Raman laser with lumped feedback

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The use of lumped feedback is proposed and the properties of a Raman laser with this feedback are considered.

In the observation of steady-state stimulated Raman scattering outside an optical resonator and in an absence of feedback of any other type, the intensity gain obtained at the first Stokes frequency is of the order of e^{28} and higher (see[1]). Obviously, at such high values of the gain even negligible feedback can lead to laser-type generation at the first Stokes frequency, owing to the onset of instability during the time of indicated scattering regime. In[2] they considered the so-called distributed feedback, which in some cases can lead to generation at the first Stokes frequency at gains on the order of e^{15} and higher in the medium.

In the present paper a different type of feedback ("lumped" feedback) is proposed and the main properties of the emission of a Raman laser with this feedback are predicted theoretically. This layer differs in its emission properties from lasers with different types of feedback and can offer a number of advantages.

Let the volume of an active medium with longitudinal dimension L and transverse dimension d fill the space between two reflecting elements with areas d_1^2 and d_2^2. The intensity reflection coefficients of a plane wave at the first Stokes frequency from such unbounded flat elements at normal incidence will be designated r_1 and r_2. We assume that

$$l_i << L << \frac{d^2}{\lambda}, \qquad \lambda \lesssim d_i \ (i = 1, 2), \tag{1}$$

where $l_i = d_i^2/\lambda$ and λ is the length of the Stokes wave in the considered medium.

It can be verified that the condition for the self-excitation of a laser with such feedback is given by

$$A_1 A_2 r_1 r_2 l_1^2 l_2^2 e^{2KL} \gtrsim L^4, \tag{2}$$

where e^{KL} is the gain, over a length L of a plane wave of the first Stokes frequency in the pumped medium; A_i is a quantity determined by concrete form of the ith reflecting element and depends in general on its orientation. If the angle θ_i between the normal to the surface of the ith element and the axis joining these elements satisfies the relation

$$\theta_i \lesssim \frac{\lambda}{2d_i}, \tag{3}$$

then $A_i \sim 1$. We present a numerical example. We assume $r_1 = r_2 = 0.3$, $d_1 = d_2 = 10\lambda$, $\lambda = 0.6 \times 10^{-4}$ cm, and $L = 1$ cm. We then obtain from (2) $e^{KL} \gtrsim e^{12}$. If (1) is valid only at $i = 1$ and d_2 satisfies the relation $d_2 > d$, rather than (1), then the self-excitation condition takes the form

$$A_1 A_2 r_1 r_2 l_1^2 e^{2KL} \gtrsim 4L^2, \tag{4}$$

where $A_2 \sim 1$ at $\theta_2 \leqslant d/2L$.

In spite of the resonatorless character of the feedback, the radiation of the considered laser should have a high degree of spatial coherence, inasmuch as this radiation can be focused at least into a spot with area d_1^2 or d_2^2. Owing to the absence of modes in the feedback, it is possible to have also a continuous narrowing of the spectrum of the Stokes component in the course of the lasing, from the initial width determined by the line width of the spontaneous Raman scattering and by the lasing threshold to values determined by the width of the pump spectrum and by the excess over the indicated threshold.

In addition to excitation of the intense first Stokes component, it is also possible to have in the considered laser parametric excitation of intense anti-Stokes and higher Stokes components, i.e., components with frequencies $\omega_l = p + l(p - \omega_{-1})$, where p is the frequency of the pump wave, ω_{-1} is the first Stokes frequency, $l = 1, 2, \ldots, l = -2, -3, \ldots$ By virtue of (1), the distribution of the field of the first Stokes component in the vicinity of the end faces of the active volume is close to the distribution of the radiation field of an individual pointlike source.[1)] Parametric excitation of the anti-Stokes and higher Stokes components of any order will therefore occur in accordance with the theory developed in[1] for a pointlike source of the first Stokes frequency. At $d \geqslant 2L\theta^{(1)}$, where $\theta^{(1)}$ is the so-called absorption angle in the first Stokes component ($\theta^{(1)} \sim 2 \times 10^{-2}$ for liquids and solids), the predominant radiation of the anti-Stokes and higher Stokes component will occur along the generators of cones with vertex angles determined by the following relations for the wave vectors:

$$\mathbf{k}_l + l\mathbf{k}_{-1} = (l + 1)\mathbf{k}_0, \tag{5}$$

where $\mathbf{k}_0$ is the wave vector of a plane pumping wave in the considered medium, $k_l = (\omega_l/c)n(\omega_l)$, $n(\omega_l)$ is the refractive index of the medium at the frequency ω_l, and c is the velocity of light in vacuum. The corresponding picture of the emission of the anti-Stokes and higher Stokes components, for both isotropic and anisotropic active media, is treated in detail in[1] and will therefore not be discussed here further.

According to (3), the laser under consideration does not need to satisfy any stringent requirement on the relative orientation of the reflecting elements. Therefore in the earlier experiments aimed at observing stimulated Raman scattering, the role of the reflecting elements could be satisfied in certain cases by surface defects, invisible to the naked eye, on the end faces of the investigated samples or cells with the investigated liquid. By the same token, the so-called intensity jumps of the first Stokes component as functions of the pump intensity (see[3,4]) can be attributed to the onset of the above-described generation at the first Stokes frequency, as a result of the lumped feedback.

We note in conclusion that lumped feedback can be used to excite lasing in amplifying media of all types, provided sufficiently large gains are realized in them. It is also obvious that it is possible to use here not only three-dimensional active volumes, but also active objects in the form of waveguide layers (or films).

1)It is therefore natural to call feedback of this type "point-like" or "lumped."

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