

Spectrally distributed bright cone-shaped laser emission from dye doped cholesteric liquid crystal

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Abstract—Bright conical laser emission from a dye doped cholesteric liquid crystal is obtained. The emission refers to the type of the strong cone-shaped lasing in the spectral region of the dye luminescence maximum as recently reported by the authors [10]. It has been shown that such emission is not an exclusive property of the specific violet-blue dyes, but can also be observed in the green part of spectrum using a commonly available dye. Also, unlike the previous case, the conical lasing is strictly distributed over the spectrum depending on the angle of the cone, and the laser peaks are significantly narrower.

Planar-oriented dye doped cholesteric liquid crystals (DDCLCs) are considered as photonic band gap crystals and are of particular interest due to their ability to generate low-threshold laser emission with a very small thickness of the layer [1]. The emission occurs at the edges of the band gap and is directed normally to the DDCLC layer. Since at an angle to the normal the band gap is retained, but shifted to the short-wave region, it would be reasonable to assume that the lasing should also be retained and shifted. This idea was supported theoretically [2] and then demonstrated and studied experimentally [3-8]. Such out of normal laser emission is directed along the generatrix of a cone located symmetrically to the normal. The considered lasing should not be confused with other types of conical laser emission, which is not generated in the form of a cone, but is the conventional normal lasing that is partially scattered and then amplified at an angle. A detailed analysis of the various types of laser emission from DDCLC is given in Ref. [9], where the considered conical lasing is defined as the only genuine conical lasing. Until the recent times, according to literature the conical lasing had one major drawback: it was believed that, unlike the normal lasing, the conical lasing was quite weak, and therefore not visible on a screen, so it could be detected only by a spectrometer [4, 9]. But, not long ago, the authors of this letter showed that some peculiar dyes of the violet-blue range exhibit strong, visible conical lasing in the spectral region of their luminescence peak maxima [10]. On assumption, this occurs due to a sharp increase in emission nearby the luminescence maximum when

increasing excitation and with the presence of a predominant direction of light amplification in the DDCLC. In this work, we will describe the conical lasing in the region of dye luminescence maximum, obtained in the green range using the most common dye in research practice. The qualitative differences of the obtained laser emission from that described earlier will be shown.

The following components with their percentage indicated in parentheses were used for DDCLC mixture preparation:

- nematic matrix QYPDLC-102, Qingdao, China (73 wt. %);
- optically active dopant QYLC-S2011, Qingdao, China (26.6 wt. %);
- luminescent dye DCM, Sigma-Aldrich (0.4 wt. %).

The cell was fabricated by the conventional method using 1.1mm thick glass plates covered with polyvinyl alcohol (PVA), dried for 1 hour at 90°C and then rubbed in anti-parallel directions to reach planar alignment. The thickness of the DDCLC layer was 12μm. Since the effect is very sensitive to the quality of the layer, the sample was preconditioned at 30°C within a month. A Q-switched Nd:YAG laser (532nm, 100μJ per pulse after attenuation, pulse duration 10ns) was used for pumping.

The transmission spectra of the cell in the normal direction and at the angle of 28° to the normal are shown in Fig.1. The angle of 28° was chosen specifically, as described below. Due to the absorption of the dye, in the figure only the long-wave edge of the band gap is more or less visible. To clarify the positions of the band gap against the absorption and emission spectra of the dye, the band gap spectra of the CLC mixture without adding the dye are shown in Fig. 2. The absorption and emission spectra of the DDCLC mixture were measured in the isotropic phase in a 12μm thick layer. The latter is meaningful since the measurements of emission showed that the luminescence maximum location, which plays a key role in explaining the effect, is highly dependent on the thickness of the DDCLC layer. Therefore, all studies in this work were performed using the layers of the same thickness (12μm). In Fig. 2 it can be seen that at an angle the long-wave edge

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of the band gap shifts towards the maximum of the luminescence peak.

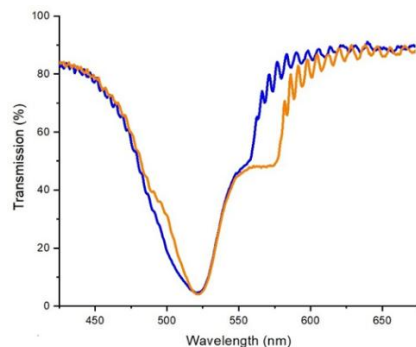


Fig. 1. Transmission spectra of the cell in the normal direction (yellow) and at the angle of 28° to the normal (blue).

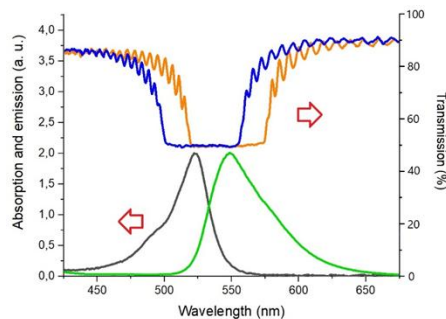


Fig. 2. The band gap positions in the normal direction (yellow) and at the angle of 28° (blue) related to the absorption (black) and emission (green) peaks.

