

# Stimulated emission lasing by organic dyes in a nematic liquid crystal

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(Submitted August 12, 1976)

Pis'ma Zh. Eksp. Teor. Fiz. **24**, No. 6, 336-339 (20 September 1976)

Lasing of organic dyes dissolved in a nematic liquid crystal was obtained for the first time. The rotation of the plane of polarization in such a system following mechanical rotation of the cell with the liquid-crystal solution is demonstrated experimentally.

PACS numbers: 81.55.+x, 78.45.+h

It is known that organic dyes dissolved in a liquid crystal form a molecular solution in which the molecule axes are oriented.<sup>[1]</sup> If the dissolved molecules are isomorphic with the liquid-crystal molecules, then the degree of their order approaches the order of the liquid crystal.<sup>[2]</sup> Molecules of polymethine dyes, which have strong anisotropy of their spatial structure, are similar in their structure to the linear molecules of nematic liquid crystals, but are in the main not soluble in the latter.

We have obtained combinations of ionic polymethine dyes with liquid crystals, having group solubility and optical and chemical strengths adequate for practi-

cal applications. These were solutions of indolenine dyes in *n*-methoxybenzylidene-*n'*-*n*-butylaniline (MBBA) in the nematic phase at room temperature.

To obtain oriented samples, the solutions were poured into a cell 0.2–0.5 mm thick, the inside walls of which were rubbed-in by the method of [3]. The dye molecules were predominantly oriented with their long axes along the optical axes of the liquid single crystal. Owing to the orientation of the dye molecules, the liquid-crystal solution has positive dichroism of the optical absorption ( $D_{\parallel} > D_{\perp}$ ), since the direction of the dipole moment of the transition coincides with the long axis of the dye molecule, as is typical of dyes of the polymethine class. [4]

The experimentally observed dichroism of the absorption of one of the dyes—indodicarbocyanine—at a concentration  $10^{-4}$  mole/liter is shown in Fig. 1 (curves 1 and 2).

When the dye fluorescence is excited by radiation of an He-Ne laser with  $\lambda = 6328 \text{ \AA}$  (the registration was in the direction of excitation) the fluorescence yield of the indodicarbocyanine dye in the MBBA increased from 2.5 to 4 times, depending on the orientation of the vector *E* of the excitation in comparison with the isotropic solution in alcohol, other conditions being equal. The dichroism of the fluorescence of the same dye is shown in Fig. 1 (curves 3 and 4). The decrease of the dichroism in comparison with the dichroism of the absorption is due primarily to reabsorption of the fluorescence. For the indodicarbocyanine dye, at a concentration  $10^{-4}$  mole/liter, a strong quenching action was exerted by the dimerization of the dye molecules, so that their fluorescence yield was lower than in the isotropic solution under the same conditions.

The fluorescence of the dyes in the liquid crystal, as a system of oriented radiators, is polarized with a ratio of the parallel and perpendicular polarizations (relative to the polarization of the exciting light) that depends on the degree of ordering of the dye molecules. For the indodicarbocyanine dye molecules in MBBA, the ratio  $I_{\parallel}/I_{\perp}$  was equal to two and remained unchanged in the entire fluorescence band. When the cell with the dye was rotated through  $90^{\circ}$  relative to the excitation vector *E*, the fluorescence polarization changed by the same angle at a constant intensity ratio  $I_{\max}/I_{\min}$ .

In the study of the lasing we used cells of maximum thickness, in which the liquid crystal still retained the orientation governed by the walls (0.5 mm).

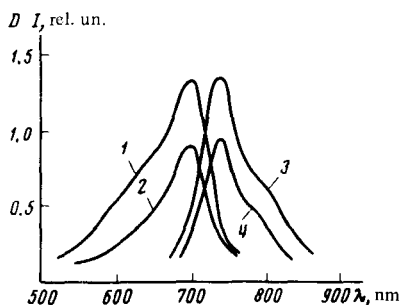


FIG. 1. Dichroism of the absorption bands (1,2) and of the fluorescence bands (3,4) of indodicarbocyanine in MBBA. Curves 1,3 and 2,4 correspond to parallel and perpendicular orientation of the excitation vector *E* relative to the predominant direction of the molecules.

