Spatially Modulated Pumping for Cholesteric Liquid Crystal Lasers

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Received May 20, 2025; accepted June 29, 2025; published June 30, 2025

Abstract—Excitation of cholesteric liquid crystal lasers with a large diameter pumping spot is considered. It is shown that the introduction of spatial modulation into the pump beam transfers light emission of the liquid crystal layer from the luminescence mode to the lasing mode. Furthermore, the possibility of dynamic recording of information on a laser optical layer with a thickness of 12µm and an area of about 40mm^2 is demonstrated.

The well-studied laser emission from a planar-oriented dye-doped cholesteric liquid crystal (DDCLC) is considered as photonic band edge (PBE) lasing and is observed at the edges of the photonic band gap of the CLC layer [1, 2]. The direction of emission is along the CLC axis, i.e., normally to the CLC layer.

A CLC laser is a thin layer of the DDCLC formed between two glass surfaces (Fig. 1).

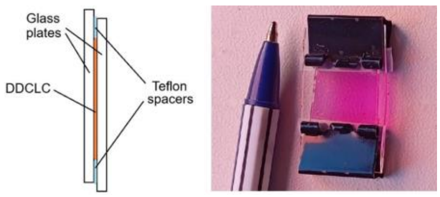

Fig. 1. DDCLC cell design (left) and photograph (right).

The layer thickness is usually chosen within the range of 5÷40µm, and the layer area is about 1cm^2. Like most dye lasers, CLC lasers are excited by pulsed optical pumping. The Q-switched Nd:YAG lasers equipped with a second harmonic generator are recognized as the most convenient for pumping the CLC lasers, and the overwhelming majority of all studies on CLC lasers published in the world are performed using these pump lasers. Figure 2 shows the conventional pumping scheme for the CLC lasers.

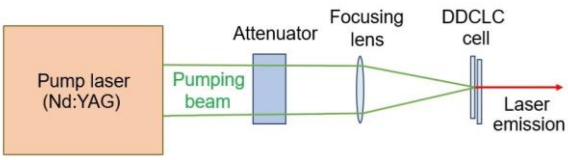

Fig. 2. DDCLC lasers pumping scheme.

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There is also laser emission from the DDCLC cell in the opposite direction, but we will not use it, and it is not shown in Fig. 2. Let us consider the relative parameters of such a pumping system. The focusing lens on this scheme does not serve to increase the pumping density, as it seems at first glance, but to reduce the ratio of the width of the excited region to its length. The higher this ratio is, the more difficult it is to obtain normally directed lasing, and eventually, the laser emission becomes impossible, regardless of the pump energy [3]. This follows from the general principles of constructing “active medium + resonator” systems [4]. This fact forces researchers to focus the pump beam into as small a spot as possible. Typically, the pump spot diameter varies from tens to hundreds of micrometers.

To operate, the CLC lasers require pump pulse energy of the order of microjoules, while the Nd:YAG lasers typically possess hundreds of millijoules of pulse energy, so the use of an attenuator (see Fig. 2) is essential; otherwise, the CLC layer will inevitably be damaged.

As a result, a strange picture emerges from the point of view of the efficiency of such a system: first, we weaken the pump beam by a thousand times, and then with the help of this beam residue, we put to work a thousandth part of the entire DDCLC area at our disposal. Is it really impossible to use the pump energy and the layer area more productively?

Previously, the authors demonstrated the possibility of obtaining coherent emission by exciting a DDCLC layer with a spatially modulated pump spot [5]. A small area (about 1mm^2) of the DDCLC layer was used, on which an array of micro-lasers was formed by a dynamic information recording system.

In the present work, we attempted to (1) implement a system for dynamic recording of information on an increased area of the DDCLC layer and, thereby, (2) obtain laser emission on a large area of the DDCLC layer and (3) increase the efficiency of using the pump beam.

We used a CLC mixture of 75%BL-036 + 25%MLC-2011 (both components from Merck), to which 0.6% of the fluorescent dye Nile Red (Sigma Aldrich) was doped. The layer thickness was 12µm. The pumping was performed with the second harmonic of a Q-switched Nd:YAG laser (532nm). Puls energy was approximately 100mJ.

