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LIQUID CRYSTAL DEVICES AND DEVICES FOR LIQUID CRYSTAL RESEARCH.

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Abstract In this paper we focus on liquid crystal Fabry-Perot as a liquid crystal device which can also be used to obtain information about the liquid crystal materials used in these devices. The paper outlines the evolution form the simple need of such a device to the construction and testing which led to some unexpected results. Through analysis of these results a better insight in to the working of these devices further led to other interesting structures and eventually to the use of this structure to obtain information about liquid crystal materials in absence and presence of electric field.

INTRODUCTION

The technological benefits of the developments in the field of liquid crystals is evident by the existence of a variety of consumer products that use these materials in displays ranging from simple indicators to sophisticated color lap-top computers. The scientific break throughs in this field is equally impressive, with discoveries of new phases with different structures from antiferroelectrics to twist grain boundary phases. Other structures such as polymeric liquid crystal gels and large macro-molecules may also lead to unique structures and eventually to unique application of these materials. To a degree, however the engineering and the scientific efforts are disjointed, due simply to the nature of these sciences which require in-depth focus on different aspects of the problems. On the scientific front, the complex engineering issues that have to be considered are often disregarded with focus on the investigating whether a particular concept is true or not. Similarly on the engineering front the fundamental issues are often disregarded and assumed to be true, instead issued such as reliability and the ease of use becomes the central focus.

Although one can not exist without the other, it often becomes necessary to focus on one or the other task, even though it is well recognized that some combination of both is needed particularly for industrial research. While it is necessary to focus on the task at hand it is often rewarding to pursue interesting observation that can lead to fascinating discoveries. In this article we will discuss my experience of making a simple liquid crystal device that lead to a better understanding of the working principles of this device and how this knowledge was used to gain insight of the electric field effect and the structure of liquid crystals.

NEED FOR OPTICAL FILTERS

The goal was to make a tunable optical filter that can select a single wavelength from a group of incoming wavelengths, much as a spectrometer does, but in a much more cost effective and a compact way. The ability to select a desired wavelength channel from a range of available wavelength channels is of great interest for advanced lightwave systems. This is particularly true for high-density wavelength-division-multiplexed (HD-WDM) networks[1] in which components capable of wavelength selections are crucial. While several devices have been proposed to achieve this wavelength selection[2,3,4,] most require significant power to operate or have complex design. For example, certain acousto-optic tunable filters require about 10 watts of power[5,] although recent work suggests that these requirements can be relaxed[6].

An interesting structure that can perform this task is a Fabry-Perot structure which lets through only that wavelength which is resonant with the cavity. Tuning this wavelength requires adjusting the optical cavity length with can be done either by physically changing the gap between the two mirrors or by changing the effective refractive index, preferably using an electric field. It is convenient to construct a device in which the gap is maintained, and tuning is achieved by changing the refractive index in the cavity. Thus liquid crystals are attractive candidates for this application since the index can be changes by applying an electric field.

LIQUID CRYSTAL FABRY-PEROT FILTERS

The use of liquid crystals as an electro-optic material in a Fabry-Perot cavity is therefore an attractive solution to this problem. Thus liquid crystal Fabry-Perot filters (LCFP) can be thought of as active optical devices that permit only a narrow band of optical wavelengths to pass while rejecting all other wavelengths. The physical principle is based on the Fabry-Perot resonator which consists of two parallel dielectric mirrors separated by a medium whose refractive index can be changed. The resonator only transmits a narrow range of wavelengths that are determined by the intra-cavity refractive index, the length of the cavity, and the reflectivity of the dielectric mirrors. By electrically changing the intra-cavity refractive index, the wavelength transmitted through the Fabry-Perot can be changed. In LCFPs, the required change in the cavity resonance conditions are produced by the application of an electric field that induces reorientation of the long axis of the liquid crystal molecules which results in the change of the cavity index. The structure of such a device is shown in figure 1. which shown the simplest geometry in absence of any applied field and where the two surfaces have the molecules oriented parallel to each other.

