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Emission Characteristics of the Side Radiation of Excited of the Layer of Alcohol Solution of Rhodamine 6G with the Round Geometric Shape

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Abstract

The spectral-spatial characteristics of the lateral radiation of a circular-shaped Rhodamine 6G solution layer were investigated. The layer is a part of the laser dye solution, which is in optical contact with the bottom of optical cylindrical cell, the shape of which determines the geometric shape of the exciting layer. Homogeneous excitation of this layer by the second harmonic of the Nd+: YAG (λ = 532 nm) laser is realized. Circular, plane-directed radiation, with a small, vertical, divergence was obtained from the edges of the excited layer. Is investigated experimentally the spectral and spatial characteristics of radiation. Excitation of the layer was performed from the side of the cuvette bottom. It turned out that within the concentrations of the dye in the solution from 0.12 to 0.03 wt%, the following processes are observed: 1) Plane-directed radiation, with a small vertical divergence, uniform in intensity, around the optical cell in the plane of the luminescent layer; 2) An increase in the amplitude of radiation pulses with a decrease in the concentration of the dye in the solution; 3) Shifting of the maximum of the emission spectrum to the short-wave region, significant narrowing of the radiation spectrum and decrease of the vertical divergence of radiation.

Keywords

Light-Excitation, Superluminescence, Superradiance, Light Divergence, Spectral Selectivity, Total Internal Reflection, Lasing

1. Introduction

From the one hand, the investigated layer in combination with an optical cell can be considered a monolithic ring resonator (MRR), operating on the basis of total internal reflection (TIR) [1] [2]. For the cylindrical cuvette, the main directions form a kind of corona at the periphery creating conditions for the lasing far from the center, near the walls of the cell [2]. Total internal reflection (TIR) from the cuvette walls will provide lasing within the cell only, which is enclosed in a layer of dye solution and cannot leave the optical cell. To output the generated light from such a resonator, it is necessary to violate the condition of total internal reflection at some point of the cell walls in the plane of the emitted layer [2]. However, in addition to the main directions, the population inversion created in the layer should provide amplification of radiation in other directions that are not subject to total internal reflection. It's obvious that these radiations already can leave the optical cell in the form of superradiance, superluminescence, and, maybe, lasing in the resonator, formed as a result of Fresnel reflection, for normal incidence of beams, on the walls of the cell [3]-[13]. Particularly noteworthy is the path of rays with angles of incidence less than the critical angle of total internal reflection. For the ring resonators, beams with angles of incidence slightly smaller than the critical angle of total internal reflection (TIR) can emerge from it (**Figure 1**).

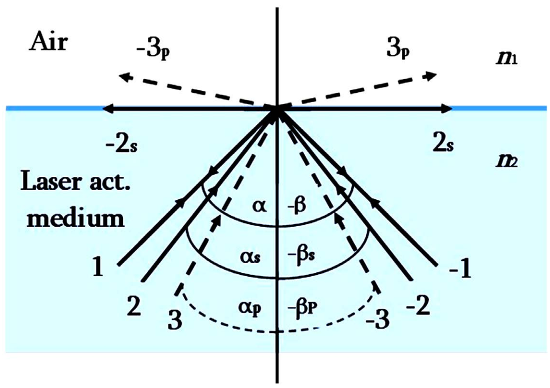


Figure 1. The scheme of propagation of the beams in the MRR near the angle of TIR.

1, −1-beams directions at angles $(\alpha, -\beta)$ of TIR; 2, -2_s -beams directions at critical angles $(\alpha_s, -\beta_s)$; 3, −3-beams directions at a little less of critical angle $(\alpha_p, -\beta_p)$; $(2_s, -2_s)$ -sliding beams of light when the critical angle; $(3_p, -3_p)$ -penetrating through the interface light beams when an angle of incidence is less than critical.

