INVESTIGATION OF PARTIALLY VIOLATED MODE COMPETITION IN POLYCHROMATIC PULSED DYE LASER

P.A. Vorotnev, A.G. Zhiglinskii, A.M. Izmailov, A.P. Lyutikov, and V.A. Ozolov

Scientific-Research Institute of Physics
at the St. Petersburg State University
Received May 18, 1995

The influence of the cavity geometry upon the intensity of spectral components generated by a polychromatic pulsed dye laser is studied for the case of partially violated mode competition. The possibility of total violation of mode competition has been justified and demonstrated experimentally. The continuum lasing has been reached within the spectral interval comparable with that of active medium luminescence and much broader than in a traditional dye laser with nondispersive cavity under the same conditions.

In order to solve a number of scientific and applied problems, polychromatic or broadband laser radiation tunable over a wide spectral range is needed. The main physical reason, hindering the generation of such a radiation by lasers, is the mode competition. This results in narrowing of lasing spectrum. In order to violate the mode competition, it was proposed in Ref. 1 to use the spatial separation of channels of generation at different wavelengths. As shown in Ref. 2, the control over the power spectrum of the output radiation becomes feasible due to redistribution of the pumping radiant flux density over the active medium. For spatial separation of lasing channels we have proposed and studied point reflecting resonators,[3] which have made the basis for development of polychromatic pulsed dye lasers.[1–4] In experimental studies of these lasers it was discovered[5,6] that in a number of cases optical coupling occurs between spatially separated portions of active medium. As a result, the mode competition turns out to be violated only partially rather than totally. This paper is aimed to study partially violated mode competition as well as the conditions under which the total violation could be observed.

Within the framework of this paper we consider only polychromatic laser proposed in Ref. 1 and shown in Fig. 1. Spontaneous radiation from the pumped portion *1* of active medium *3* is resolved into spectrum by an intracavity spectral device *4*, comprising of a diffraction grating *5* and an objective *6*. Then it comes back and is amplified at that wavelength, the radiation of which reflects from the diffraction grating backward. The right-hand side of the cavity (the objective *7* and the cavity making mirror *8*) reflects the portions being pumped into themselves.

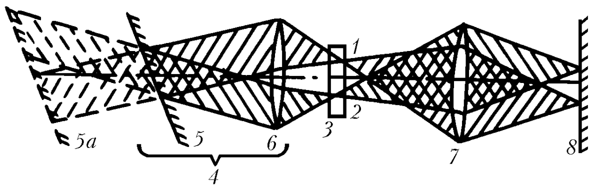

FIG. 1. Optical arrangement of the polychromatic dye laser.

Thus, for any portion of the active medium the positive feedback takes place at the wavelength, for which the conditions of autocollimational reflection are satisfied. In this case, if the amplification of radiation at all the rest wavelengths, non-autocollimationally reflected from the grating, is insufficient for lasing or this radiation is vignetted by optical elements,[4] then in each section the lasing takes place only at one wavelength, i.e. the total violation of the mode competition occurs.

When several portions of active medium (for example, *1* and *2*) are pumped, the case is possible when the radiation emitted by one portion, after non-autocollimational reflection from the diffraction grating, is focused by the objective *6* into the other pumped portion and amplified in it. In this case, the competition occurs only between the additional spectral component and the basic ones (at which the autocollimational reflection takes place), whereas the basic components do not immediately compete with each other. Such a situation is called as a partially violated mode competition.

In addition, if only one portion of the active medium (for example, *1*) is pumped, then the radiation of wavelength λ_{ad} subsequently passes through the nonpumped section *2* and the pumped one *1*, i.e. it is

0235-6880/95/11 930-03 $02.00 © 1995 Institute of Atmospheric Optics

amplified every other time than radiation at the basic wavelength λ_0. However, if the latter is in the wing of the gain profile of an active medium, then the former may appear at its maximum or near it, and the conditions for its amplification will be more favorable. As we have already shown,[6] in this case a part of continuous spectrum, located near the maximum of the gain profile of the active medium, is generated.

The analysis carried out in Refs. 5 and 6 has shown that the mode competition essentially depends on the ratio between lifetimes of the basic spectral components, τ_0, and the additional ones, τ_{ad}, which can be varied by moving the diffraction grating *5* along the resonator optical axis (see Fig. 1). For the case of partially violated mode competition to occur, the rays emitted by the pumped portion *1* and focused by the objective *6* into the section *2* have to be not vignetted by the objectives *5* and *7* during the successive passages. All the rays, passing through the first or second section of the active medium without vignetting are shown by different hatching in Fig. 1. As seen from the figure, the optical coupling between the sections *1* and *2* can occur if the corresponding beams overlap at the diffraction grating. It can be easily shown that such an overlap is maximum when the distance l_1 from the grating to the objective *6*, expressed in terms of focal length of this objective, is equal to unity.

When the grating is moved away from this position, for example, into the position *5a*, the optical coupling between the two sections of active medium *1* and *2* disappears, i.e. the case of totally violated mode competition occurs.

By assuming that the photon lifetime is proportional to the ratio of cross sections of the corresponding beams at the diffraction grating, we obtain the following expression for the ratio of photon lifetimes of an additional and basic spectral components:

$$\frac{\tau_{ad}}{\tau_0} = \frac{2\arccos y - 2|y|\sqrt{1-y^2}}{\pi},$$
$$y \equiv (1 - l_1)(\Delta x / 2\omega_0), \quad (1)$$

where Δx is the distance between sections *1* and *2*, ω_0 is the cross section of the basic-component beam at the diffraction grating. The values of intensity of the components generated, we obtained in Ref. 5 as functions of the lifetime ratio τ_0/τ_{ad}, with regard for Eq. (1) can be expressed as functions of the distance l_1. The results are presented as curves in Fig. 2.