To demonstrate the effect of spatial modulation of the pump beam on the emission of the DDCLC layer, it is sufficient to slightly modify the optical scheme shown in Fig. 2. Namely, we defocused the pump spot, removed the attenuator, and installed a grid-shaped mask in the pump beam path. The effect is achieved even without careful focusing of the mask image on the DDCLC layer; it is sufficient to simply install the mask in front of the cell (Fig. 3a) or in front of the lens (Fig. 3b).

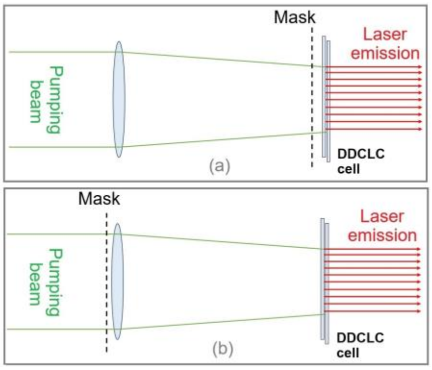

Fig. 3. The simplest methods of spatial modulation of the pump beam: the mask is installed in front of the cell (a) and in front of the lens (b).

The method shown in Fig. 3, b, is more convenient for experiments, since it allows, using one mask, to vary the period of spatial modulation of pumping and the size of the excited region of the layer within wide limits by moving the lens with the mask. A metal mesh (Fig. 4) was used as a mask.

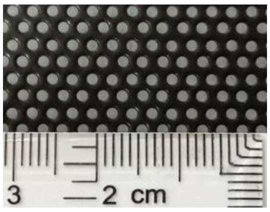

Fig. 4. The mask used in the experiments.

The effect of the mask on the emission from the DDCLC cell was observed on the screen (Fig. 5a). To prevent the pump beam from hitting the screen, a filter cutting off the green part of the spectrum was installed after the cell.

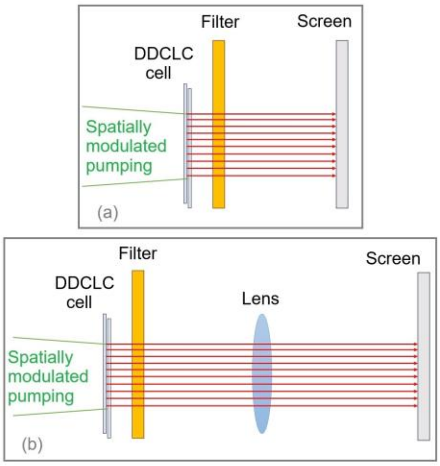

Fig. 5. Optical schemes for observing light emission on the screen: the spot of lasing (a) and the image of the emitting spot of the layer (b)

The difference in emission can be seen in Fig. 6. The spatially modulated pumping generates a directional beam of light (Fig. 6a). The uniform pumping (with the mask removed) causes only layer luminescence (Fig. 6b). The photo shows reflections of the cell in the filter, but without the filter, the screen is strongly illuminated by the green pump beam.

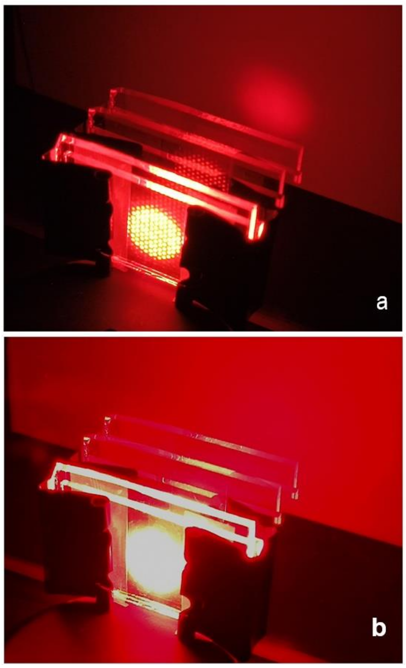

Fig. 6. Light emission under spatially modulated (a) and uniform (b) pumping. The optical diagram in Fig. 5 (a) was used. In both cases, the pumping spot diameter is 7mm

The following spatial parameters of pumping were used:
spot diameter on the mask: 24 mm;
spot diameter on the DDCLC layer: 7 mm;
hole diameter in the mask – 1.4 mm;
hole image diameter on the DDCLC layer: 0.41 mm.