The directions corresponding of beams incidence of incidence angles, less than the critical angles of total internal reflection deserves special attention.. In particular, for the case shown in **Figure 1**, beams of incidence angles slightly less than critical angle of total internal reflection (TIR-i.e. $\alpha = \beta \le \arcsin n_1/n_2$, where $\alpha = \beta$ are the angles of incidence and reflection, n_2 is the refractive index of the optical cell wall, n_1 is the refractive index of air) leave the ring resonator. In **Figure 1**, 1, −1 are path of beams inside of MRR at total internal reflection at angles $\alpha = -\beta$; 2, −2 and $2_s, -2_s$ -are path of beams at the critical angle of total internal reflection $\alpha_s, -\beta_s$; and 3, -3 and $3_s, -3_s$ are path of beams of the critical angles less than total internal reflection $\alpha_p, -\beta_p$. In this case, $2_s, -2_s$ are path of sliding beams along the interface at the critical angle of incidence, and $3_p, -3_p$ -are penetrating beams through the interface light when an angle of incidence is less than critical. Here it is taken into account that beams are falling on the interface of MRR-Air from both sides symmetrically to the normal to the surface. On the other hand, it should be borne in mind that at angles less than the angle of total internal reflection, some of the beams are, nevertheless, reflected inside the resonator, the intensity of which depends on the reflection coefficient from the interface MRR-Air. Due to great amplification along the layer, these radiations, outside of the resonator, will be more intense in the plane of the exciting layer and should have a uniform circular distribution around the optical cuvette [4]-[11].

2. Results

For observing and investigating of radiation of the dye solution layer, the experiments were carried out with an alcohol solution of the laser dye Rhodamine 6G, placed in a cylindrical optical cuvette made of isotropic optical glass K8 with a refractive index n = 1.51 (**Figure 2**). The alcohol solution of Rodhamine 6G (R6G) was prepared with the concentrations: 0.15, 0.12, 0.09, 0.06 and 0.03 wt%, and the average refraction indexes were $n_g = 1.37$.

Figure 2. Photo of the cylindrical cuvette with R6G alcohol solution.

The inner diameter of the cell was 28 mm, the thickness of its glass wall was 3 mm, which fully satisfied the conditions of a monolithic ring resonator (MRR). Optical excitation (pumping) was carried out by the second harmonic of an Nd^+: YAG (λ = 532nm), from the side of the bottom of the optical cell, at a strict perpendicularity of the luminescent layer of the dye solution to the walls of the cell and to the pumping beam (**Figure 3**). The second harmonic of Nd^+: YAG laser (λ = 532 nm) is expanded by a collimator and after the diaphragm forms a circular light spot with size and form corresponding to the size and profile of the cell bottoms. The pumping beam is directed perpendicular to the bottom of the optical cell, i.e., to the plane of the exciting layer. The energy density of the pumping light was 0.2 - 0.3 J/cm^2 and the duration of the pulses of the pumping was τ ≈ 10 ns, which is sufficient to create a significant population inversion in the layer. Consequently, intense spontaneous and induced transitions should acquire an avalanche character, leading to superradiance and superluminescence [4]-[11].

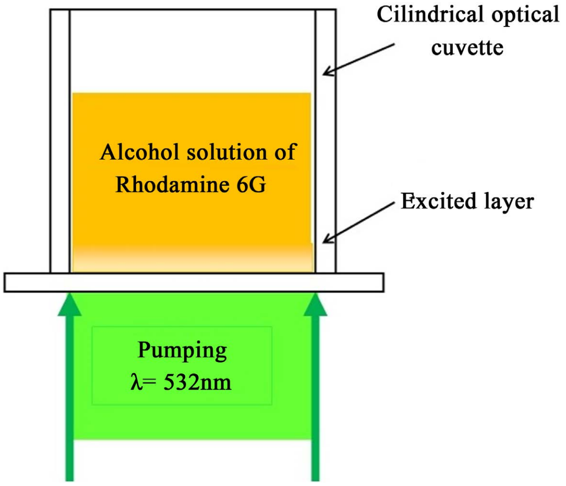
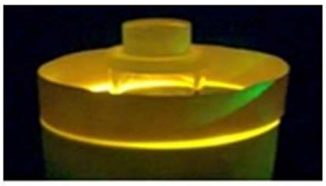


Figure 3. The scheme of excitation of rhodamin 6G dye-doped alcohol layer.