Pumping the layer with a spot of about 0.2mm diameter leads to the normal lasing in the yellow region of the spectrum (Fig. 3a). There is nothing unusual here: multiple rings are typical for lasing at the long-wave edge of the bandgap; though for a long time they were attributed to the diffraction nature, the actual nature is explained in Ref. [9]. If defocusing the pump spot to about 0.5mm diameter without changing the overall pump energy (i.e. changing the pump density), then the normal lasing weakens, releasing the pump energy for conical lasing. It appears on the screen in kind of a green ring (Fig. 3b). The angular position of the ring is from 26° to 30° against the normal; the middle of the ring is at the angle of 28°.

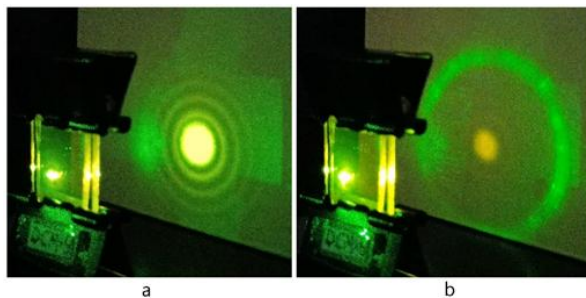


Fig. 3. Emission from the cell when pumping with a small (a) and a large (b) spot. The pump energy in both cases is the same. To enable comparison of the laser emission intensities, the photographs were taken with identical manual settings of the camera.

Spectral measurements of conical lasing require high spectral and spatial resolution of the experimental setup, otherwise the lasing peaks, distributed continuously over the spectrum and over the angle against the normal, merge into one broad peak and become indistinguishable [11]. In our case, the distribution of emission over the spectrum and over the angle is clearly not uniform. This is evident both from the ring structure (Fig. 3b, Fig. 4) and the spectrum recorded with high spectral, but low spatial, resolution (Fig. 5).

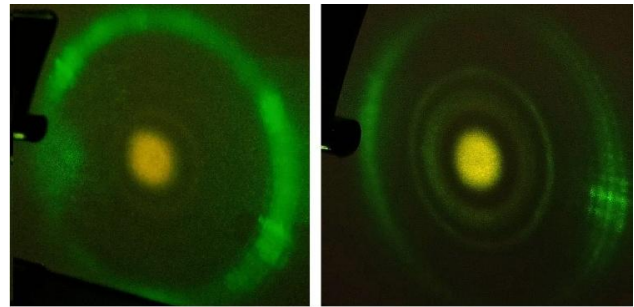


Fig. 4. Intensity non-uniformities in the ring.

The spectrum in Fig. 5 was recorded using a 0.8mm diameter fiber optic cable without a collimator, from a distance of 6cm. The collimator was removed in order to increase the spatial resolution of the spectrometer. The peak shown in Fig. 5, although relatively narrow, is clearly seen to contain at least three narrower peaks, the tops of which are separate. This indicates that the laser emission is distributed not uniformly over the spectrum and the angle against the normal. This may be due to the influence of imperfectness of the DDCLC structure on formation of the predominant direction of light amplification in it.

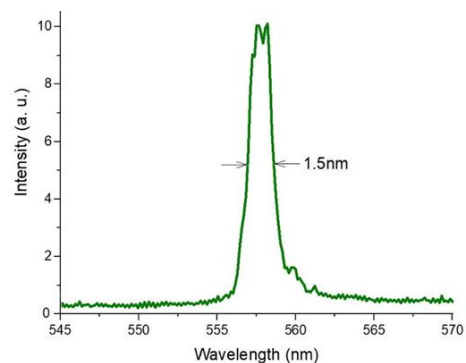


Fig. 5. Typical conical lasing peak shape recorded at high spectral, but low spatial, resolution.

To further improve the spatial resolution of the measuring equipment, we replaced the thick fiber-optic cable with the thinnest one of 0.2mm diameter and installed it at the distance of 11cm from the DDCLC cell. The angle was changed by rotating the cell. This allowed us to see individual peaks of conical lasing (Fig. 6). In the figure, for each peak, the angle against the normal, at which the peak was recorded, is indicated. The peak of the normally directed lasing (0°) is also shown. All peaks

shown have a full width at half maximum (FWHM) of 0.4nm, which is close to the resolution limit of our spectrometer in this spectral region.

