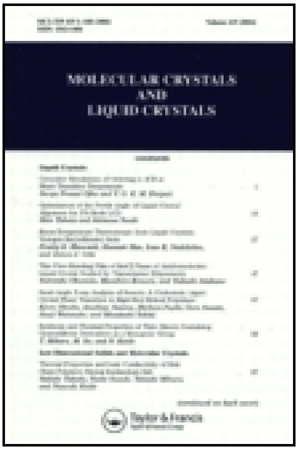

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Effect of Axial Symmetry on the Polarization Dependence of a Liquid Crystal Fabry-Perot Tunable Filter

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We have demonstrated an electrically tunable nematic liquid crystal Fabry-Perot (NLC FP) filter which is completely insensitive to the input polarization in the whole range of tuning. The NLC molecules are aligned in a hybrid configuration with axial symmetry. An additional transparent layer of the UV curable polymer between two substrates improves the wavelength selectivity as well as the tuning speed.

Keywords: nematic liquid crystal; tunable filter; axial symmetry; polarization insensitive

INTRODUCTION

There have been many research activities on high-density wavelength division multiplexing (HD WDM) network to accommodate increasing data transmission. Since it is of great importance to select a desired wavelength from available channels in WDM networks, tunable filters and several types of wavelength tuning devices are proposed to meet this demand. For practical applications, tunable filters need the characteristics of a wide tuning range, maximizing the number of tunable channels, high wavelength selectivity avoiding crosstalks between selected channels, fast tuning speed, low power consumption, stability, and low manufacturing cost. Of particular importance is polarization insensitive wavelength selection of the tunable filter because the polarization states of light in the fiber are generally arbitrary.

Considering the above arguments, a liquid crystal Fabry-Perot (LC FP) filter can be one of candidates in many respects. However, conventional LC FP filters are polarization sensitive because of the uniaxiality of a LC in itself and the other performances such as the tuning speed and the bandwidth are poor in the current state of art. In order to overcome these problems, we demonstrate a new type of a polarization insensitive FP filter in an axially symmetrical hybrid configuration of a nematic LC (NLC) with an additional transparent layer of the UV curable polymer between two substrates. In this structure, the NLC FP filter can be easily scalable into arrays with axial symmetry through an appropriate photo-masking process.

STRUCTURE & PRINCIPLE

In a general FP filter, the transmittance at a given wavelength λ for radiation incident normal to the surface of the FP cell is given by

$$Tr(\lambda) = \frac{T^2}{(1-R)^2} \frac{1}{1 + F\sin^2(\frac{2\pi nd}{\lambda})}, \tag{1}$$

where R and T are the reflectance and the transmittance of a single mirror substrate, respectively. The refractive index and the thickness of the active medium are denoted as n and d, repectively. Here, F is the finesse coefficient determining the sharpness of a selected peak. It can be seen from Eq. (1) that two orthogonally polarized eigenmodes corresponding to the ordinary and extraordinary refractive indices, n_o and n_e, respectively, experience different optical paths in a conventional NLC FP filter with homogeneous alignment. Therefore, the wavelength selection through such FP filter depends on the relative angle of the LC director to the polarization direction of the incident light. In contrast, a LC FP filter with a director distribution preserving axial symmetry with respect to the propagation direction has the characteristic of the polarization insensitive wavelength selection[1]. The polarization insensitive configuration is shown in Figure 1. Compared to a planar concentric configuration, it has a simple process of assembling a FP cell.

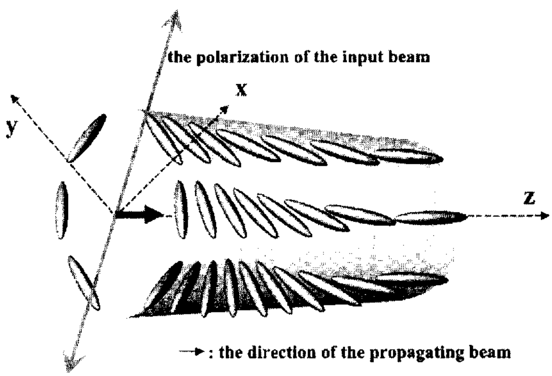

Figure 1 A hybrid configuration with axial symmetry.