These devices can be constructed using fabrication standard techniques in the liquid crystal industry, except for the coating of the dielectric mirrors on top of the conductive electrodes and the power requirements are comparable to those for ordinary liquid crystal displays used in calculators and watches. While high finesses resonant cavities require that the two mirrors to be exactly parallel to each other the use of small beams as in the case of fiber-optics, greatly simplifies the construction of these resonators.

Such devices were constructed using commercial nematic liquid crystal E7. The reflectors were made by using a dielectric stack. The electric field was applied to the liquid crystal using transparent indium tin oxide electrodes which were deposited on the glass plates prior to the deposition of the dielectric mirror stacks. An thin alignment layer was deposited on top of the dielectric mirror to promote alignment of the liquid crystal molecules[7].

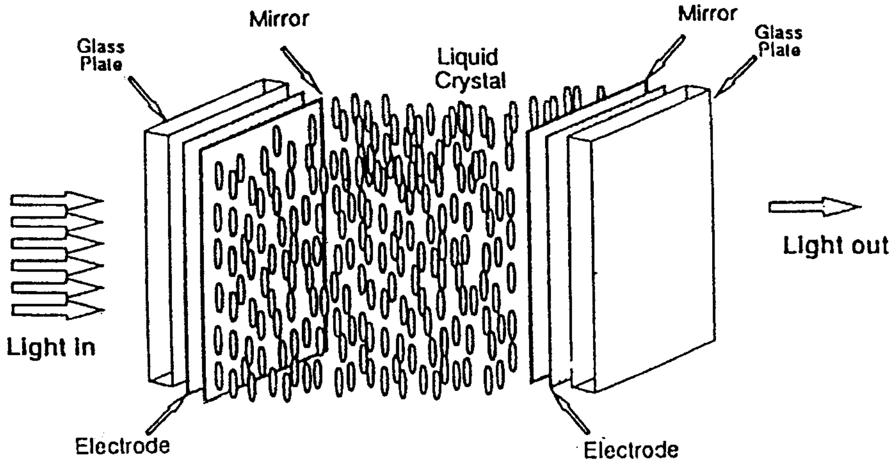


FIGURE 1. Structure of Liquid Crystal Fabry-Perot Device

Typical results for light transmission through such a structure is shown in figu 2. The data shows that one of the resonance is unaffected by the application of t field, while the other changes with the field. This results from the birefringent nature the liquid crystals, which results in two optical cavity lengths for the same physic length. This is because light experiences two different refractive indices, depending the input polarization of the light. For light polarized along the long axis of t molecules, the tilting of the molecules towards the propagation direction would result an increase in the refractive index. On the other hand, for light polarized along t short axis of the molecules there is no change in the effective cavity length due to t tilting of the molecules towards the light propagation axis. Note that the tilting of t molecules is achieved by the application of the electric field across the liquid crys cell.

The resonance condition can be obtained by the simple relationship $m\lambda=$ where m is the mode number d is the thickness and n is the effective index of material in the cavity. Since the refractive index of liquid crystals is typically in the range of 1.5 to 1.7. light with wavelength of 1.5μm will pass through the filter when the gap is of the order of 10 μm and the etalon is used in the 20th order. In this wavelength region, the free spectral range for a 10 μm etalon would be about 75 nm

