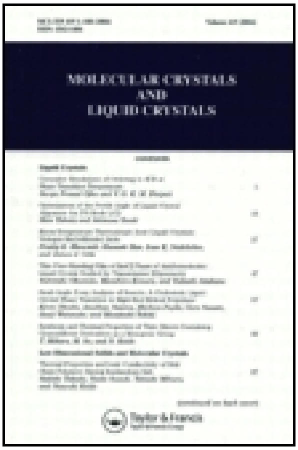

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Analysis on Fabry-Perot Interferometer using Cholesteric Liquid Crystal

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Analysis on Fabry-Perot Interferometer using Cholesteric Liquid Crystal

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Optical characteristics of a Fabry-Perot interferometer using cholesteric liquid crystal (CLC) are analyzed rigorously based on electro-magnetic wave equations. Being different from the conventional Fabry-Perot interferometer, the minimum cavity length for resonance is a quarter of wavelength, not half of wavelength. When the refractive indices of the CLC mirrors and material inside the cavity are the same, perfect circular polarization resonance with high finesse is obtained for the incident circularly polarized light.

Keywords: cholesteric liquid crystal; Fabry-Perot interferometer

INTRODUCTION

Cholesteric liquid crystal (CLC) has such a unique property as selective reflection of circularly polarized light. A Fabry-Perot interferometer for circularly polarized light was proposed by utilizing the CLC mirrors [1], and some basic experiments and simple calculations based on the matrix method have been demonstrated before [2]. However, rigorous analysis of the optical cavity based on the wave equation has not been achieved.

This paper analyzes the behavior of a Fabry-Perot interferometer using the electro-magnetic wave equation. The next section is devoted to the theory for analyzing the characteristics of the CLC Fabry-Perot interferometer. Then, we show the simulation results. Final section discusses the simulation results and concludes the paper.

THEORY

Suppose that plane light wave is incident on a right-handed helical structure of cholesteric liquid crystal (CLC) with a helical pitch of P. In the laboratory coordinate system (x, y, z) with z directed along the symmetric axis of CLC, the wave equation is given by [3] as follows,

$$\frac{\partial^2 E_x}{\partial z^2} = \frac{1}{c^2}\left\{\bar{\varepsilon}(1+\delta\cos 2qz)\frac{\partial^2 E_x}{\partial t^2} + \bar{\varepsilon}\delta\sin 2qz\frac{\partial^2 E_y}{\partial t^2}\right\}, \qquad (1)$$

$$\frac{\partial^2 E_y}{\partial z^2} = \frac{1}{c^2}\left\{\bar{\varepsilon}\delta\sin 2qz\frac{\partial^2 E_x}{\partial t^2} + \bar{\varepsilon}(1-\delta\cos 2qz)\frac{\partial^2 E_y}{\partial t^2}\right\}, \qquad (2)$$

where E denotes electric field, c the speed of light, and q is $2\pi/P$. The parameters $\bar{\varepsilon}$ and δ are $(\varepsilon_x + \varepsilon_y)/2$ and $(\varepsilon_x - \varepsilon_y)/(\varepsilon_x + \varepsilon_y)$, respectively, where ε_x and ε_y are dielectric constants of CLC along optical principal axes.

When the wavelength of the incident light λ is in the range of

$$n_L P\left(1-\frac{\delta}{2}\right) < \lambda < n_L P\left(1+\frac{\delta}{2}\right), \qquad (3)$$

the CLC layer has a high selective reflection of circularly polarized light and four eigen modes exist in the CLC. The electric field is expressed by the linear combination of these modes.

A Fabry-Perot interferometer consisting of the CLC mirrors is illustrated in Fig. 1. Under the condition that the field is successive at the surfaces of the CLC mirrors, we can determine the electric field in the CLC Fabry-Perot cavity and derive the resonance characteristics.

