GENERATION OF INDUCED RADIATION IN A DISPERSION RESONATOR

PHYSICS

1969

SovietRxiv

Abstract

Full Text

UDC 535.35

PHYSICS

B. L. LIVSHITS, V. N. TSIKUNOV

GENERATION OF INDUCED RADIATION IN A DISPERSION RESONATOR

(Presented by Academician I. V. Obreimov, 15 XI 1968)

In order to tune the frequency composition of generation, dispersion resonators are used, which makes it possible either to narrow the spectral width of generation or to substantially change the mean frequency of the generated radiation ([1–4]). The calculations we have carried out made it possible to obtain the spectral characteristics of the radiation as a function of the parameters of the dispersion resonator.

If N_i is the number of photons in a mode; n is the density of the inverted population; n_0 is the density of the inverted population that would exist in the absence of generation; g_i is the amplitude of the luminescence contour at the frequency of the i-th mode; γ_i are the relative losses in the i-th mode; L is the resonator length and D is a coefficient proportional to the probability of an induced transition; τ_{e} is the characteristic pumping time, then the generation process in a plane resonator, taking into account the axial inhomogeneity of the modal field, is described by the system of equations ([5])

$$\frac{dn}{dt} = -\frac{n - n_0}{\tau_{\mathrm{e}}} + 2\sum_k D g_{kN_{kn}} \left(1 - \cos\frac{2\pi m_k z}{L}\right); \tag{1}$$

$$\frac{dN_i}{dt} = -\gamma_{iN} i + \int_0^L D g_{iN} in \left(1 - \cos\frac{2\pi m_i z}{L}\right) dz. \tag{2}$$

We shall regard the resonator as tuned to the center of the luminescence line, where the mode with number 0 falls (the counting of modes is carried out from zero, in both directions). In this case

$$g_i = g/(1 + \beta i^2),$$

where $\beta = (\delta\nu/\Delta\nu)^2$; $\delta\nu$ is the spacing between neighboring modes; $2\Delta\nu$ is the width of the luminescence curve at half intensity.

In the stationary case this system of equations can be reduced to a system of quadratic equations

$$\gamma_i(1+\beta i^2)/\alpha - 1/(1+\Sigma Q_k) + {}^1\!/_2 Q_i/(1+\Sigma Q_k)^2 = 0. \tag{3}$$

Here $Q_i = 2Dg_{iN}i\tau_\mathrm{e}$, $\alpha = DgLn_0$.

Let the losses depend quadratically on the mode number i, and let the center of the dispersion curve coincide with the center of the luminescence line; then

$$\gamma_i = \gamma_0(1+\xi i^2), \tag{4}$$

where γ_0 is the loss in the central mode, and ξ characterizes the steepness of the dispersion curve.

Taking into account the condition $Q_j \geqslant 0$, from equation (3), with (4) taken into account, we find j—the number of the outermost mode entering into generation at the given pumping. To determine this number j, the inequality obtained is

$$\alpha \geqslant \frac{(1+\beta j^2)^2(1+\xi j^2)^2}{1-(\beta+\xi)\left[{}^8\!/_3 j^3 - j^2 - {}^2\!/_3 j\right] - \beta\xi\left[{}^{16}\!/_5 j^5 - j^4 - {}^4\!/_3 j^3 + {}^2\!/_{15} j\right]}. \tag{5}$$

The threshold occurs at $\alpha = 1$. With a further increase in α, fewer modes enter generation than for the same α in the case of an ordinary resonator. If $j \gg 1$, then condition (5) is simplified, and it can be rewritten in the form

$$2j \leq \sqrt[3]{\frac{\alpha-1}{\alpha}\frac{3}{\beta+\zeta}}. \tag{6}$$

The limiting number of modes $2j_\mathrm{lim}$ does not exceed the quantity $3^{1/3}(\beta+\zeta)^{-1/3}$. By varying the steepness of the loss curve, one can substantially narrow the radiation spectrum. Thus, for $\zeta = 10^{-2}$, $\beta = 10^{-4}$, the generation spectrum is narrowed by a factor of 5. For clarity it may be noted that the loss curve is characterized by a large steepness; specifically, the losses upon displacement from the center of the luminescence line by 5 cm^{-1} must increase by a factor of 100 compared with the losses on the central mode.

If the minimum of the loss curve is shifted with respect to the center of the luminescence line into the region, say, of the l-th mode, i.e.,

$$\gamma_i = \gamma_0[1+\zeta(l-i)^2], \tag{7}$$

then it is interesting to trace how the frequency corresponding to the onset of generation is tuned as a function of changes in the parameters l and ζ.

