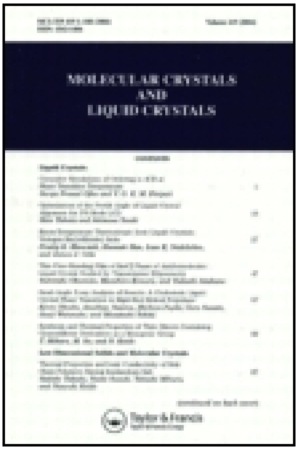

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

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

Wavelength Selection in a Fabry-Perot Filter with an Axially Aligned Nematic Liquid Crystal

Ju-Hyun Lee [a] , Hak-Rin Kim [a] , Tae-Young Yoon [a] & Sin-Doo Lee [a]

[a] School of Electrical Engineering, Seoul National University, Kwanak P. O. Box 34, Seoul, 151-742, Korea

Version of record first published: 24 Sep 2006

Mol. Cryst. and Liq. Cryst., 1999, Vol. 337, pp. 19-24
Reprints available directly from the publisher
Photocopying permitted by license only

Wavelength Selection in a Fabry-Perot Filter with an Axially Aligned Nematic Liquid Crystal

JU-HYUN LEE, HAK-RIN KIM, TAE-YOUNG YOON and SIN-DOO LEE

School of Electrical Engineering, Seoul National University, Kwanak P. O. Box 34, Seoul 151–742, Korea

A polarization-insensitive, electrically tunable Fabry-Perot filter (FP) with a nematic liquid crystal (NLC) is demonstrated. In an axially symmetrical hybrid geometry, the wavelength selection property of the FP filter is independent of the polarization state of the input light in the whole range of tuning. The alignment of a NLC between the two substrates is homeotropic at one surface and axially homogeneous on the other surface. Such alignment preserves in-plane symmetry of the input polarization state for the normal incidence, which makes the resulting transmission through the FP filter be polarization-insensitive.

Keywords: liquid crystal; wavelength selection; tunable filter

INTRODUCTION

Several types of wavelength-tuning devices are used for channel selection in high density wavelength-division multiplexing (HD-WDM) systems. One of such devices is an electrically tunable Fabry-Perot (FP) filter with a liquid crystal which allows for low operating voltage, relatively wide tuning range, and compact and easy fabrication. In a FP structure in which a LC is used as an active medium, there are several optical modes depending on the LC phase and the alignment geometry. Patel *et al.* reported on NLC-based FP tunable filters in various twisted configurations[1-4]. A ferroelectric LC can be also used as an active medium to improve the tuning speed of FP filters[5,6]. In conventional LC FP structures, the wavelength-selection property is normally sensitive to the polarization state of the incident light relative to the optic axis of the active LC layer. This makes those FP filters less attractive for practical applications such as fiber optic communications when an arbitrary polarization is involved. Therefore, a new type of a polarization-insensitive FP filter is currently one of important issues in the area of optical communications. In a space multiplexed structure[2,3] and in a highly deformed state of a twisted nematic (TN) structure[4], the polarization dependence was suppressed to some extent.

In this paper, we demonstrated a new type of a polarization-insensitive NLC-based FP filter in an axially symmetric configuration. This FP filter provides a wide range of wavelength tuning, low operating voltage, easy fabrication. Moreover, it can be implemented in a simple and compact space multiplexing scheme for optical communications.

EXPERIMENTAL

The NLC FP cell used in this study was constructed using a commercial nematic LC, E7 of E. Merck. The reflecting mirrors were made with a dielectric stack on transparent electrodes. Two different polyimides (PIs), JALS-204 for homeotropic alignment and AL-1051 for homogeneous alignment, were obtained from Japan Synthetic Rubber Co. Each PI layer was spin-coated on top of the dielectric mirror to promote LC alignment. An axially symmetric rubbing was performed on the homogeneous alignment layer so as to produce in-plane axial symmetry. The thickness of the LC medium was maintained using spacers of 50 μm thick. The FP cell configuration was shown in Fig. 1.

The light of amplified spontaneous emission (ASE) from an optically pumped Er-doped fiber laser was used as a broadband input source whose wavelength covers from 1520 nm to 1570 nm. Our NLC FP cell was characterized at room temperature using an optical spectrum analyzer (HP70952B). The voltage applied to the FP cell was generated from a

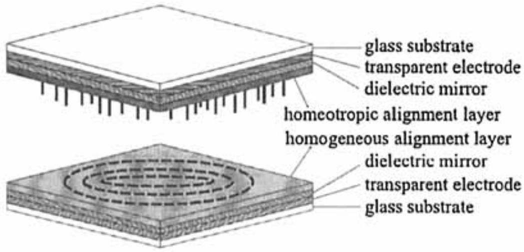

FIGURE 1 The FP cell configuration.

programmable arbitrary waveform generator (SRS DS345). The voltage used was a square wave at 1 kHz. The transmitted intensity was measured as a function of the applied voltage in steps of 0.1 V.

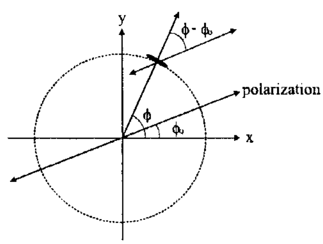

FIGURE 2 The geometry of the polarization direction.

RESULTS AND DISCUSSION

In our NLC FP cell, the LC molecules were aligned in an axially symmetric hybrid configuration. If a linearly polarized light along an arbitrary direction is incident on the FP cell, the polarization direction at any position on the cell surface can be decomposed into two orthogonal components. One is parallel to the molecular director on the homogeneous alignment layer and the other is perpendicular to the director. The perpendicular component always experiences the phase retardation associated with the ordinary refractive index of LC regardless of the applied voltage. However, the parallel component experiences the phase retardation which varies with the applied voltage through the effective refractive index of LC. This component will play an essential role in tuning the wavelength electrically.