We propose a new FP structure which has an additional transparent layer as shown in Figure 2. In order to improve the bandwidth of the FP filter, the cavity gap must be increased. However, this results in large optical loss due to inhomogeneity in the alignment of the LC layer, reduction in the free spectral range, and slow response[2, 3]. For improving the bandwidth and the tuning speed, and for reducing the optical loss simultaneously, the UV curable polymer layer is formed in the FP filter. As shown in Figure 2, this structure has an advantage of scalability through a patterned photo-mask process. The scalability is not normally achievable by the mechanical rubbing process.

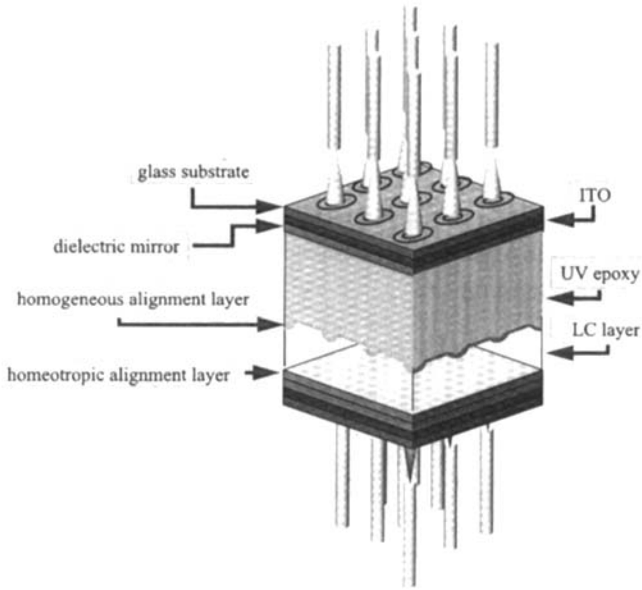

Figure 2 The axially symmetrical NLC FP filter with a transparent layer.

EXPERIMENTAL

A polarization insensitive NLC FP cell was made with transparent indium-tin-oxide (ITO) coated glass substrates. Dielectric mirror stacks, which provide multiple reflections in the cavity by 99% in the wavelength range between 1.45 μm and 1.65 μm, was deposited onto the ITO electrodes. The UV curable polymer, NOA 60 (n=1.56, Norland Products, Inc.), was subsequently spin-coated and cured by

UV radiation onto one of the substrates. JALS-204 (Japan Synthetic Rubber Co.) was used for homeotropic alignment on the polymer layer. The phase matching condition between the ordinary refractive index of LC and the refractive index of polymer should be considered. On the other substrate, AL-1051 (Japan Synthetic Rubber Co.) was coated and then rubbed to promote axially symmetric alignment of the LC molecules. The tuning characteristics of the FP filter may be improved by non-contacting symmetric alignment which reduces the surface roughness. A commercial nematic LC, E7 (E. Merck, n_e : 1.72, n_o : 1.51) was filled into the FP cavity as an active medium. The thickness of the LC layer and the polymer layer were 5 μm and 44.5 μm, respectively.

RESULTS & DISCUSSION

The experimental results for wavelength selection through our FP filter is shown in Figure 3. Figure 3 (a) shows the optical transmittance of the unpolarized light, and Figure 3 (b) shows that of the p–polarized light. There are two types of resonant peaks in the transmission spectra, one of which can be tuned by an applied voltage while the other is fixed. The two types of the resonant peaks, corresponding to two optical modes, are associated with the ordinary and extraordinary refractive indices, respectively. The transmittance has a fixed free spectral range (FSR) which limits the tuning range of the FP cell. The FSR measured is about 15 nm in this study. The tuning range is about 8 nm. Such characteristics together with the resonance peaks can be controlled by adjusting the cell thickness and the LC material parameters. There exists no threshold for the Fredericks transition, and thus, a continuous wavelength selection can be achieved in the hybrid configuration. The features shown in Figure 3 (a) agree well with those in Figure 3 (b) except for the fact that the transmittance of one component is generally suppressed. There is no difference in the resonant peak wavelengths for different polarization states. However, the total transmittance varied due to anisotropic optical loss. In reality, the polarization dependent loss (PDL) derived from anisotropic loss can be avoided by precise fabrication or noncontacting alignment with no surface defects. The operation voltage is somewhat high due to the presence of the large dielectric constant of the additional polymer layer.