The projections of radiation onto a round and flat screen of the excited layer are shown in **Figure 4**. The radiation is propagated around the optical cuvette in the plane of the excited layer and has a very small vertical divergence. The distribution of the emission spectra, for the concentration of R6G 0.12wt%, along to cross section of the radiation plane is shown in The projections of radiation onto a round and flat screen of the excited layer are shown in **Figure 5**. The results obtained show that the maximum of the spectrum practically does not change across the cross-section of the plane of radiation and, is decreasing only by intensity, from the bottom of the cell up to the upper edge of the radiation plane.



(a)

(b)

Figure 4. Light emission from an exciting layer of an alcoholic solution of the R6G.

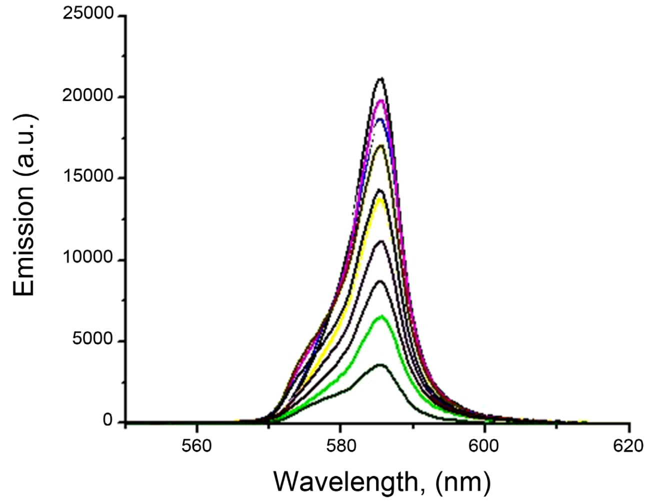


Figure 5. Distribution of the spectra of radiation along of cross section of radiation plane.

The spectral characteristics of radiation were investigated with different concentrations of the dye in solutions (0.15, 0.12, 0.09, 0.06 and 0.03 wt%). The spectral characteristics of the radiation of the layer of the solution of R6G at different concentrations of the dye in an alcohol solution are shown in **Figure 6**.

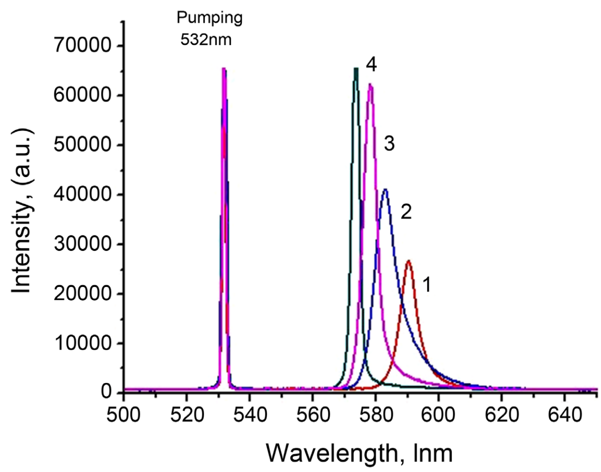


Figure 6. The spectrums of radiation of the dye solution layer at the different concentrations of the dye (1: 0.12 wt%, 2: 0.09 wt%, 3: 0.06 wt%, 4: 0.03 wt%).

As the dye concentration decreases, the emission spectrum narrows and at a concentration of 0.03wt.% it approaches the spectrum characteristic of superradiance, superluminescence and lasing (half-width of spectrum 3 - 4 nm). In this case, the maximum of the radiation spectrum shifts to the short-wave region, and the peak of the radiation energy reaches saturation.

It was also found that with a decrease in the dye concentration, in addition to a shift in the spectrum of maxima and a narrowing of the emission spectrum, the vertical divergence of the emission decreases. **Figure 7** shows projections of the radiation of the excited layer, on the plane screen, for the concentrations 0.12, 0.09, 0.06, and 0.03 wt% accordingly.

