Colorful Liquid Crys tal Fil ter Abstract Color filters are very important components for optical equipment. Basically,color filters are made of high-density glass or isinglass. They can select a certain part of aspectrum before further processed.However,the transmitting spectral band is usually fixed. In Transmitting spectral band is usually fixed. In traditional color filtera. A different filter has to be used if one would like to select a different spectral band. This way is some what Inconvenient. In this study, we design and develop an adjustable color filter by making use of the optical activity dispersion(OAD)in quartz and birefringence of the liquid crystal (LC) under the in flu ence of ap plied electric field. The LC filter which is consisted by one OAD plate,one LC shutter,and two polarizers is set up.The theoretical numerical calculation using Jones maxtrix is per formed based on this configuration for guidance,and the char ac ter iza tion experiments of the LC filter are also carried out . The results verify that an spectral band tunable filter could be developed by this method. The intensity dis tri bu tion of the transmission spectrum world then possess the cos pattern. Furthermore,if multiple passes are employed,the spectral distribution will then be,with n being the total number of passes. Finally,an electrid field tunable color filter is extremely useful for the application on optical process. 2 1.Motivation Color filters are useful and important com po nents in a lot of applications, such as imaging de vic es and optical instruments. They are used to se lect the desired portion of a spectrum from the in ci dent beam before further processing. However, the trans mit ting bandwidth of them are often fixed in con ven tion al color filters. A different filter has to be used to change the transmitting spectral band. Thus, it is of great interest to have a tun able color filter. Optical activity was discovered in 1811 by Biot . The measurement of it is often used to de ter 1 mine the concentration of optically active ma te ri als such as glucose. In this study, we propose to make use of the dispersion of optical activity in quartz and the tuning capability of liquid crystal display (LCD) devices to develop a tunable color filter.2.Purposes (1) In this investigation, we want to explore the feasibility in using a LCD plate to rotate the po lar iza tion plane of the incoming light. 2 3

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(2)We then develop a tunable bandpass color fil ter that can be adjusted by changing the ap plied voltage on th 3.Equipments A.Two polymer polarizers B.One liquid crystal display plate C.One quartz plate (Its surface cut optic axis as shown in Fig.1) D.One spectrometer (Grating & CCD) E.One Programmable Voltage Source F.Tv G.halogen light source (S) 4.Theory and Computation Algorithm The basic operational principle of the optical transmission coefficient can be de scribed by Jones Matrix as following: 2 1

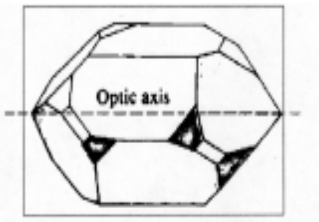

Fig.1 (

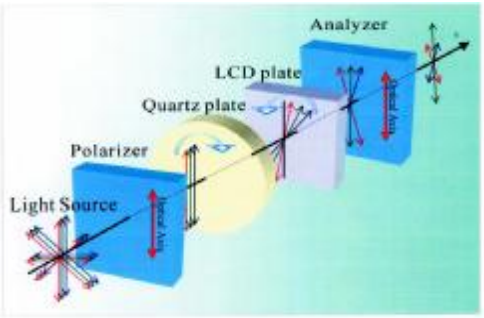

Fig.2 Schematics of a tunable color filter setup.

$$T = \cos^{2p}(\rho -$$

$$I_T = \cos^{2p}(\frac{\pi d}{\lambda}(n_R -$$

$$\begin{pmatrix}\text{Transmission}\\ \text{coefficient}\end{pmatrix}=\begin{pmatrix}X\\ \text{Polarizer}\end{pmatrix}\begin{pmatrix}\text{LCD}\\ \text{Device}\end{pmatrix}\begin{pmatrix}\text{Quartz}\\ \text{plate}\end{pmatrix}\begin{pmatrix}X\\ \text{Polarizer}\end{pmatrix}$$

$$T=\frac{I_o}{I_i}=\left(\begin{bmatrix}1&0\\0&0\end{bmatrix}\begin{bmatrix}e^{i\phi}&-ie^{i\phi}\\-ie^{i\phi}&e^{i\phi}\end{bmatrix}\begin{bmatrix}e^{i\psi}&-ie^{i\psi}\\-ie^{i\psi}&e^{i\psi}\end{bmatrix}\begin{bmatrix}1&0\\0&0\end{bmatrix}\right)^2$$

The LCD plate functions as a voltage con trol la ble wave plate. An ro ta tion al an gle of the polarization plane on LCD plate as a func tion of applied voltage. ,where d is the t quartz plate, λis the wave length of the incoming beam. For neg a tive ly ac tive quartz, nR-nL is a constant number of round-trips. The results of Jones matrix transformation can also be expressed by the following equat in numerical simulation.5.Methods (1) Numerical simulation is performed according to the theory described in and the flow chart of the numerical calcula-tion is shownin Fig.3.(2) The schematic diagram of the setup is sho transmitting spectra at various voltages were measured by a spectrometer and pho to graphs of the setup is dis p8. $\rho=\frac{\pi d}{\lambda}(n_R-n_L)$ -5

