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Figure 1

Figure 1: Figure 1

Abstract

Full Text

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A Rhodamine 6G Solution Laser with Increased Spectral Brightness and Tunable Frequency

(Presented by Academician A. M. Prokhorov on 26 XII 1969)

Using a new effective scheme of longitudinal laser pumping in a prism dispersion resonator, tunable stimulated emission of a rhodamine 6G solution with increased spectral brightness and a conversion coefficient close to the theoretical one has been obtained. It is shown that under these conditions lasing with a minimum threshold suppresses lasing at other frequencies within the entire luminescence band.

1. It is known that the longitudinal variant of pumping is preferable both from the standpoint of conversion efficiency and for controlling the lasing spectrum by means of dispersion resonators. Until now, strictly longitudinal pumping has been carried out through selective resonator mirrors or through unsaturated transparent plates^(1,2). Both methods lead to large losses associated with destruction of the mirrors or with separation of the pump and lasing beams. The fundamental distinction of our scheme is the introduction of the pump into the cuvette with liquid past the output mirror through a dispersion prism in such a way that the pump and lasing beams are completely superposed in the active medium (Fig. 1a)*.

Fig. 1. *a* –scheme of a dispersion resonator with strictly longitudinal laser pumping; *b* –scheme of a dispersion resonator simultaneously tuned to three frequencies. 1 –cuvette with active liquid; 2, 3, 5, 6 –mirrors; 4 –dispersion prism. *I* and *II* –respectively the directions of the beams under strict and non-strict longitudinal pumping.

A solution of rhodamine 6G in isoamyl alcohol (concentration 10^{16} cm⁻³) was pumped by radiation with frequency $\nu = 18900$ cm⁻¹ and density ~ 30 MW/cm². Tuning of the lasing frequency within the range 16400–17850 cm⁻¹ was carried out by rotating a plane-parallel glass plate, which served as the output mirror of the resonator. The pump and lasing radiation were incident on the end faces of the cuvette and on the prism faces at Brewster

Fig. 2. Generation spectra of a rhodamine 6G solution.

Figure 2: Fig. 2. Generation spectra of a rhodamine 6G solution.

angles, which ensured minimal losses. When operating at the frequency $\nu \cong 17\,500\text{ cm}^{-1}$, the lasing efficiency was $\sim 70\%$, which is a record for tunable optical quantum generators based on solutions of organic dyes.

As is known, neglecting reabsorption, the laser efficiency is determined by the expression

$$k = \frac{E}{E_p} \cong \frac{\gamma_u}{\gamma_u + \gamma_{\text{loss}}} \frac{\nu_g}{\nu_p} \eta \left(1 - \frac{E_{\text{thr}}}{E_p}\right), \quad (1)$$

* This pumping scheme appears promising for parametric tunable generators, VUV lasers, etc.

where E_g , E_p , and E_{thr} are, respectively, the energies of generation, pumping, and threshold pumping; γ_u and γ_{loss} are the coefficients of useful and harmful losses; η is the quantum yield of luminescence; ν_p and ν_g are, respectively, the pump and generation frequencies. For rhodamine 6G, $\eta = 0.98$ and $\nu_g/\nu_p \leq 0.91$. Therefore the limiting attainable efficiency ($\gamma_u \gg \gamma_{\text{loss}}$, $E_p \gg E_{\text{thr}}$) should be $\sim 90\%$. In our experiments $E_p/E_{\text{thr}} \leq 10$, i.e., in accordance with (1), $k \leq 80\%$. The closeness of the experimentally observed and calculated conversion coefficients indicates the effectiveness of the pumping system and the smallness of harmful losses.

Fig. 2. Generation spectra of a rhodamine 6G solution. **a**—resonator according to scheme 1a; **b**, **c**—resonator according to scheme 1b. In case **b'**, mirror 3 is blocked.

The width of the generation spectrum over the entire tuning range did not exceed 10 \AA and was determined mainly by the angular dispersion of the prism⁽³⁾. At the same time, the spectral power of the laser, which is its most important characteristic, was $\sim 3\text{ MW/cm}^2 \cdot \text{\AA}$, which is an order of magnitude higher than in the case of OKG with nonselective resonators.

2. In a number of works, the large width and complex structure of the generation spectra of lasers based on solutions of organic dyes were associated with spectral inhomogeneity of the working luminescence bands⁽⁴⁾. On the other hand, spectroscopic data indicate homogeneous broadening of these bands⁽⁵⁾. To resolve this contradiction, the competition of generation at individual frequencies within the luminescence band of rhodamine 6G under different pumping conditions was investigated. A special dispersion resonator was used, which provided an increased quality factor for two frequencies,* determined by the angular position of mirrors 3 and 4 (Fig. 1b). The generation thresholds at these frequencies could be varied by changing the transparency of the mirrors or their tilt. The experiment

consisted in first alternately closing mirrors 3 and 5 and recording separate generation at frequencies ν_1 and ν_2 (Fig. 2a, b), and then opening both mirrors and studying the generation spectrum in the compound resonator.

It turned out that, under strictly longitudinal pumping, generation in the frequency region with the lower threshold (ν_1 in Fig. 2) completely suppresses generation at other frequencies, where separate generation is still possible, over an interval of the order of 1400 cm^{-1} . At the same time, the broadband orange emission⁽³⁾, which occurs at frequencies in the region of the maximum of the gain curve, is practically completely suppressed. An analogous result was obtained for generation in a rhodamine 6G solution.

When an angle is created between the pump and generation beams, the suppression effect is weakened, and generation occurs at all resonator tuning frequencies (Fig. 2c). The sensitivity of the generation spectra to violation of the strictly longitudinal character of pumping is highest when the filamentary structure of the pump beam is well expressed.

* A more rigorous consideration of such a resonator shows that not only the frequencies ν_1 and ν_2 , but also the frequency $\nu_3 = (\nu_1 + \nu_2)/2$, possess an increased quality factor.

The results obtained allow one to assert that the luminescence bands of organic dyes, in agreement with spectroscopic data, are homogeneously broadened, with a transverse relaxation time shorter than the rate of the lasing processes. The occurrence of multifrequency lasing is determined purely by laser mechanisms and, first of all, by the spatial inhomogeneity of the pump and lasing field. Its elimination will make it possible to increase still further the efficiency and the spectral brightness of the lasing.

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