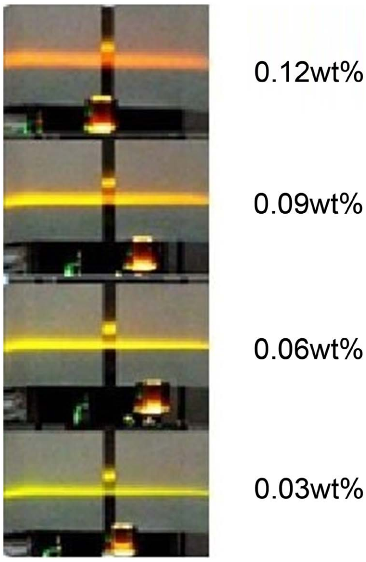


Figure 7. Projection of emission of the excited layer on a flat screen for different concentration of dye R6G.

The dependence of the vertical divergence of radiation of the dye concentration is represented in **Figure 8**.

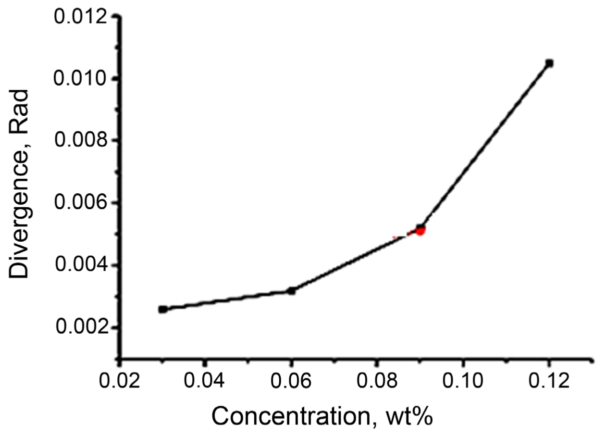


Figure 8. The dependence of vertical divergence of emission of the excited layer in the cylindrical cell.

According to **Figure 8**, the initial vertical divergence decreases with the decreasing dye concentration and reaches 2.5 - 3 mrad for a concentration of 0.03 wt.%. The study of spatial coherence showed its practical absence. With regard to temporal coherence, the radiation provided fairly clear interference when dividing the amplitude with a path difference of 1.0cm for beams with a diameter of 0.5 mm, cut off by the corresponding diaphragm, and subsequently divided into two identical beams. The emitted light is unpolarized.

3. Discussion

So, was obtained narrowband (3 - 14 nm) radiation of the thin layer of alcohol solution of the dye Rhodamine 6G, of circular geometrical form. This radiation is characterized with the uniform circular distribution of emitted light, in the excited layer plane and with sufficient low vertical divergence (2 - 10 mrad).

As is known, with a change in the dye concentration, the penetration depth of pump radiation into the dye solution (in the case of linear absorption) changes according to the law [14] [15]:

$$d = \frac{\ln I_0 - \ln I_{act}}{k_\lambda}$$

where I_0 is the intensity of the incident pump light, I_{act} is the intensity of the penetrated pump light in the absorbing solution of the dye which is sufficient for the population inversion, and k_λ is the absorption coefficient at the pump wavelength λ = 532 nm. It should be noted that accurate measurement of an active luminescent layer subjected to population inversion is a rather difficult task and it requires a separate study, which is planned for the future. According to measurements with an adjustable diaphragm, the thickness of the active superradiant and superluminescent parts of the excited layer was in the range of 40 - 250 μm.

The almost complete absence of spatial coherence and low temporal coherence indicates a lack of lasing. This also indicates that the conditions for superradiant lasing according to Dicke and superluminescent lasing in one pass were not achieved, which indicates insufficient excitation of the luminescent layer to achieve a maximal population inversion [3]-[13].

4. Conclusions

It should be noted that, in the given case, accurate measurement of the thickness of the active luminescent layer subjected to population inversion is a rather difficult task and it needs a separate study, which is planned for the future.

In the author's opinion, the increasing in the density of the excitation energy, will might be achieve the Dicke condition and obtain radiation with better spectral characteristics and obtain even laser radiation [3].

Almost similar results were obtained for the same layer, only of a rectangular shape, which indicates the universality of the results achieved and indicates the need for further research for other geometric forms of the excited layer [15] [16].

From the point of view of the applied optics, the results obtained can be used to create a laser beacon, the efficiency of which will be much better than the existing, at this time, similar devices.

May be also possible to use the results of obtained to create aerospace navigation systems and systems of optical information processing.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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