Concerning the reproducibility of the frequency of a laser stabilized against the transition frequency of the absorbing gas

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Power resonances at the centers ω_+ and ω_- of the amplifying and absorbing components respectively, were obtained simultaneously for a ring helium-neon laser with a nonlinear absorbing cell. By varying the pressure in the amplifying medium, these resonances can be made to coincide with accuracy $\sim 10^4$ Hz, thus uncovering a possibility of obtaining a high reproducibility, $\sim 10^{-15}$ in terms of the parameter $(\omega_+ - \omega_-)$, of the frequency of gas lasers.

1. It is known that the reproducibility of the frequency of optical standards stabilized against laser power resonances at the center of the line of an absorbing gas depends significantly on the extent to which the centers of the gain and absorption lines are made to coincide. The effect is connected physically with the repulsion and attraction between the laser-emission frequency and the central frequencies of the gain and absorption lines.[1] We report here that it is possible to generate simultaneously in a ring laser with a two-component medium power resonances that fix the gain and absorption line centers ω_+ and ω_-, respectively. We shall show that even if the homogeneous gain line width is of the order of the Doppler width it is possible to align (with accuracy 10^4 Hz) the absorption and gain line centers. Physically, such a regime is due to competition of three effects: the phase interaction of the traveling wave, the spectral burnout of the lines, and the spatial burnout of the medium.[2,3] We report theoretical and experimental investigations of the generation regimes of a ring He-Ne laser at $\lambda = 3.39\ \mu$ with a methane absorbing cell.

2. The system of equations describing the laser generation regimes can be reduced to the form

$$\psi = m \sin\phi + p \sin\psi \cos\psi , \tag{1}$$

$$\dot{\phi} = \cos\psi \left[\Delta + m \frac{\cos\phi}{\sin\psi} \right] ,$$

where $\phi = \phi_1 - \phi_2$ is the phase difference of the traveling waves of the field

$$E(t,x) = E_1(t) \cos[\nu t + \phi_2(t) - kx] + E_2(t) \cos[\nu t + \phi_2(t) + kx] \tag{2}$$

m is the coupling coefficient between the waves, which is governed by reflection from the inhomogeneities of the dielectric constant and leads to synchronization of the wave frequencies. The variation of the traveling-wave intensities is described by a variable ψ, defined in accordance with the relation

$$E_1^2 = (E_1^2 + E_2^2) \cos^2 \frac{\psi}{2}, \quad E_2^2 = (E_1^2 + E_2^2) \sin^2 \frac{\psi}{2} . \tag{3}$$

The coefficients p and Δ are connected with the parameters of the laser medium in the following manner:

$$p = \frac{1}{2} \frac{\nu}{Q} (R-1) \left\{ -\frac{\gamma\Gamma}{(ku)^2} + \frac{(\xi/\eta)^2}{1 + (\xi/\eta)^2} \right\} ,$$
$$\Delta = \frac{1}{2} \frac{\nu}{Q} (R-1) \left\{ \frac{\xi}{1 + (\xi/\eta)^2} \right\}, \quad \xi = \frac{\omega - \nu}{ku}, \quad \eta = \frac{\gamma}{ku} , \tag{4}$$

where Q is the resonator quality factor, R is the excess of the pump over threshold ($R_0 = 1$), and γ, Γ, and ku are the homogeneous, radiative, and Doppler line widths, respectively. The coefficients p and Δ are given for one of the media of the laser. In the case of a multicomponent medium it is simply necessary to sum (with appropriate weights) the values of p_i and Δ_i, in which case we put in (1) $p = \sum p_i$ and $\Delta = \sum \Delta_i$.

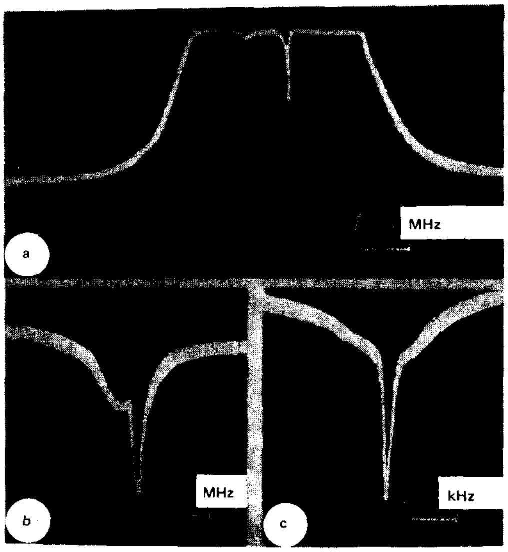
The stationary solution of the system (1)

$$\cos\phi = -\frac{\Delta}{m} \sin\psi, \qquad \sin\phi = -\frac{p}{m} \sin\psi \cos\psi \tag{5}$$

describes the power resonances in the laser emission. At small ψ it follows from (5) that

$$\psi^2 = \frac{m^2}{p^2 + \Delta^2} . \tag{6}$$

In a laser with amplifying and absorbing media, the quantity $E_2^2 \sim \psi^2$ has, in accord with (4), two maxima that fix the central frequencies ω_+ and ω_- of the amplifying and absorbing gases. These maxima coincide at $\omega_+ = \omega_-$.



Oscillograms illustrating the power resonances of the laser emission at the central frequencies of the gain and absorption lines, and their dynamics when the pressure of the He-Ne mixture is varied. More contrasty resonances are produced at the central frequency of the CH_4 line, and less contrasty at the central frequency of Ne (Fig. a). The coming together of the power resonances and their coalescence at $\omega_+ = \omega_-$ are illustrated in Figs. b and c, respectively.

3. In the experiment described below, a ring resonator of length $L = 100$ cm was made up of flat mirrors with reflection coefficients 99%, 99%, and 75% at $\lambda = 3.39\ \mu$. One of the mirrors was mounted on a piezoceramic. The amplifying tube was 30 cm long and the absorbing cell ~40 cm long. The laser emission was registered with a germanium photoresistor doped with gold. The phase coupling between the laser traveling waves was produced by a quartz plate placed inside the laser resonator. The oscillograms (see the figure) show the dependence of the radiation out put power on the lasing frequency with emission resonances at the frequencies ω_+ and ω_-.

As the pressure of the He-Ne mixture is varied, the frequency ω_+ shifts relative to ω_-, and the power resonances corresponding to generation at the center of the gain line shift relative to the power resonances at the center of the methane line. As $\omega_+ - \omega_-$ the power resonances come closer together (cases a and b). Oscillogram (c) corresponds to the case when the centers of the lines of the amplifying and absorbing media coincide.

Similar results were obtained for a ring laser with the following parameters: resonator length 300 cm, amplifying-cell length ~90 cm, and absorbing cell length ~180 cm.

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[1] W.E. Lamb, Phys. Rev. **134A**, 1429 (1964).

[2] N.G. Basov, E.M. Belenov, M.I. Vol'nov, M.A. Gubin, M.V. Danileiko, and V.V. Nikitin, Dokl. Akad. Nauk SSSR **210**, 306 (1973) [Sov. Phys.-Dokl. **18**, 316 (1973)].

[3] V.A. Alekseev, N.G. Basov, E.M. Belenov, M.A. Gubin, V.V. Nikitin, and A.N. Nikolaenko, Zh. Eksp. Teor. Fiz. **3** (1964) [sic!]