EXCITATION THRESHOLD AND OUTPUT POWER FOR GAS LASERS WITH TWO-PHOTON SPATIALLY-PERIODIC PUMPING

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This paper reports calculations of the characteristics of lasers with distributed feedback produced by two-photon optical pumping. Two-photon absorption of a strong field in a gaseous medium have been extensively investigated in connection with high-resolution spectroscopy [1]. On the other hand, two-photon optical pumping is promising as a means of producing generation in the far infrared ($\lambda > 10\ \mu$) [2]. In addition, two-photon optical pumping may result in an improvement in the selective excitation of rotational sublevels. It is therefore interesting to consider a laser system with opposite pump waves which ensure distributed feedback [3]. We begin by considering the equations for the density matrix for molecular gases [1]. The distributed feedback "grid" is produced by interference between the two pump beams [4]. The condition for the effective isolation of a line with a homogeneous width in the pump channel in this geometry is $k\langle v\rangle < \cos\theta\Gamma_{21}$ (the notation is the same as in [1, 4, 5]). When L/c, $\tau_r < \tau_p$ and either $\tau_p < \tau_v$, τ_r/q, or only $\tau_v < \tau_r/q$ are satisfied (L is the length of the active medium; τ_r and τ_v are the rotational and vibrational relaxation times; τ_p is the length of the pump pulse; and q is the equilibrium population factor for the rotational sublevels), we can separate the equations for the diagonal and nondiagonal elements of the density matrix for all three working levels:

$$\left(\frac{\partial}{\partial t}+v\frac{\partial}{\partial z}+\gamma\right)(n_m-n_m^0)=(-1)^m\sum_k(1-\delta_{km})\,Im\,\{\sigma_{2k}V_k\},$$

$$\left(\frac{\partial}{\partial t}+v\frac{\partial}{\partial z}+\Gamma_{2k}-i\Omega_k\right)\sigma_{2k}=-iV_k^*(n_2-n_k),\quad m,\ k=1,\ 2,\ 3. \qquad (1)$$

We assume that the two-photon absorption of the pump is due to the transition $1 \to 2$, whereas the amplification of the signal wave is due to the transition $2 \to 3$; $V_2 = 0$. The polarization will be calculated as follows: 1) we expand n and σ over the spatial Fourier harmonics (without the Doppler effect, $\langle v\rangle = 0$, averaging over the spatial period $\Lambda = 2\pi c/\omega$, ω can be carried out exactly, where ω is the signal frequency); 2) we determine the spatial polarization harmonics by solving (1) in the stationary state ($\partial/\partial t = 0$); and 3) we average the polarization of a molecule over the Maxwell thermal velocity distribution.

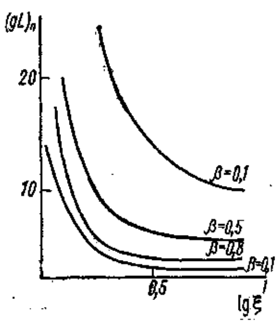

Fig. 1

Substituting the expression for the mean polarization into the wave equation, we obtain the equations for the slow amplitudes A_a, A_b of the opposite waves at the signal frequency:

$$\pm\frac{dA_{a,b}}{dz}=g\,(GA_{a,b}+HA_{b,a}). \qquad (2)$$

The amplification coefficients gG and the coupling coefficients gH are complicated nonlinear functions of the laser parameters and the amplitudes $A_{a,b}$.