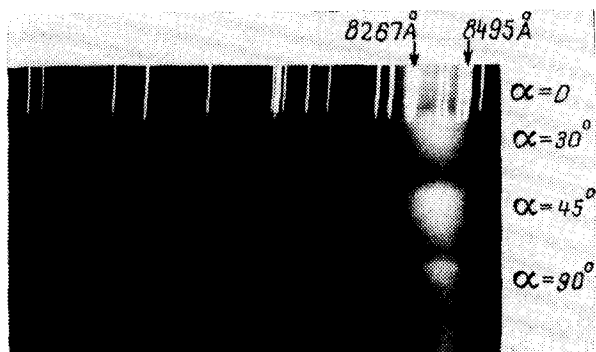


FIG. 2. Lasing spectrum indotricarbocyanine dye in MBBA when the cell with the solution is rotated relative to the excitation vector  $E$  from  $0$  to  $90^\circ$ .

The background-scattering level at this thickness, measured in the transparency region of the dye and the liquid crystal, was 12%. The excitation source was a ruby laser  $Q$ -switched with a passive shutter. We used a longitudinal excitation system, the resonator mirrors were the walls of the cell on which a transparent coating of  $\text{SnO}_2$  was sputtered. The reflection coefficient of such mirrors was 13% in the range  $7000$ – $8500 \text{ \AA}$ . The parallelism of the cell was determined by the parallelism of the Teflon liners and amounted to  $2$ – $4'$ .

Lasing was obtained with both solutions with homogeneous orientation in the MBBA. The generation threshold for the indotricarbocyanine dye, when the excitation vector  $E$  was oriented parallel to the direction of the molecule orientation, was  $\sim 1 \text{ mW/cm}^2$ , which is much higher than in the case of the isotropic solution in alcohol, owing to the quenching of the fluorescence due to the formation of the dimer and the nonoptimal optical density ( $D(\lambda_H) = 1.5$ ). The maximum width of the lasing spectrum was  $200 \text{ \AA}$ , with an average wavelength  $8300 \text{ \AA}$ .

Figure 2 shows the lasing spectrum of the same dye solution. When the cell with a liquid crystal solution was rotated from  $0$  to  $90^\circ$  relative to the excitation vector  $E$ , the lasing spectrum became monotonically narrower, and the lasing threshold increased.

For the indodicarbocyanine dye, the average lasing frequency was  $7360 \text{ \AA}$ , at a spectrum width  $80 \text{ \AA}$ . The minimum excitation threshold was  $\approx 0.5 \text{ mW/cm}^2$  and increased by a factor 2.5 when angle between the excitation vector  $E$  and the direction of the oriented molecules was changed by  $90^\circ$ .

The polarization of the stimulated emission was determined by the polarization of the fluorescence component with the larger intensity, so that when the cell was rotated, the polarization of the stimulated emission is rotated simultaneously with the rotation of the fluorescence polarization. Thus, when the cell with indodicarbocyanine dye is rotated from  $0$  to  $90^\circ$  relative to the excitation vector  $E$ , the lasing polarization plane was rotated in synchronism through the same angle. The lasing energy decreased in this monotonically and decreased by one-half after rotation through  $90^\circ$ .

Such a rotation of the plane of polarization of the lasing radiation makes it

possible to conclude that it is possible to control its position by an electric field, by neutral generating molecules in liquid crystals with positive anisotropy of the dielectric constant.

The results also confirm the possibility of producing different types of lasers with controlled lasing characteristics by using the known ability of liquid-crystal matrices to change their macroscopic state under the influence of electric, magnetic, and acoustic fields.

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