The laser emission spot on the screen (Fig. 6a) does not show any structure, since each individual beam has a divergence inherent to the conventional CLC lasers. The structure of the emitting region of the layer during laser emission can be seen if the layer is focused on the screen according to the scheme shown in Fig. 5b. A photo from the screen is shown in Fig. 7.

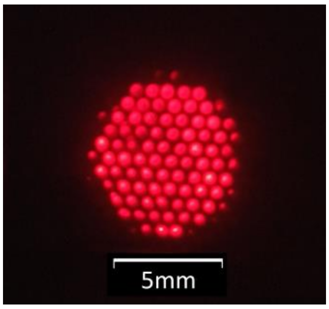

Fig. 7. Image of the layer at the moment of a laser emission pulse, created on the screen according to the scheme Fig. 5b.

The laser emission modes in the spectrum (Fig. 8, red line) are distributed in the interval of about 7nm, which is due to the non-uniformity of the layer thickness and, consequently, the pitch of the CLC helix. The emission of the layer with the mask removed (Fig. 8, green line) has a characteristic, narrowed shape of the luminescence spectrum at strong pumping.

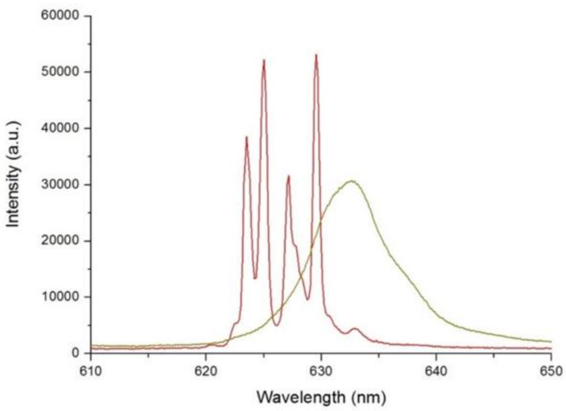

Fig. 8. Emission from the layer when pumping with spatially modulated (red graph) and uniform (green graph) beam

When pumping the layer using the conventional method, by weakening the beam and focusing it into a spot of about 0.4 mm in size, we obtain separate peaks depending on the selected section of the layer (Fig. 9).

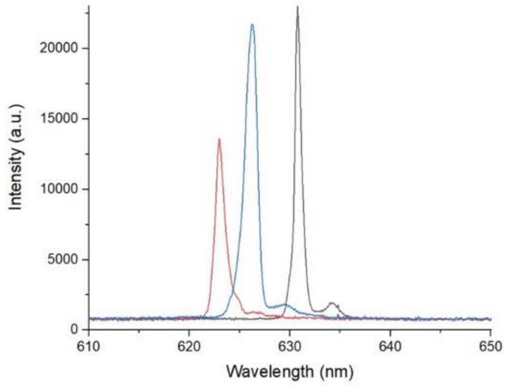

Fig. 9. Lasing from separated areas of the layer

It is obvious that in order to eliminate the emission inhomogeneity, it is necessary to increase the homogeneity of the layer thickness. In laboratory conditions, this can be achieved by using high-quality optical glasses. In this work, such a task was not posed.

Thus, we have shown that the excitation of a CLC laser with a large spot leads only to luminescence of the layer. But, by converting the pumping into a spatially modulated form, we obtain lasing. The emitting region of the layer is a matrix consisting of a large number of microlasers. The obtained results allowed us to demonstrate a principle of dynamic recording of information on a thin (12µm) optical layer with an area of about $40mm^2$. And considering that, apart from DDCLC, there is hardly any other material capable of producing normally directed laser emission at a thickness of 12µm, we believe that this principle is worthy of the attention of researchers.

The work was supported by Shota Rustaveli National Science Foundation of Georgia (FR-22-3061).

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