \sum_m b_{nm} I_m), \tag{1}$$

where

$$I_n = \frac{\mu^2}{2\hbar^2} \frac{E_n^2}{\Gamma}\left(\frac{1}{\Gamma_1} + \frac{1}{\Gamma_2}\right)$$

is the dimensionless intensity of the nth of the four possible (Fig. a) traveling waves, $a_n = 4\pi^{3/2}(\nu\mu^2/\hbar ku)\bar{N}$ is the linear amplification coefficient of the nth traveling wave,[4] and b_{nm} is the saturation parameter of the nonlinear gain of the nth wave in the field of the mth traveling wave of frequency $\nu^{(m)}$ and amplitude E_m, with

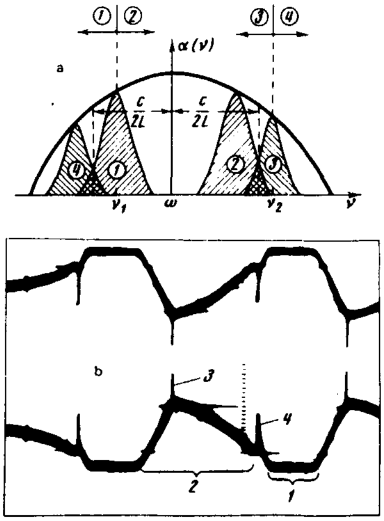
$$\begin{gathered} b_{ii} = 1,\ b_{ij} = b_{ji},\quad b_{13} = b_{24} = 2L(\Delta/\Gamma),\ b_{14} = b_{23} = L(\xi/\Gamma), \\ b_{12} = L(\xi_1/\Gamma),\quad b_{24} = L(\xi_2/\Gamma),\ a_n = \exp\left\{-\left(\frac{\nu^{(n)} - \omega}{ku}\right)^2\right\} - \frac{1}{\eta_n}, \\ \xi = \frac{\nu_1 + \nu_2}{2} - \omega,\quad \xi_i = \nu_i - \omega\,(i = 1,2),\quad \nu^{(1)} = \nu^{(2)} = \nu_1, \\ \nu^{(3)} = \nu^{(4)} = \nu_2, \end{gathered} \tag{2}$$

where $\eta_n = (4\pi^{3/2}\mu^2/\hbar ku)\bar{N}Q_n$ is the excess of the pump over the threshold value at the line center (Q_n is the figure of merit of the resonator for the nth wave), Γ and ku are the homogeneous and Doppler line widths, Γ_j is the relaxation constant of the jth level ($j = 1$ or 2), $\Delta = c/L$ is the distance between modes, and $L(x) = (1 + x^2)^{-1}$. The regions of the existence of instability of the stationary solutions of the system I_n^{cm} are determined from the conditions

$$\text{a)}\ I_n^{cm} > 0;\qquad \text{b)}\ \mathrm{Re}\,\lambda < 0, \tag{3}$$

where λ are the eigenvalues of the matrix $-2b_{nm}I_n^{cm}$. Then the modes go through a symmetrical position relative to the center of the Doppler line ($\nu = (\nu_1 + \nu_2)/2$ is scanned through ω), an abrupt change takes place in the generation regimes. As a result, very narrow and contrasty resonances appear in the output power of the waves traveling in one direction. In particular, if $\Delta/\Gamma < \sqrt{2}$, at definite ratios of the coefficients (2), lasing is possible at only one of the modes, with the exception of a narrow region of detunings near the symmetrical position of the modes, where both modes are stable (standing waves). On the other hand, if $\Delta/\Gamma > \sqrt{2}$, then a different sequence of regimes is produced when ν is scanned through ω.

3. We investigated experimentally an He-Ne laser ($\lambda = 3.39\ \mu$). The resonator, with a perimeter 3.2 m, was made up of three mirrors with reflection coefficients $R_1 = R_2 = 99\%$ and $R_3 = 80\%$. One of the mirrors was fastened on a piezoceramic to scan the laser generation frequency. A gas-discharge tube 70 cm long was placed inside the resonator. At He-Ne mixture pressures from 3 Torr upward, generation in the entire band was single-mode (Fig. b; region 1-traveling wave, region 2-standing wave). When the mode approached a symmetrical position in the detuning region $|\xi| < 50$ kHz, the generation regime of one standing wave changed over jumpwise into the generation regime of two standing waves (region 3), and vice versa. Since the



a) Competition between traveling waves (1, 2, 3, 4), due to cross-saturation within the Doppler line $a(\nu)$; b) oscillogram of output power of waves traveling in one direction, as function of the frequency in the case $\Delta/\Gamma < \sqrt{2}$ (1—one-wave generation region, 2—one standing wave, 3—two standing waves).

competing resonances establish exactly the position of the gain line, we obtained, by measuring their frequency position (the methane peak (4) was used as the reference) the Ne^{20} and Ne^{22} line shifts as functions of the mixture pressure ($\partial\nu/\partial P = 24.5 \pm 1$ MHz/Torr) and their isotopic shifts (78 ± 2 MHz).

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