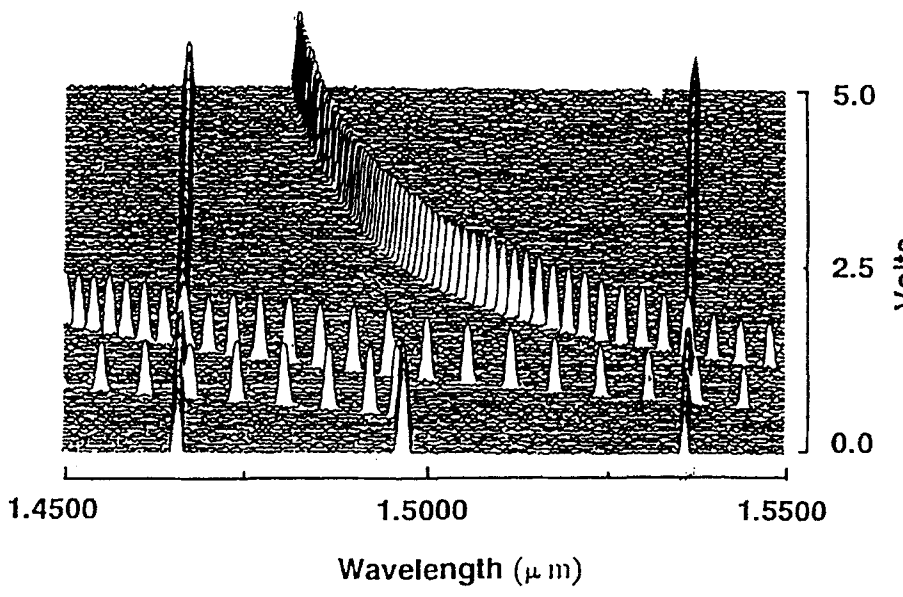


FIGURE 2. Position of the transmission peaks in the unpolarized spectrum as a function of voltage for a 11.32 μm liquid crystal Fabry-Perot etalon.

Thus the construction of this device revealed no new physics since the resonances occur as predicted by the simple relationship $m\lambda = nd$. Furthermore it is easy to show that the mode spacing should decrease with increase in the gap between the two mirrors. However in attempting to verify this experimentally we were surprised to find that the observed behavior was completely unexpected and much more complicated as shown in figure 3. This, as we discovered latter, was due simply to th error in construction of the device, but a fortunate error which led us to interestir insight into the working of the Fabry-Perot.

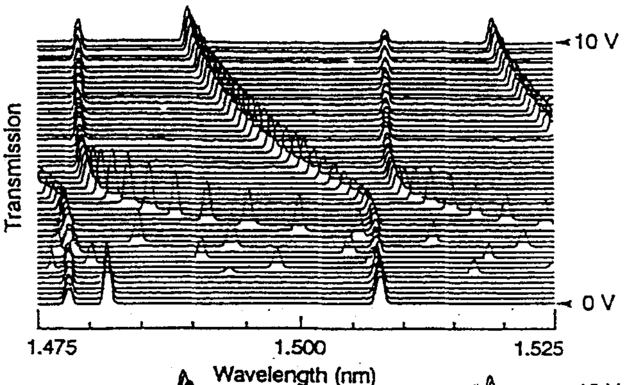
FABRY-PEROTS CONTAING LIQUID CRYSTALS WITH TWISTED STRUCTRE

It can be shown that in cases where the director at the surfaces are no longer parallel each other, the eigen modes in the Fabry-Perot are no longer linearly polarized eige states. Instead the eigen states of the twisted structures are elliptical modes in gener and these can be obtained to explain the results shown in figure 3, which resembles th calculations using a simple model[8] published earlier. The results of these calculatio are shown in figure 4. It is possible to simulate the results exactly using more exa calculations as we have done in the past.[9] These results shown that the in the case birefringent material in an optical cavity, the results are more complicated especially f cases where the birefringent material forms a twisted structure. Furthermore, in th high field regime, when the tilt of the molecules in the middle of the cell is tilted suc that it is perpendicular to the surface, then the continuos twist from top to bottom pla disappears and the structure can be approximated by just two wave plates which a arranged such that the angle between the two wave plates is offset between the rubbir axis at the two surfaces.