Three different regions can be separated in this figure. For l_1 below 0.85, only the basic components are generated with the intensity J_1 and J_2. In the region $0.85 < l_1 < 0.9$, only one of the basic components and one additional component are generated, and change in l_1 results in significant redistribution of the intensity between them. For $l_1 > 0.9$, the basic components are totally suppressed, and only the generation of an additional component takes place. The photon lifetime of this component, and, consequently, its intensity depend upon l_1. The experimental results for the corresponding components are shown by dots in Fig. 2.

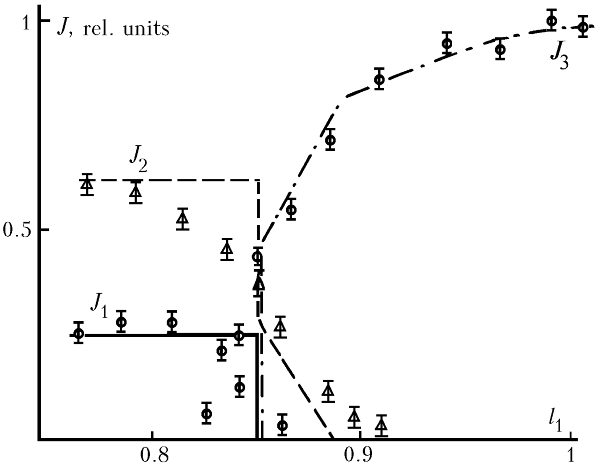

FIG. 2. Relative intensity of the components generated vs the distance between the diffraction grating and the objective.

Certain discrepancy between the theoretical and experimental results in the range, where the change in the lasing modes occurs, are, in our opinion, due to the following reasons. The calculations are done for the stationary mode of generation. However, near the boundaries of the regions indicated above the conditions for amplification of the corresponding components prove to be nearly the same, and during the pulse (about 15 ns when a rhodamine 6G in ethanol is pumped by an excimer laser) the stationary mode has no time to establish.

Thus, by varying the position of the diffraction grating in a laser,[1] it is possible to affect the mode competition and, in particular, to realize the conditions under which it is totally violated.

As was mentioned above, the violation of the mode competition allows a significant increase in the width of continuous spectral interval generated by pulsed dye lasers. This has been experimentally performed for different solutions of pure dyes and their mixtures.

For comparison the table presents the measured widths of the luminescence spectrum of the active media used and widths of the spectra generated by laser with nondispersive resonator under the same conditions of experiment. The width of all spectral regions was measured at the level 0.2 of the maximum value. The results presented in the table show that the width of spectrum generated by a laser with violated mode competition is 50%–80% of the width of the active medium luminescence spectrum and essentially, 3–8 times, wider than that of the spectrum generated by a laser with nondispersive resonator. It should be noted that the values presented were obtained with pumping of active medium by radiation from excimer laser (pulse power of 500 kW) and may be increased, as it follows from Ref. 2, for the laser with violated mode competition by increasing the pumping power.

TABLE I. Width of spectrum generated by dye lasers.

Dye (solvent)	Width of the luminescence spectrum $\Delta\lambda_0$, nm	Laser with a nondispersive resonator		Laser with violated mode competition		$\frac{\Delta\lambda_2}{\Delta\lambda_1}$
		Width of the spectrum generated $\Delta\lambda_1$, nm	$\frac{\Delta\lambda_1}{\Delta\lambda_0}$	Width of the spectrum generated $\Delta\lambda_2$, nm	$\frac{\Delta\lambda_2}{\Delta\lambda_0}$	
Sodium fluorescine (alkaline ethanol)	45	8	0.18	22	0.50	2.7
Rhodamine 6G (ethanol)	46	6	0.13	29	0.63	4.8
Rhodamine 6G (ethylene glycol)	46	7	0.15	29	0.63	4.1
Pyrile salt (acetone)	81	8	0.10	62	0.77	7.8
Rhodamine 6G+oxazine 17 (ethanol)	138	22	0.16	115	0.83	5.2

Thus, partially violated mode competition in a polychromatic pulse dye laser has been studied. It has been shown that the change in the cavity geometry allows the mode competition to be totally violated and the continuous spectrum generation to be obtained with the width comparable to the width of the gain profile of the active medium.

REFERENCES

1. A.G. Zhiglinskii and A.M. Izmailov, Vestn. St. Petersburg Univ. Ser. 4. Fizh. Khim. **4**, No. 25, 71–73 (1992).

2. A.G. Zhiglinskii, A.M. Izmailov, I.A. Smirnova, and P.A. Vorotnev, Vestn. Leningr. Univ. Ser. 4. Fiz. Khim. **2**, No. 11, 8–12 (1991).

3. A.G. Zhiglinskii, A.M. Izmailov, and I.A. Smirnova, Vestn. Lenigr. Univ. Ser. 4. Fiz. Khim. **4**, No. 25, 15–20 (1991).

4. P.A. Vorotnev, A.G. Zhiglinskii, and A.M. Izmailov, Vestn. St. Petersburg Univ. Ser. 4. Fiz. Khim. **4**, No. 25, 73–75 (1992).

5. M.E. Abramenko, P.A. Vorotnev, A.G. Zhiglinskii, and A.M. Izmailov, Opt. Spectrosc. **74**, No. 3, 603–610 (1993).

6. P.A. Vorotnev, A.G. Zhiglinskii, and A.M. Izmailov, Opt. Spectrosk. **75**, No. 6, 1307–1313 (1993).