Solving equation (3) with allowance for relation (7), one can determine the number of the mode i_0 on which generation will begin. The value i_0 is found from the relation

$$\alpha(i_0) = \alpha_{\min},$$

where

$$\alpha(i_0) = [1 + \zeta(l - i_0)^2](1 + \beta i_0^2). \tag{8}$$

Here a number of interesting situations arise.

Let $\beta = \zeta$; then, for displacements

$$\delta\nu \cdot l \le 2\Delta\nu, \tag{9}$$

generation begins on the mode $i_0 = l/2$, and

$$\alpha_{\text{thr}} = (\beta l^2/4 + 1)^2. \tag{10}$$

If, however,

$$\delta\nu \cdot l \ge 2\Delta\nu, \tag{11}$$

then generation occurs on two modes with numbers

$$i_0 = \frac{l}{2} \pm \frac{1}{\sqrt{\beta}}\sqrt{\frac{\beta l^2}{4} - 1}, \tag{12}$$

and in this case

$$\alpha_{\text{thr}} = \beta l^2.$$

Fig. 1. Curves of the dependence of the frequency $i_0\delta\nu$, at which generation begins at threshold pumpings, on the quantity $l\delta\nu$ (the difference between the frequencies corresponding to the minimum of the loss curve and the center of the luminescence line) in the case when: $\Delta\Gamma = 2\Delta\nu$ (1); $\Delta\Gamma = \Delta\nu$ (2); $\Delta\Gamma = \Delta\nu/2$ (3).

Thus, as the minimum of the dispersion curve is gradually moved away from the center of the luminescence curve (the quantity l increases), the generation spectrum splits and will group in the region of two frequencies, one of which tends toward the frequency corresponding to the minimum of the dispersion curve, while the other "returns" to the center of the luminescence curve.

It is convenient to introduce the width of the dispersion curve $2\Delta\Gamma$ as the distance between the frequencies where the losses increase by a factor of 2. Then from the analysis of (8) it can be established that splitting of the initial generation frequency occurs in that and only that case when $\Delta\nu = \Delta\Gamma$ ($\beta = \zeta$) [6]. For other relations between these parameters, say $\Delta\Gamma > \Delta\nu$, at the initial stage, as l increases, the initial generation frequency will shift toward the dispersion curve; with further growth of l, it will return to the center of the luminescence line. It will be difficult to achieve substantial frequency tuning.

Figure 1 shows the dependence of the initial generation frequency $i_0\delta\nu$ on the value of the shift $l\delta\nu$, measured in units of $\Delta\nu$. Three cases are considered, corresponding to: $\Delta\nu < \Delta\Gamma$ ($\Delta\Gamma = 2\Delta\nu$) (1); $\Delta\nu = \Delta\Gamma$ (2); $\Delta\nu > \Delta\Gamma$ ($\Delta\Gamma = \Delta\nu/2$) (3).

For tuning to be achieved, it is necessary that $\Delta\Gamma$ be less than $\Delta\nu$. Then, as l increases, the magnitude of the shift (from the center of the luminescence line) of the initial generation frequency will also increase.

In the present work a quadratic dependence of losses on frequency has been considered. This makes it possible to use the theoretical data obtained for analyzing the operation of resonators in which Fabry–Perot etalons or dispersing prisms are used as discriminators. In this case it is necessary to know only the value of $\Delta\Gamma$ for the corresponding dispersion curve.

Institute of General and Inorganic Chemistry
named after N. S. Kurnakov
Academy of Sciences of the USSR

Received
18 X 1968

REFERENCES

1. S. A. Collins, G. R. White, *Lasers and Applic* Columbus Ohio, 96, 1963.

2. V. L. Broude, M. S. Soskin, N. F. Prokopyuk, Author' s Certificate No. 164324, 1.III. (1963); *Bulletin of Inventions and Trademarks*, No. 15 (1964).

3. V. L. Broude, O. N. Pogorelyi, M. S. Soskin, *Dokl. Akad. Nauk SSSR*, 163, 1342 (1965).

4. V. L. Broude, V. I. Kravchenko et al., *Pis' ma v ZhETF*, 2, 519 (1965).

5. B. L. Livshits, V. N. Tsikunov, *ZhETF*, 49, 1843 (1965).

6. V. N. Tsikunov, *Questions in the Theory of the Spectral Composition of Radiation from Solid-State Lasers*, Candidate' s dissertation, Kiev, 1966.