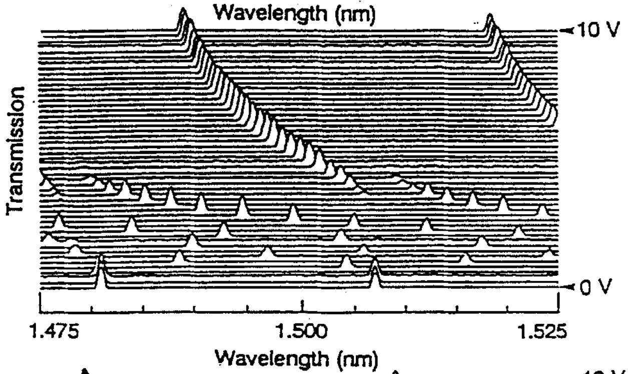
POLARIZATION INSENSITIVE STRUCTURES

One of the important issues for any real optical communications device is that if at a possible it should be polarization insensitive, because polarization dispersion can lea to lowering of the transmission bandwidth. It is clear from the results described in th previous paragraph that by using a twisted nematic liquid crystal structure with 9 degree twist within the Fabry-Perot cavity, it may be possible to obtain a polarizatio insensitive structure in the high field limit. At high fields the twisted structure can b considered to be composed of two birefringent layers, with their principal axis

(a)



(b)



(c)

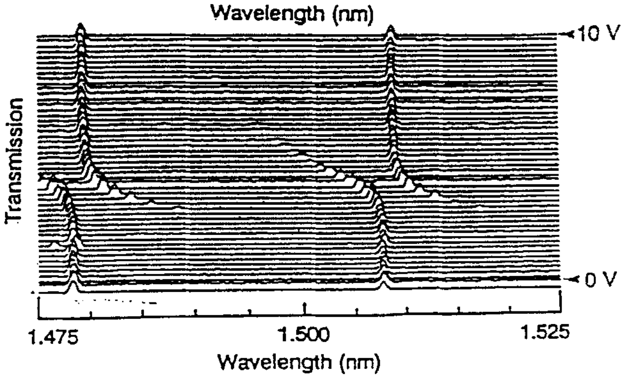


FIGURE 3. Experimentally observed Position of the transmission peaks for (a) unpolarized spectrum , (b) polarized spectrum and (c) orthogonally polarized spectrum as a function of voltage for about 30 μm liquid crystal Fabry-Perot etalon.

