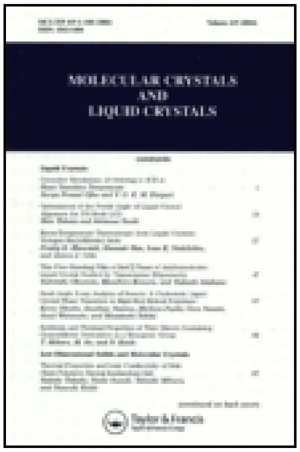

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Laser-Induced Nonlinear Gaussian Lens in Liquid Crystal Cell Gives Birth to Optical Vortices

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Laser-Induced Nonlinear Gaussian Lens in Liquid Crystal Cell Gives Birth to Optical Vortices

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For the first time we report the study of self-induced nonlinear lens in a liquid crystal cell with azo dye and the phase dislocations on a wave front of the beam passing through the lens. Depending on the experimental conditions, circular edge dislocation or optical vortices pairs may be created on the wave front.

Keywords: phase singularities; optical vortices; Gaussian lens

INTRODUCTION

Phase dislocations of a wave front, in particular optical vortices, are intensively investigated in modern optics[1-8]. The wave front distortion of an optical beam passing through non-uniform optical system results in occurrence of phase singularities, or spatial lines, where the amplitude of a wave vanishes, and phase is indeterminate. If the line of a zero amplitude crosses consecutive wave fronts, it produces their association in a common helical surface, or optical vortex. When the line of zero amplitude lays in the plane of the wave front, such singularity is called the edge dislocation. The optical vortex can be used as a bit of information, because it is a topologically robust structure in space, and it also allows to operate easily by imposing a coherent background. Besides, on the basis of optical vortices the "optical tweezers" have been created, allowing to grasp and to rotate microparticles.

For the first time dislocations of wave fronts were theoretically described and classified by Nye and Berry[1]. Optical singularities can arise in speckle-fields, laser cavities, optical fibers, in the process of diffraction on the synthesized holograms[2-5]. Of particular interest is the passage of a beam through nonlinear medium and the natural birth of phase dislocations. The nucleation of singularities in a laser beam with initially smooth wave front was observed after passing through photorefractive crystals[6, 7]. From this point of view liquid crystals (LC), possessing giant optical nonlinearity, are suitable object for studying the properties both dislocations and LC.

EXPERIMENTAL RESULTS

It is known that in nonlinear media under action of a light beam of sufficient intensity the nonlinear lens can be induced, which form is close to the intensity distribution of incident radiation[8]. In general, the mechanism of its occurrence can be various. After passing a laser beam through the lens (we consider the Gaussian beam and, accordingly, the induced Gaussian lens) phase singularities or tears of a wave front may be observed. The astigmatism of the lens defines the occurrence either circular edge dislocations (in case of stigmatic Gaussian lens), or pair of optical vortices (in case of astigmatic Gaussian lens).

In our experiments 4'-pentyl-4-cyanobiphenyl (5CB) nematic LC in both homeotropic and planar orientation with the 0.5% content of azo dye methyl red (MR) was used. The thickness of the cells was 20 μm. The planar cell was combined, with one polyamide-coated surface, rubbed in one direction, and another one was covered with isotropic nonrubbed layer of a modified poly(vinyl)-cinnamat (PVCN). The experimental setup is shown in Fig.1. The radiation of argon laser (wavelength 488 nm) was split by beamsplitter BS1 to reference and signal beams. Signal beam was focused by a lens L1 on the liquid crystal cell LCC. Filters were used to control the necessary power of incident light. By means of the beamsplitter BS2 and the system of mirrors M1, M2 the reference and signal beams were collected together. The resulting picture was detected with the CCD camera. The lens L2 was used to provide comfortable detection of the interference picture. The appearance of phase singularities was shown a shift of the interference fringes in case of edge dislocation or "forks" when optical vortices were born. LC cell was located in a waist plane of a laser beam having the Gaussian profile of intensity distribution. The waist radii for the used lenses were 10 microns and 65 microns (the corresponding Reyleigh ranges were equal 0.7 mm and 27 mm). The signal beam was incident to the cell normally.