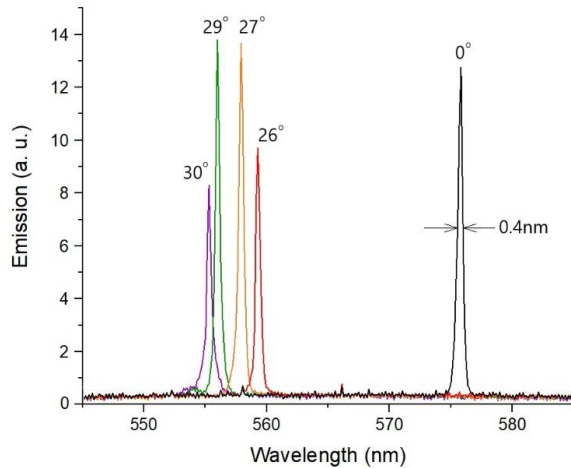


Fig. 6. Lasing peaks position depending on the angle against the normal.

Despite the inhomogeneities in the ring on the screen, the angular dependence of the spectrum remains unbroken. The emission occupies the spectral range of 555–559nm. Outside this range, the emission is indistinguishable against background noise. Detecting that would require increasing the sensitivity of the measuring setup, but that was not our goal.

According to the theory, the laser emission should be distributed continuously, both angularly and spectrally [2, 4]. However, in our experiments this phenomenon is observed only partially. In our view, the factors below influence distribution of the laser emission.

Gradual and/or abrupt changes in the helical pitch due to a non-uniform thickness of the layer lead to a few-nanometers variation of the wavelength of lasing (either conical or normal). To obtain conical lasing, we increase the pump spot, which leads to an increase in the helical pitch gradient in some directions and, consequently, to a decrease in the gain in these directions; to a drop in the lasing intensity; and, to possibility of new modes to appear. As a result, on the screen, the ring is divided into bright and dark sectors (see photographs). Small structural defects, particularly disclinations, also lead to a decrease in gain in certain directions. Presumably, spatial inhomogeneity in the helical pitch is responsible for the division of the ring also along the radius, into many thin rings by shape resembling interference patterns, but this issue requires special research. Finally, the instability and unpredictability of the DDCLC structure's behavior during a short, high-energy absorption-emission pulse exerts an influence. For normal lasing, this is manifested only in strong temporal instability of the lasing intensity; for conical lasing, the temporal instability, in turn, apparently leads to spatial instability. This is especially evident in the radial structure of the rings, which changes with each pulse.

Comparative measurements of the threshold characteristics by a spectrometer show that, when pumped with a defocused spot (Fig. 3b), normal and conical lasing occur almost simultaneously. The threshold pumping energy ranges from 2μJ to 10μJ per pulse. Pumping with a focused beam (Fig. 3a) demonstrates a lasing threshold of less than 2μJ per pulse, which strongly depends on the spot diameter. Conical lasing energy measurements have not been performed due to a very high complexity of such measurements.

Thus, we have demonstrated that when using the common DCM dye, a sharp increase in conical laser emission is observed, reaching a level that is visible on the screen in the spectral region of the dye's luminescence peak maximum. The emission occupies a relatively narrow range, within which it is divided into even narrower individual laser peaks depending on cone angle.

It should be taken into account that studying of this type of conical lasing requires a lengthy process of preparing of the LC layers. Even with the most careful glass preparation and cell assembly, the conical lasing never appears immediately (unlike the normal lasing). The most reliable way to get a bright ring on the screen is to keep the DDCLC layer untouched for at least a few weeks before the experiment, since this allows improving its quality significantly.

References

- [1] L. Blinov, R. Bartolino, *Liquid Crystal Microlasers* (Transworld Research Network, 2010).
- [2] S.P. Palto, JETP **103**, 472 (2006).
- [3] S.P. Palto, N.M. Shtykov, B.A. Umansky *et al.*, Opto-Electron. Rev., **14**, 323 (2006).
- [4] C.-R. Lee, S.-H. Lin, H.-C. Yeh *et al.*, Opt. Expr. **17**, 12910 (2009).
- [5] C.-R. Lee, S.-H. Lin *et al.*, Opt. Expr. **17**, 22616 (2009).
- [6] C.-R. Lee, S.-H. Lin, H.-S. Ku *et al.*, Opt. Lett. **35**, 1398 (2010).
- [7] S.-H. Lin, Ch.-R. Lee, Opt. Expr. **19**, 18199 (2011).
- [8] C.-R. Lee, S.-H. Lin, J.-D. Lin *et al.*, Appl. Phys. B **109**, 159 (2012).
- [9] C.L. Folcia, J. Ortega, J. Etxebarria, ACS Photonics **5**, 11, 4545 (2018).
- [10] A. Chanishvili, K. Chubinidze, G. Petriashvili *et al.*, Opt. Lett. **49**, 5515 (2024). <https://doi.org/10.1364/OL.532553>
- [11] S.P. Palto, N.M. Shtykov, B.A. Umanskii, M.I. Bamik, J. Appl. Phys. **112**, 013105 (2012).