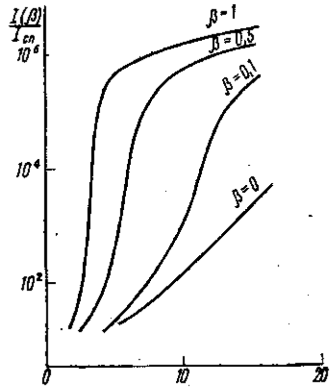

Fig. 2

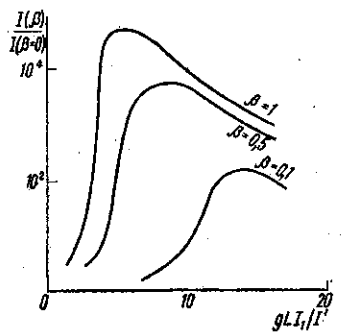

Fig. 3

The generation threshold can be found by linearizing (2) with boundary conditions $A_{\alpha,b}$ $(\pm L/2) = 0$. In the absence of Doppler broadening,

$$(gL)_{n} = (G^2 - H^2)^{-1/2} \ln\left(\frac{G + (G^2 - H^2)^{1/2}}{H}\right), \qquad (3)$$
$$A_{a,b} = 0,$$

where $g = \pi\omega\Gamma_{23}|P_{23}|^2 n_1^0/2\hbar c(\Gamma_{23}^2 + \Omega_3^2)$. The dependence of $(gL)_{th}$ on the pump parameter $\xi^2 = 1 + (I_1/I_1^0)^2$ is shown in Fig. 1 for different values of β. In the above expressions, I_1 is the pump intensity and the saturation parameter for the two-photon transition is given by $(I_1^0)^2 = \hbar^4\gamma(\Gamma_{21}^2 + \Omega_1^2)/\Gamma_{21}|M_{21}|^2$. It is interesting to note that the threshold amplification is a nonmonotonic function of I_1. For large values of ξ, the inversion periodicity is found to vanish.

When the Doppler width exceeds the homogeneous width, i.e., the mean thermal velocity is $\langle v\rangle \gg c\Gamma_{21}/\omega$, the threshold pump intensity is given by

$$(I_1^2)_{th} = \frac{\hbar^6 c\gamma^3\Gamma_{21}\alpha \ln\alpha}{\pi n_1^0 L|P_{23}|^2|M_{21}|^2\omega}, \qquad (4)$$

where $\alpha = 4\pi^{1/2}\omega\langle v\rangle/c\gamma$ is proportional to the ratio of the Doppler to the homogeneous widths.

The distribution of the amplitudes of the opposite waves in the distributed feedback laser is highly nonhomogeneous over the length of the medium so that interference effects in the signal wave can be neglected with a higher degree of accuracy than in lasers with mirror resonators: $|A_\alpha|^2 + |A_b|^2 \gg 2|A_\alpha A_b|$. The nonlinear equations in (2) can be integrated exactly for $I_1 \ll I_1^0$, and the output intensity when the threshold is exceeded is $I = I_0[(gL)/(gL)_{th} - 1]$, where the saturation intensity for the working transition is $I_0 = 4\hbar^2\gamma(\Gamma_{23}^2 + \Omega_3^2)/\Gamma_{31}|P_{33}|^2$. The output intensity of the distributed feedback laser is shown in Fig. 2 as a function of gain. The spontaneous noise intensity is $I_{sp} = 10^{-6} I_0$. The ratio of I(β) to the output amplified spontaneous emission intensity I(β = 0) can amount to several orders even for a slight excess above the threshold (Fig. 3).

The total output power can be obtained by taking the geometry of the problem into account [4]. The area of the generation region is $2r_p L_\perp$, where r_p is the radius of the pump beam and $L_\perp$ is the distance over which two-photon absorption ensures that the pump intensity falls to its threshold value. When the threshold is exceeded, the power efficiency (for β = 1) is proportional to the total pump power:

$$\eta = 5,2\cos^6\theta I_0 P_p/\hbar I_1^0 r_p^3 \gamma n_1^0\omega. \qquad (5)$$

The approximation under which the original equations given by (1) are valid is satisfactory for nonlinear molecules with a high density of rotational sublevels, for example, the SF_6 molecules pumped by CO_2 laser pulses with $\tau_{th} \sim 10^{-7}$ sec ($\tau_r \sim 10^{-8}$ sec and $\tau_v \sim$ $\sim 10^{-6}$ sec, $q \sim 10^2$). It is difficult to estimate how easy it is to reach the threshold in such a system because there are no accurate data on M_{21}.

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