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Recording of Geometric Phase Elements Based on Liquid Crystal Polymers

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Abstract—A technique is developed for recording the centrally-symmetric liquid crystal phase plates with the anisotropic orientation of molecules providing a smooth change of the optical axis in a thin film of liquid crystal polymer. The technique enables one to record the elements with the cylindrically-symmetric and planar-symmetric distributions. Such structures can be used to develop the optical elements with the new functional possibilities. Using the developed techniques, the polarization-sensitive Fresnel lens is realized which is functioning either as a collecting or as a scattering lens for the light beams with the orthogonal circular polarizations.

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1. INTRODUCTION

The orientation of liquid crystal (LC) molecules is the main technological operation in the manufacture of optical elements based on the LC. Traditional methods of orientation are the rubbing [1] and the vacuum oblique evaporation of the orienting coating [2]. The rubbing, even under strict control, is accompanied by a number of defects that are critical with the decreasing in pixel sizes, and the oblique evaporation requires the use of expensive vacuum technologies. The creation of new LC-containing polymers [3], made it possible to avoid the problems typical for the above-mentioned methods of orientation. The uniqueness of the LC polymers is primarily related to their ability to change the orientation of molecules exclusively under the influence of light (the photo-orientation). The photo-orientation is a non-contact method that allows one to obtain the high-quality orientation with the possibility of forming both the discrete and continuously changing orientation.

Precisely for this reason, the LC polymers are forming the basis of optical elements of a new generation. When the LC polymer is used to form a periodic structure by changing the local orientation of the LC molecules continuously, it is possible to obtain the necessary diffraction phase element. These elements are polarization selective and multifunctional. They can be used for optical switching, beam splitting, optical interconnection, etc. Such elements include the phase plates with the planar orientation, which are simple in realization, the centrally symmetric planar elements with the radial and azimuthal distribution of the LC director, as well as more complex structures: the vortices of different orders [4], polarization diffraction gratings [5], centrally symmetric polarization periodic structures forming the Pancharatnam–Berri element class [6, 7]. The latter often have no analogues in modern optics, have the fundamentally new properties, and belong to the class of optical elements of a new generation. The combination of such elements can become the basis of modern optical devices (the ellipsometry, polarimetry, the Raman spectroscopy, optical communication systems, optical tweezers, the atom cooling, etc.), which will significantly improve their technical characteristics and expand the field of applications.

The realization of optical phase elements to form a wavefront was proposed relatively recently [8, 9], and was experimentally demonstrated for the creation of elements of the middle infrared region using the inhomogeneous gratings [9, 10]. In [11], the possibility of realizing the Pancharatnam–Berry elements on the basis of uniaxial birefringent materials, such as the LC, was considered. Moreover, the use of the LC polymers enables to realize similar elements on flexible substrates with practically 100% diffraction efficiency [12, 13].

In the present work, the possibility of realizing the spatially modulated geometric phase plates with the use of the technique of the LC structuring is described.

2. EXPERIMENTAL

A technique for the recording of centrally symmetric LC phase plates with the anisotropic molecular orientation is developed. The structure of the elements is such that the orientation of the LC molecules is the same along the circuit with the constant radius and varies continuously during the transition from one circuit to another (Fig. 1). At that, the polarization diffraction grating is formed along each radius, and the orientation pattern along each diameter is symmetric with respect to the center. The elements with a planar-symmetric (Fig. 1a) and a cylindrically symmetric (Fig. 1b) distribution of the LC molecules have been realized by us. The formation of the described structures was carried out by two different methods. Let us consider each of them.

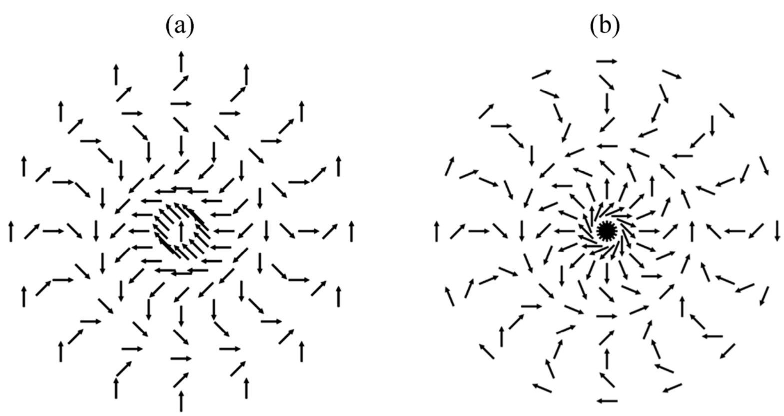

Fig. 1. Scheme of orientation of the director of the LC molecules: (a) the planar-symmetric orientation, (b) the cylindrically-symmetric orientation.

2.1. Recording of Elements with the Planar-Symmetric Distribution

The linearly polarized radiation of the helium–cadmium laser (325 nm) passing through an expander, a half-wave plate and a lens with a mask, is focused on a substrate coated with the photo-orientable orientant (Fig. 2). The lens imposed on the mask transmits light in the form of a ring. In the process of recording, the substrate is moving along the optical axis of the focused ring to the focal length, at the expense of which, the diameter of the recording light ring is reducing. The polarization of the laser