Estimation of Incident Angle Dependent Reflection Wavelength of Patterned Cholesteric Liquid Crystal Film by Using a Geometric Method

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ABSTRACT

The bandwidth of a patterned cholesteric liquid crystal is analyzed using a geometric method in which the short and long wavelength edges of selective reflection are estimated by the average refractive index of the optical path. The estimated wavelength edges approximately agree with those obtained by the finite-difference time-domain (FDTD) method.

1 Introduction

Diffractive and holographic optical elements, both isotropic and anisotropic, based on organic and inorganic materials have been proposed and investigated [1-4]. Liquid crystals (LCs) are attractive materials by which to fabricate diffractive optical elements owing to their high transparency, large birefringence and solution-processability. Patterning of the LC director, or the local orientation direction of the constituent rod-like molecules, gives rise to the Berry-phase effect, in which light acquires a phase in proportion to twice the orientation angle of the director measured from some reference axis [5-7]. Cholesteric LCs (ChLCs) in which the LC molecules self-assemble into a helical super-structure are additionally capable of reflecting light by Bragg diffraction [8,9]. The helical superstructure confers the material circular polarization selectivity, so that only polarized light having the same circular handedness as the helical structure is reflected, while the opposite polarization is transmitted. Thus, patterning of the LC director in ChLCs, or control in the structural phase of the helical structure, enables circularly polarized light to be Bragg reflected and diffracted at the same time [10,11]. After the first proposal that ChLCs can function as holographic optical elements, various beam shaping optical elements have been demonstrated and analyzed [12-19].

In this work, we focus our attention on patterned ChLC deflectors where the director is modulated linearly in the direction perpendicular to the helical axis, and examine its light transmission and reflection properties using the finite-difference time-domain (FDTD) method. We also estimate the short and long wavelength edges of selective reflection from the patterned ChLC deflector by a geometric method. The wavelength edges calculated by the proposed geometric method show good agreement with those calculated by the FDTD method.

2 FDTD simulation

Figure 1 shows a patterned ChLC, and a light ray incident on the sample at angle θ from a medium with refractive index n_1. The ChLC is defined by the ordinary and extraordinary refractive indices n_o and n_e, and helical pitch P, which is the distance over which the director rotates by 2π.

FDTD simulations were performed to calculate the optical transmittance spectra and electromagnetic field distributions for ChLCs with varying incident angle θ or slant angle α. The material parameters were set to n_o = 1.5, n_e = 1.7, and P = 500 nm. The patterned ChLC with thickness of 5 μm (corresponding to 10 helical pitches) were modeled in a medium with n_1 = 1.5, and either a CW light or a Gaussian light pulse was used for the light source. Note that in this model, θ is not the incidence angle from air but that from the surrounding medium with n_1 = 1.5. Simulations were performed using self-implemented code using mesh sizes of $\Delta x = \Delta y$ = 20 nm. At the edges of the calculation area, Mur's second-order absorbing boundary condition was imposed.

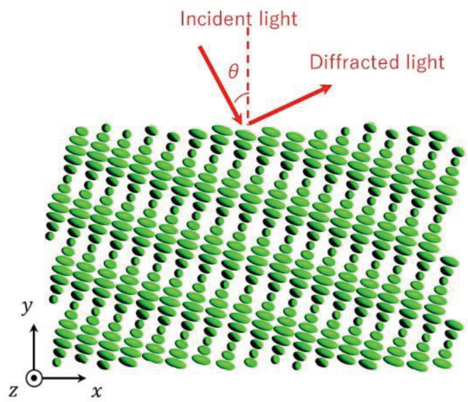

Fig. 1 Patterned cholesteric liquid crystal.

3 Results and Discussion

Figure 2 shows the calculated transmission spectra of the patterned ChLC with α = 10° for θ = 0°, 10°, 20°, and 30°. Here, we used a 45° linear polarized Gaussian pulse as the input, and obtained the transmission spectrum by calculating the Fourier transform of the temporal response.

We also estimate the bandwidth of a patterned cholesteric liquid crystal by using a geometric method in which the short and long wavelength edges of selective reflection are estimated by the average refractive index of the optical path. Figure 3 compares the angular dependence of the band-edge wavelengths of the ChLC obtained by the FDTD method and the geometric method. The wavelength edges obtained by the geometric method approximately agree with the FDTD results.

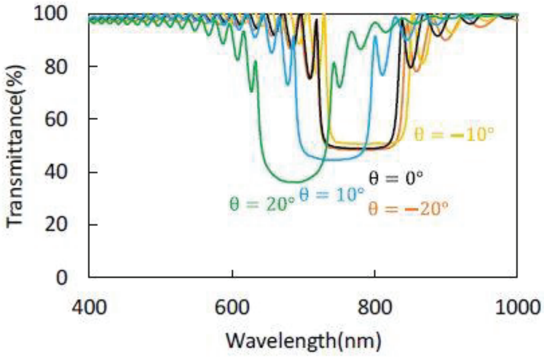

Fig. 2 FDTD calculated transmission spectra of patterned cholesteric liquid crystal for some incident angles.

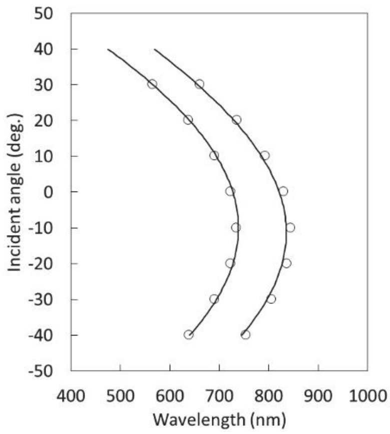

Fig. 3 Angular dependence of short and long wavelength edges of selective reflection from patterned cholesteric liquid crystal.

4 Conclusions

The angular dependence of selective reflection of a patterned ChLC have been analyzed using the geometric method and the FDTD method. The geometric method gives us a physical explanation the angular dependence of the selective reflection based on the interaction of light with the director in the ChLC. The method serves as practical tools to calculate the ChLC pitch required to realize deflectors with specific diffraction angles and bandwidths.

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