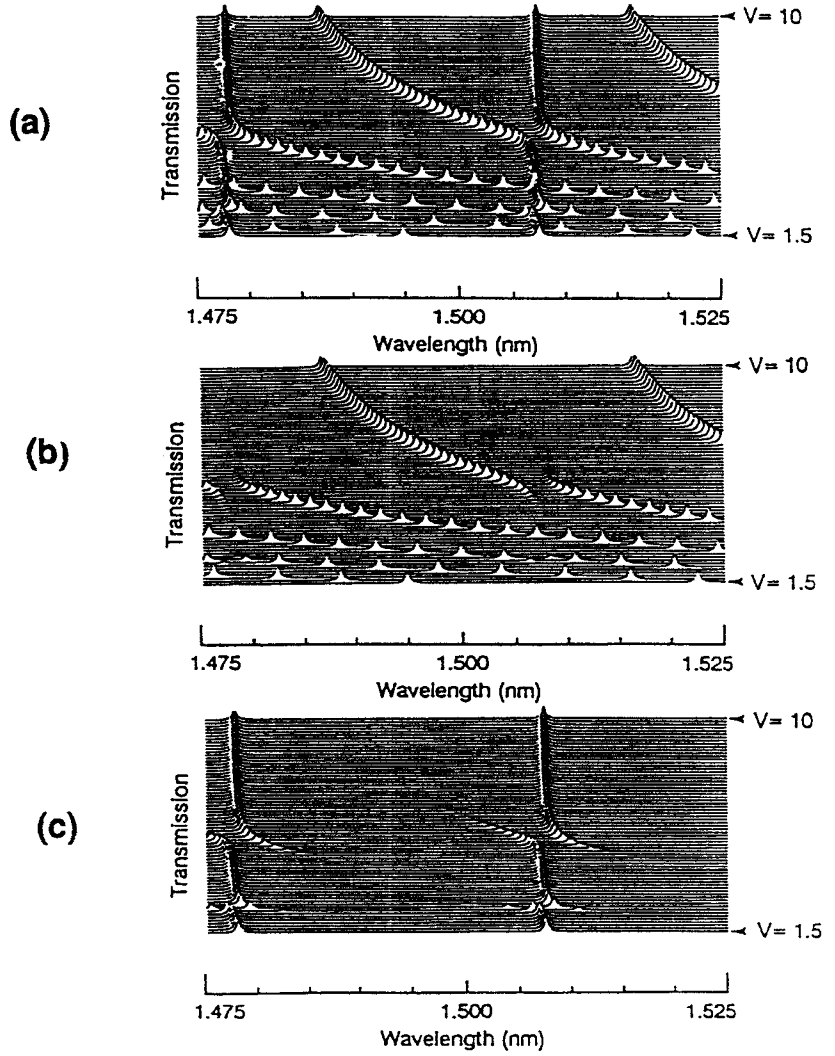


FIGURE 4. Calculated position of the transmission peaks for (a) unpolarized spectrum , (b) polarized spectrum and (c) orthogonally polarized spectrum as a function of voltage for about 30 μm liquid crystal Fabry-Perot etalon.

orthogonal to each other. In this situation it is easy to show that the two eigenvalues are the same for the eigenvectors corresponding to two orthogonally polarized input light directions. The results of such an experiment is shown in figure 5 which shows the polarization independent operation of the liquid crystal Fabry-Perot.

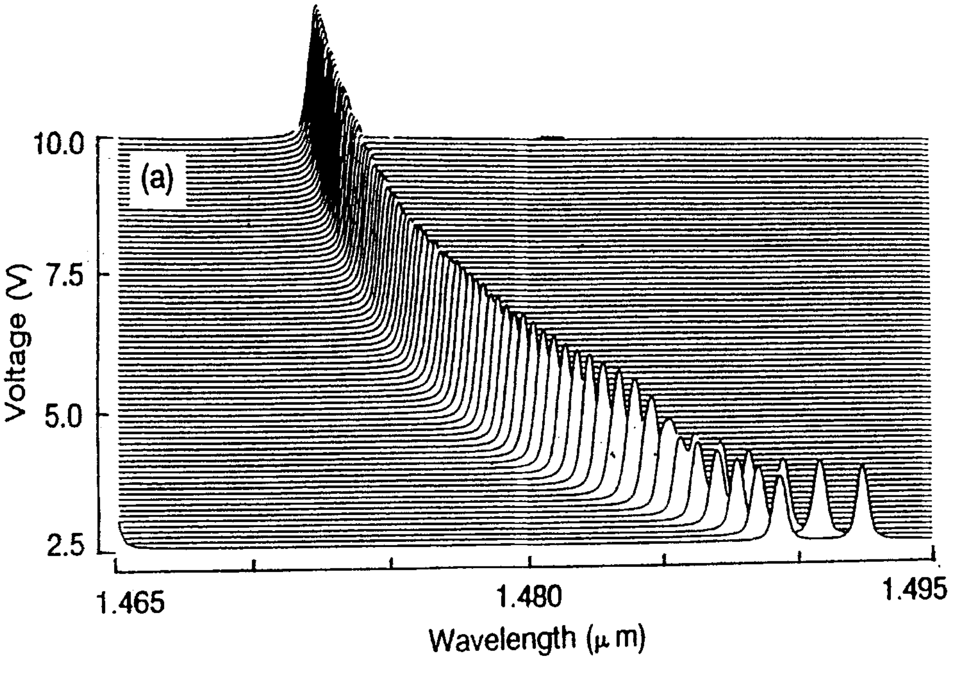


FIGURE 5. Position of the transmission peaks for 90 degrees twisted structure in a Fabry-Perot cavity as a function of voltage.

ANALYSING TWISTED STRUCTURES

By comparing the results of the optical resonances produced due to a twisted and an untwisted structure, shown in figure 2 and 5, it is clear that in the case of untwisted structure, one of the resonance modes does not change while in the twisted case, both the modes are affected by the applied electric field. This observation can be used as a diagnostic tool for exploring the existence of twisted or untwisted structure in unknow cases as was recently done in the case of inverse twisted nematic liquid crystal device.