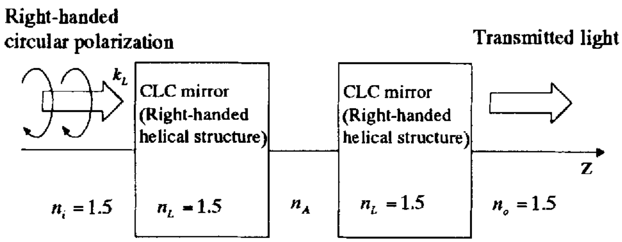

FIGURE 1 Schematic of CLC Fabry-Perot interferometer

SIMULATION RESULTS

Suppose that the molecules of the CLC have right-handed helical structure and the circularly polarized light is incident on the cavity. The helical pitch P, refractive index n_L, and index difference of CLC are 447 nm, 1.5, and 0.07, respectively. In this case, the center wavelength for selective reflection is expected to be 670 nm, since $\lambda = n_L P$.

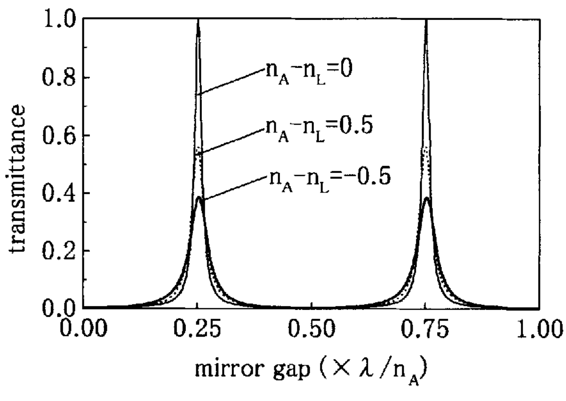

FIGURE2 Resonance curves of CLC Fabry-Perot cavity ($k_L = q$)

Under the condition that the wave number k_L is in perfect agreement with q, resonance curves of the Fabry-Perot cavity are shown in Fig. 2.

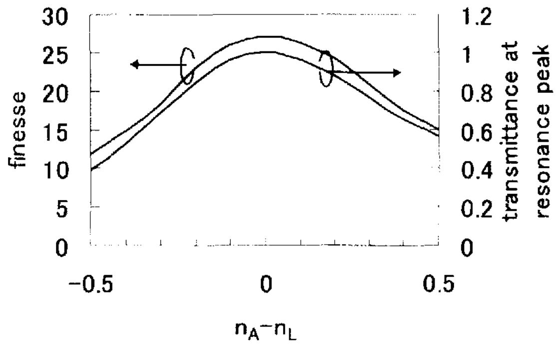

FIGURE 3 Finesse and transmittance at resonance peak ($k_L = q$)

The incident light is right-handed circular polarization. The reflectance of the CLC mirrors for right-handed circular polarization is 89 %, which corresponds to the thickness of 5.36 μm. The refractive indices of the CLC mirrors and the material outside the cavity are 1.5. Each curve is plotted for different values of the refractive index n_A of the material between two mirrors. It is different from a usual Fabry-Perot cavity consisting of conventional mirrors, in that the first resonance peak appears at mirror gap of a quarter of wavelength, not that of half of wavelength. The highest resonance peak and finesse are realized for $n_A = n_L$, that is, the refractive indices of the CLC mirrors, outside and inside the cavity are the same.

Figure 3 shows how the transmittance at resonance peak and finesse depend on the index of the cavity. As $|n_A - n_L|$ increases, both the transmittance at resonance peak and finesse decrease. They take the highest values when $n_A = n_L$.

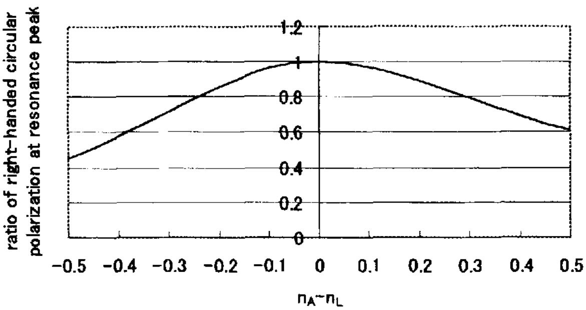

FIGURE 4 Ratio of right-handed circular polarization at resonance peak($k_L = q$)

Figure 4 shows the power ratio of the right-handed circular polarization to the output optical power. When $n_A = n_L$, only the right-handed circular polarization emits from the resonator. As $|n_A - n_L|$ increases, the ratio of the left-handed circular polarization increases and the state of polarization of the output light becomes elliptical.