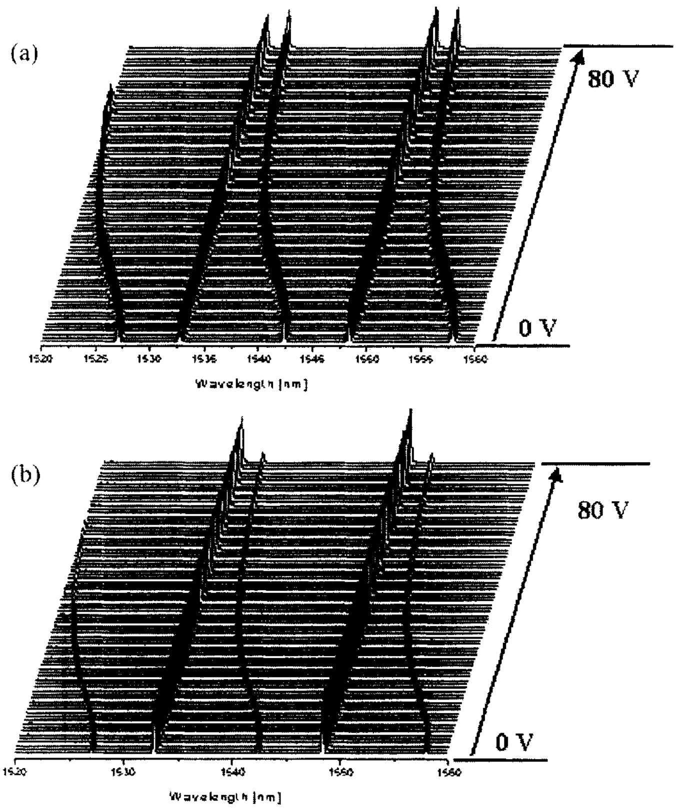

Figure 3 Optical transmission through our FP cell at various applied voltages
(a) for the unpolarized input beam (b) for the p-polarized input beam.

Figure 4 shows the polarization insensitive wavelength selection for three different states of the input polarization by the application of the same voltage. As expected, all three cases exhibit identical results for wavelength tuning. It may be then concluded that our hybrid aligned FP cell with axial symmetry is indeed polarization insensitive. In Figure 4, the deviation of the resonant peaks at different input polarization is less than 0.05 nm in the whole wavelength range.

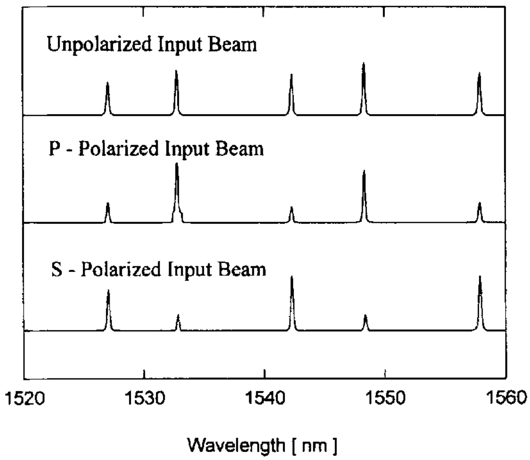

Figure 4 The polarization insensitive wavelength selection through the FP filter for three different polarization states.

It is clear that all of the transmittance (low optical loss), FWHM, and the tuning speed are much improved when the polymer layer is additionally used. While for FWHM of 0.5 nm, the thickness of a FP cell with no polymer layer is 53 μm[1], for FWHM of about 0.2 nm, the newly designed FP filter requires the thickness of 49.5 nm under the same fabrication conditions. In our new FP filter, more channels can be easily implemented.

CONCLUDING REMARKS

We demonstrated an electrically tunable NLC FP filter which is completely insensitive to the polarization of the input beam. The FP filter was realized in an axially symmetrical hybrid configuration of the LC layer as an active medium. A transparent layer of the UV curable polymer is introduced to improve the wavelength selection properties of the FP filter. The FP filter represented here is expected to play an important role in constructing WDM network systems and in other applications such as laser stabilization, frequency reference, and spectrum analysis.

Acknowledgments
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