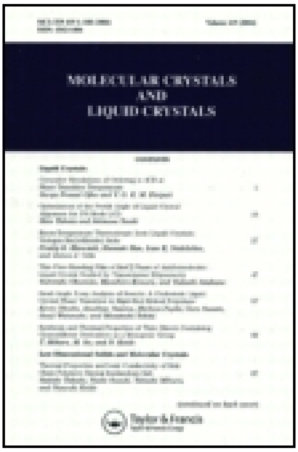

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

The Observation of Optical Vortices in the Thermal Rayleigh Scattering Field of a Liquid Crystal Film

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Version of record first published: 23 Sep 2006.

To cite this article: Peng-Ye Wang , Mao Ye , Jian-Hua Dai & Hong-Jun Zhang (1995): The Observation of Optical Vortices in the Thermal Rayleigh Scattering Field of a Liquid Crystal Film, Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals, 261:1, 143-145

To link to this article: http://dx.doi.org/10.1080/10587259508033460

Mol. Cryst. Liq. Cryst. 1995, Vol. 261, pp. 143–145
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The Observation of Optical Vortices in the Thermal Rayleigh Scattering Field of a Liquid Crystal Film

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Abstract Optical vortices are found in the thermal Rayleigh scattering light field of a nematic liquid crystal film. The optical vortices change their positions on the wave front quickly, and at a certain point, the vortices with different topological charges appear in a random way.

It is a long known fact that there exist phase singularities in the optical speckle field. Both the real and the imaginary parts of the electric field of the light wave vanish at the singularities, and hence these points appear as dark spots in the light beam section. If one performs a close loop surrounding a singularity, the phase of the field will experience a shift of a $2m\pi$, where m is an integral. Optical phase singularities bear such a striking analogy with superfluid vortices, so that Coullet et al.[2] first termed them optical vortices, and discussed their role in nonlinear optics. Until now, a number of articles are devoted to the studying of these optical topological defects. The speckle field is an example in which optical vortices are generated by linear optical processes. In nonlinear optics Arecchi et al.[3] experimentally present the evidence of optical vortices in a ring cavity containing a photorefractive crystal. Optical vortices were also observed in laser systems.[4,5] Some authors have predicted the existence of optical vortices in passive processes such as three-wave mixing and self-defocusing.[6,7] Optical vortices in light wave front can even be produced by the using of computer generated holograms.[8] The propagation of optical vortices was also investigated.[9] It was surprisingly found in a random Gaussian wave field that the nearest neighbors of optical vortex are strongly anticorrelated.[10]

We report in this paper the observation of the optical vortices in the thermal Rayleigh scattering light field of a nematic liquid crystal film. Our experimental setup was simple. The light wave oscillating at 514.5nm from an argon ion laser was splitted into two beams. One of the beam was incident into a liquid crystal cell. The cell with a thickness of about 100μm contained homeotropically aligned nematic liquid crystal 5CB, and was inclined at a bias angle about $\pi/4$. A small portion of the incident light was scattered owing to the thermal fluctuation of the director of the liquid crystal.[11] To extract the phase information of the thermal Rayleigh scattering light field, we used the other beam from the beam splitter as a reference wave to beat the scattered light wave which could be seen clearly on an observing screen behind the liquid crystal cell. The interference pattern was recorded by a CCD video camera.

The reference wave was first tilted, and an off-axis hologram was obtained. In this way, the vortices in the thermal Rayleigh scattering field appeared as optical phase dislocations.[1] A snapshot of the interference fringe is shown in Fig.1, in which the phase dislocations with topological charge both +1 and -1 can be clearly be seen.

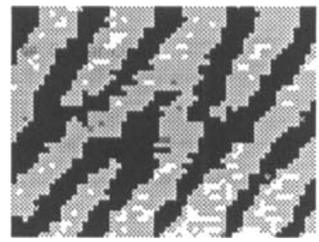

Fig.1. Phase dislocations in the scattering field.

The vortices in the thermal Rayleigh scattering field change their positions on the screen quickly, which makes them quite different from those observed in the speckle structure of a diaphragmmed phase plate. For the amplitude and the phase of the director fluctuation of the liquid crystal molecules are random, the generation of the topological defects in the thermal Rayleigh scattering light field resulted from the fluctuation is thus a dynamical process. Therefore, the dislocations in the wave front do not stand still. In Fig.1 the signature of a phase dislocation is that there is an extra interference fringe, or a disappearance of a fringe, depending upon the sign of the dislocation charge. All the fringes drift to and fro ceaselessly. A broken fringe may connect with another broken fringe and a phase dislocation disappear at this position. Some fringes may break up to form a new dislocation at another position..

In order to observe the generation of the optical vortices more clearly, we make in the experiment the reference wave collinear with the scattered wave in a certain direction to form an in-line hologram, which exhibits the motion of the topological defects much more directly. If the observed area on the wave front of the scattered light waves does not contain optical vortices, the pattern will be simply a series of circles with the same center. However, the interference pattern can not form a closed loop if there exists a vortex in the area, and makes a form of spiral. Figures 2(a) and 2(b) show the patterns when there exist optical vortices with the topological charges of +1 and -1, respectively, in the observed area. It can be seen that the pattern of an optical vortex is rather like that of a fluid vortex. In the experiment we found that the patterns shown in Fig.2 appeared in a random way, which indicate that the vortices with different charges (+1 or -1) sometimes jump in and sometimes jump out of the area we are observing. The feature of this endless motion of the optical vortices in the scattered light field is striking.

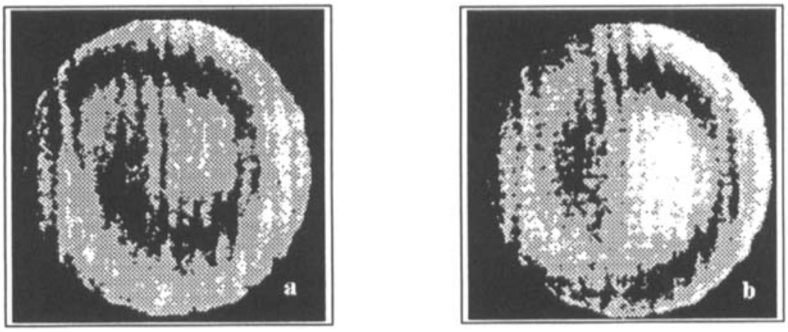

Fig.2. Optical vortices with topological charges (a) +1 and (b) -1.

In summary, we have found that there exist optical vortices in the thermal Rayleigh scattering light field of a nematic liquid crystal film. We have shown that the optical vortices changes their positions on the wave front quickly, and thus we are able to see vortices with different topological charges appear in turn at a certain point we choose. The dynamics of the vortices may reveal some statistical properties of the liquid crystal molecules.

This research was supported by the Chinese National Science Foundation and the Nonlinear Science Project of China.

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