Figures 2 to 4 indicate that the index matching among the CLC mirrors and the inserted material in the cavity is quite important to obtain a high-finesse resonator for circularly polarized light.

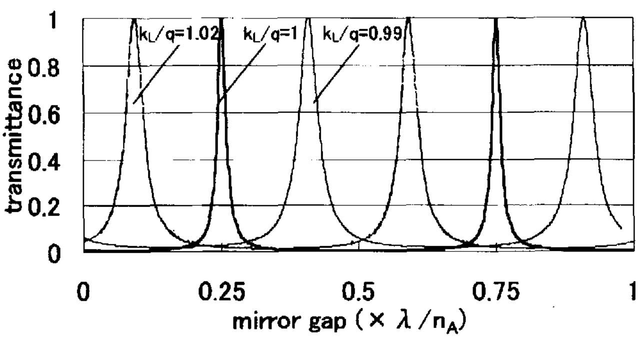

FIGURE 5 Resonance curves of CLC Fabry-Perot cavity ($n_A = n_L$)

In the following calculation, we deal with the case that $n_A = n_L$ and the wave number k_L varies around q (the wavelength λ varies around $n_L P$).

Figure 5 shows the resonance curves of the cavity. The refractive indices of the CLC mirrors and materials inside and outside the cavity are 1.5. The polarization of the incident light is right-handed circular polarization. Resonance curves are plotted for k_L/q of 1.02 ,1, and 0.99. The mirror gap is normalized by the wavelength in the cavity. The transmittance at resonance peaks is almost constant but the finesse abruptly decreases, when k_L differs from q, as shown in Fig. 6.

The output light from the cavity completely consists of right-handed circular polarization when $n_A = n_L$, even if k_L differs from q.

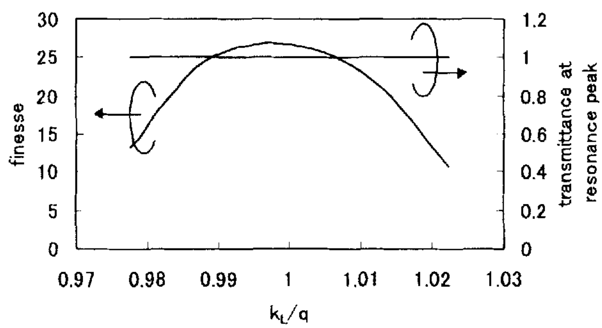

FIGURE 6 Finesse and transmittance at resonance peak ($n_A = n_L$)

DISSCUSSION AND CONCLUSION

One of the interesting characteristics of the CLC Fabry-Perot interferometer is that the minimum cavity length for resonance is a quarter of wavelength. This is explained from the phase shift at the CLC mirror. Let us consider a simple case that $k_L = q$. The phase shift of the right-handed circular polarization is $\pi/2$. Since resonance takes place when the phase rotation for one round trip in the cavity amounts to 2π, the minimum cavity length corresponds to the phase rotation of $\pi/2$, which is equivalent to a quarter of wavelength.

The important condition of the CLC Fabry-Perot interferometer is the refractive index matching between the medium inside the cavity and the CLC mirror. According to the simulation of a single CLC mirror, the left-handed circular polarization is also reflected when the refractive index of the medium outside the CLC mirror is different from that of CLC. Except for a few percent of Fresnel reflection, the left-handed circular polarization transmits through the CLC mirror to the outside, which leads to optical loss for the CLC Fabry-Perot interferometer. Therefore, by matching the index of the medium inside the cavity with that of the CLC mirrors, the high finesse cavity without optical loss can be obtained.

In conclusion, we have analyzed the characteristics of the Fabry-Perot interferometer with CLC mirrors, by using the electro-magnetic wave equation. When the refractive index inside the cavity is matched with that of CLC mirrors, perfect circular polarization resonance with high finesse is obtained for the incident circularly polarized light.

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