In this case we ask the question: Is it possible to produce a twisted nemat structure which is twisted in presence of an applied electric field and untwisted absence of an applied field. To answer this question we constructed a Fabry-Per device in which the inner surfaces of the dielectric mirror were coated wi octadecyltriethoxy silane and unidirectional rubbed with the rubbing axis perpendicul to each other at the two surfaces, prior to filling the cell with material with negati dielectric anisotropy. The idea was that in absence of an electric field, the homeotrop boundary conditions would prevail, while in the presence of the electric field, the lo axis would be in contact with the rubbed surface and would produce the twist structure. The experiment showed that the twisted structure could not be obtained usi the condition employed in our experiments[10]. The results indicated that the structu was infact untwisted even when the two surfaces had been rubbed orthogonally due the weak anchoring conditions at the surfaces which could not support the twist structure.

TUNING SPEED AND TWISTED SMECTIC STRUCTURES

The speed at which these resonances can be tuned depends on how rapidly t molecules can be re-oriented within the cavity. Using nematic liquid crystals this r orientation speed is limited, although it is possible to go off resonance in less then microseconds using ordinary nematic liquid crystals.[11] The use of faster switchi ferroelectric liquid crystals is a possible solution to increase the tuning speed. T structure of the ferroelectric is however not easy to use within the Fabry-Perot cavit This is because at larger thickness the defects in attenuated the light, while at small thickness, the bistable nature of the switching limits the tuning between one or the oth wavelength. This led us to conceive the twisted smectic structure which can be used produce somewhat continuos variation in phase as a function of applied field.

although the tuning range was somewhat limited. This structure also led us to the twisted ferroelectric liquid crystal modulator which has the fast switching speed of ferroelectric liquid crystals and the gray scale capability of the twisted nematic liquid crystal displays. The analysis of the optical properties of these structures also led us to speculate on the importance of optical biaxility in explaining the observed behavior of this device.[13]

The possibility of biaxiality in discotic liquid crystals has also been of interest for some time and there are reports suggesting evidence of this in the literature. Recently using discotic liquid crystal in a Fabry-Perot cavity, we have investigated this question and found that there is no evidence of biaxility at least in the case of materials that we have examined.[14]

SUMMARY

In this paper we show, using Liquid Crystal Fabry-Perot as an example, how the knowlege gained from making and understanding of these devices can be applied to investigate unknown liquid crystal structures.

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REFERENCES

1. Chinlon Lin, H. Kobrinski, A. Frankel and C. A. Brackett, Electron Letts., B 24, 1215, (1988)
2. S. E. Harris and R.W. Wallace, J. Opt. Soc. Am., 59,744,(1969)
3. H. Toba, K. Oda, N. Takato and K. Nosu, Electron Lett., 23, 788, (1987)
4. A. Frenkel and Chinlon Lin, J. of Lightwave Technology, 7,615 (1989)

5. J. Stone and L. W. Stulz,Electron Lett., 23, 781, (1987)
6. B. L. Heffner, D. A. Smith, J. E. Baran, A. Yi-Yan and K. W.Cheung, Elect. Let 24,1562 (1988)
7. J. S. Patel, T. M. Leslie and J. W. Goodby, Ferroelectrics, 59,129 (1984).
8. J. S. Patel and Y. Silberberg Opt. Letts., 16, 1050, (1991)
9. J. S. Patel and Y. Silberberg, Mol. Cryst. Liq. Cryst., 223, 151, (1992)
10. J. S. Patel and G. B. Cohen, Appl. Phy. Lett. (to be published) (1996)
11. J. S. Patel, Liquid Crystal Materials, Devices and Applications, Eds. Paul Drzaic and Uzi Efron SPIE 244,1665 (1992).
12. J. S. Patel , Opt. Lett., 17, 2456,(1992)
13. V. Pertuis and J. S. Patel, Ferroelectrics, 149, 1095, (1994)
14. J. S. Patel, K. Praefcke, D. Singer and M. Langner. Appl. Phys., B 60, 469 (199