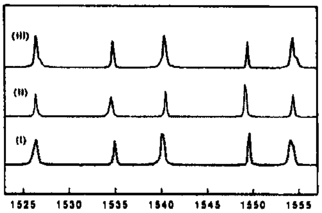

FIGURE 3 The polarization-insensitive transmitted intensities through the FP cell.

Within the elastic continuum theory, the director profiles along the direction normal to the FP cell surface (z direction) in the presence of an electric field can be calculated. The effective refractive index n_{eff} can be given in terms of the director profiles as follows.

$$n_{eff} = \frac{1}{d}\int_0^d dz \frac{n_e n_o}{\sqrt{n_e^2 \sin^2\theta(z) + n_o^2 \cos\theta(z)}} \tag{1}$$

where n_e is the extraordinary refractive index, n_o the ordinary index, and the $\theta(z)$ the tilt angle with respect to the cell surface at z. The transmitted intensity through the FP cell is given by the following multiple beam interference equation.

$$T(\lambda) = \frac{t^2}{(1-r)^2} \frac{1}{1 + \frac{4r}{(1-r)^2}\sin^2\left(\frac{2\pi}{\lambda} nd\right)} \tag{2}$$

where t and r are the coefficients of transmission and reflection, respectively. The wavelength of the incident light is denoted by λ. The refractive index and the thickness of the medium are represented by n and d , respectively.

Let us now consider the geometrical configuration of the polarization direction as shown in Fig. 2. Suppose that the angle between the polarization direction of the incident light and the x axis in the laboratory coordinate system is ϕ_o. The polarization at an arbitrary position where the radial direction makes an angle of ϕ to the x axis is described in terms of two components, parallel $[\sin(\phi - \phi_o)]$ and perpendicular $[\cos(\phi - \phi_o)]$ to the molecular director. The corresponding transmitted intensities, $T_{n_{eff}}$ and T_{n_o}, are then calculated from Eq. (2) by replacing n by n_{eff} and n_o. Accordingly, the total transmitted intensity is given by

$$T(\phi) = \sin^2(\phi - \phi_o)T_{n_{eff}} + \cos^2(\phi - \phi_o)T_{n_o}. \tag{3}$$

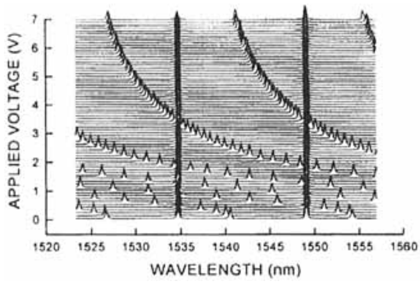

FIGURE 4 The wavelength-selection properties of our FP cell as a function of the applied voltage.

Thus, the average transmitted intensity over the whole area enclosed by the circumference is given by $< T >= \frac{1}{2\pi}\int_0^{2\pi} T(\phi)d\phi = \frac{1}{2}(T_{n_{eff}} + T_{n_o})$. Here, $T_{n_{eff}}$ and T_{n_o} will possess resonance peaks in the transmission spectrum as a function of the wavelength. The peak position is determined by the resonance condition $m\lambda = 2nd$, where m is the mode number. For $T_{n_{eff}}$, the peak position varies with the applied voltage, meaning that wavelength-tuning is achieved. For T_{n_o}, however, the peak position stays fixed since n_o is constant. Thus, T_{n_o} has a fixed free spectral range (FSR) which limits the tuning range of our FP cell when used as a wavelength-tunable filter.

The FSR and the positions of resonance peaks are controllable in terms of the cell thickness and NLC material parameters. Note that $< T >$ is insensitive to the input polarization state, i.e., independent of ϕ_o, by in-plane axial symmetry. This theoretical prediction was experimentally confirmed as shown in Fig. 3; (I), (II), and (III) correspond to the cases that the angle between x axis and the polarization direction are 0°, 45°, and 90°, respectively.

In Fig. 4, the wavelength-selection properties of our FP cell for two optical modes, associated with $T_{n_{eff}}$ and T_{n_o}, are shown as a function of the applied voltage. The experimental results agree with the simulations with parameters of $r = 0.95$, $n_o = 1.5058$, $\Delta n = 0.1742$, and $d = 53$ μm,

CONCLUDING REMARKS

We have demonstrated a new type of an electrically tunable, polarization-insensitive NLC FP filter in an axially symmetric configuration. In addition to the polarization independence, this filter is simple and compact and provides easy fabrication so that it may be integrated into a high density WDM optical network as well as an optical signal processing system in the wavelength domain.

Acknowledgements

This work was supported in part by SNU Korea Electric Power Corp.

References

[1] J. S. Patel, M. A. Saifi, D. W. Berreman, C. Lin, N. Andreadakis, and S.-D. Lee, Appl. Phys. Lett. **57,** 1718 (1990).

[2] J. S. Patel and M. W. Maeda, Photonics Technology Letters, **3,** 739 (1991).

[3] J. S. Patel, Appl. Phys. Lett. **59,** 1314 (1991).

[4] J. S. Patel and S.-D. Lee, Appl. Phys. Lett. **58,** 2491 (1991).

[5] J. S. Patel, Opt. Lett. **17,** 456 (1992).

[6] W. K. Choi, A. B. Davey, T. D. Wilkinson, and W. A. Crossland, Mol. Cryst. Liq. Cryst. **304,** 329 (1997).