The obtained experimental results allow us to state the following:

1. At rather high intensities (~ 120-3200 W/cm^2) under the variation of the incident beam power from 0.4 mW up to 10 mW, the birth and annihilation of optical vortices were observed. The presence of quadrupole of optical vortices in Fig. 2 indicates the induction of astigmatic Gaussian lens. These observations were found both for the planar and homeotropic cells. In case of planar LC cell the polarization of incident laser radiation coincided with the orientation of LC molecules. This fact allows us to suggest the

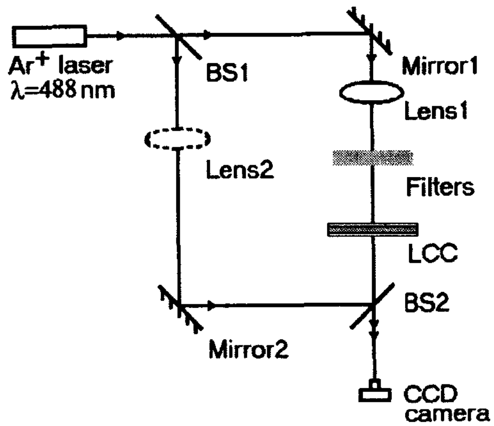

FIGURE 1 The experimental setup for the phase dislocations detection in a laser beam with initially smooth wave front passing through LC.

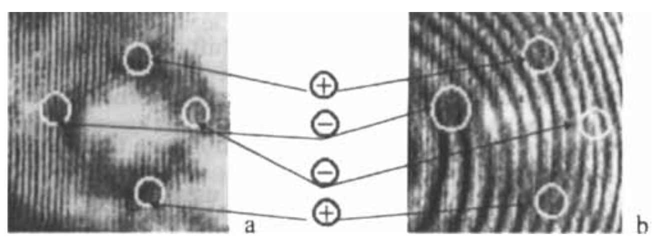

FIGURE 2 The intensity pattern of the far-field zone of the laser beam which experienced the self-action in 5CB liquid crystal with 0.5% MR (a) and the corresponding interferogram (b). Arrows point to vortex location. The quadrupole of optical vortices is visible (the distribution of topological charge signs in quadrupole is also shown[5]).

thermal character of induced lens (as the director reorientation in this case does not occur). The results were detected in a far-field zone at a distance of 240 mm away from the LC and were observed practically immediately after irradiation of the cell.

2. With the essential decrease of intensity (~ 3-0.3 W/cm^2) the resulting picture alters. The occurrence of interference rings is observed. The mechanism of their nucleation is usually connected with thermal, photoorientational and orientational nonlinearity of LC[9]. The photoorientational nonlinearity, connected with dye absorption of the incident light, is suggested to be most essential. In this case a temporal threshold of the lens nucleation realizes (the interference rings occurred after 6 minutes up to 25 minutes for the power of the radiation of 0.4 mW and 55 μW correspondingly). It should be noted that the obtained reorientation is kept during months. It is possible to explain this fact by assuming that the molecules of dye in the excited state adsorb onto a substrate, keeping the reorientation of the director fixed in time. This is the phenomenon of appearance of an axis of easy orientation[10]. The picture obtained for homeotropic cell is shown in Fig.3. The number (about 17) of induced rings indicates the strength of the induced lens (Fig.3a), and the interference picture shown in Fig.3b gives the information about the type of obtained dislocations. It is obvious that not each dark ring is an edge dislocation with exact zero of intensity. In the represented figure the shift of the fringes is visible only in the central ring. Observations were carried out in a far-field zone (z = 260 mm from a crystal). The view of the cells under polarizing microscope confirmed that the reorientation of the director for both homeotropic and planar LC cells really took place.

CONCLUSIONS

For the first time the occurrence of phase dislocations is investigated in a laser beam with initially smooth wave front passing through LC cell with self-induced nonlinear lens. We note that the thermal and photoorientational

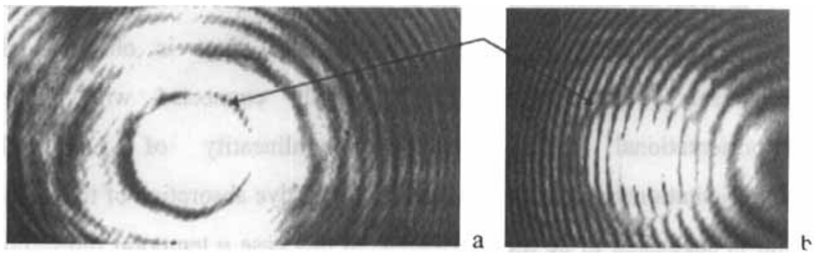

FIGURE 3 The intensity distribution in the laser beam passing through the Gaussian lens induced in 5CB with 0.5% MR liquid crystal (a) and the corresponding interferogram (b). The circular edge dislocation formed in the center of the picture is visible. It is pointed by arrows.

mechanisms of Gaussian lens creation are realized that in turn results in occurrence of various types of dislocations.

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