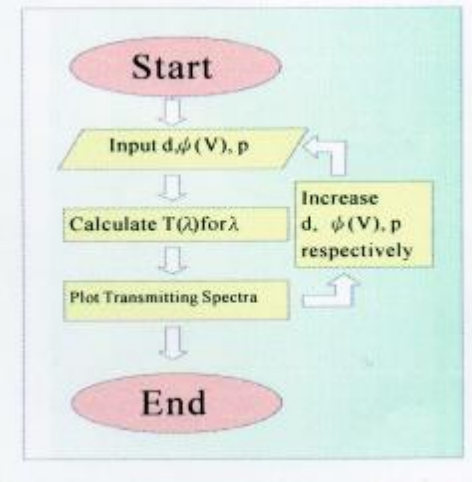

Fig.3 Flowchart of numerical simulation.

would decreases. In order to compare, the peak height has been normalized. In Fig.6(a),when we increase the thickness of quartz plate, the rotatory dispersion will be mul ti plied so that we can get a narrower peak in trans mit ting spectrum(see Fig.6(b)), but at the same time, second order peaks also appear in the spectrum. In Fig.7 (a),when we adjust the voltage, the peak of the transmitting spectrum will move gradually. The bandwidth of the peak is linear to the wave length of it.(see Fig.7(b)).

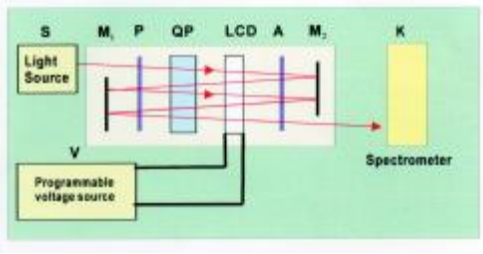

Fig.4(a) Schematic diagram of experimental apparatus.

6.ResultsA.Simulation Hypothesis: under proper voltage applied to LCD plate, the polarization plane of the ray pass ing through the LCD plate can be rotated from 0°to 90°. In Fig.5, we can easily find out the bandwidth (full width at half maximum ;FWHM ;Γ) of the transmission spectrum is narrowed down while the ray passes the filter more than one time. But as the round-

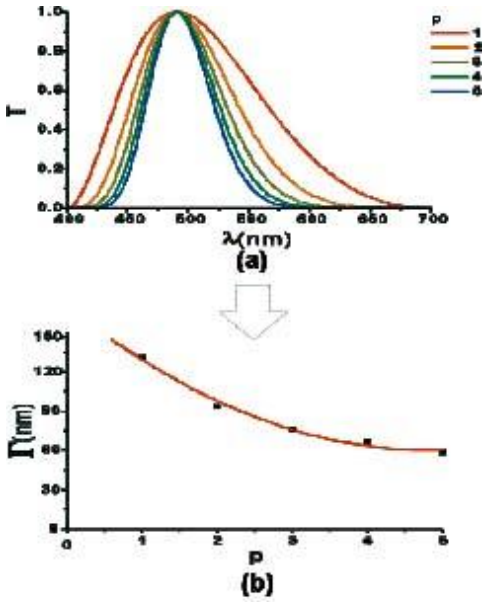

Fig.5 (a)Transmitting spectra for passing the filter1~5 times.
(b)Bandwidth (Γ) versus to number of round-trip (p).

trip increase, the ef fi cien cy of multi-pass

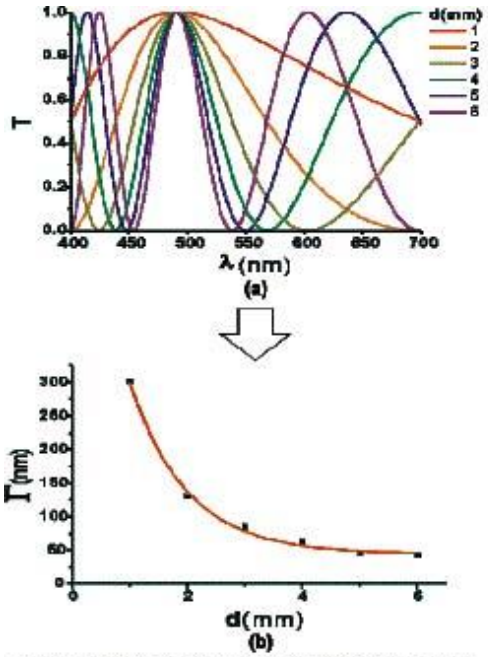

Fig.6 (a)Transmitting spectra for quartz plate thickness(d) 1~6 mm.
(b)Bandwidth (Γ) versus to the thickness(d) of the quartz plate.

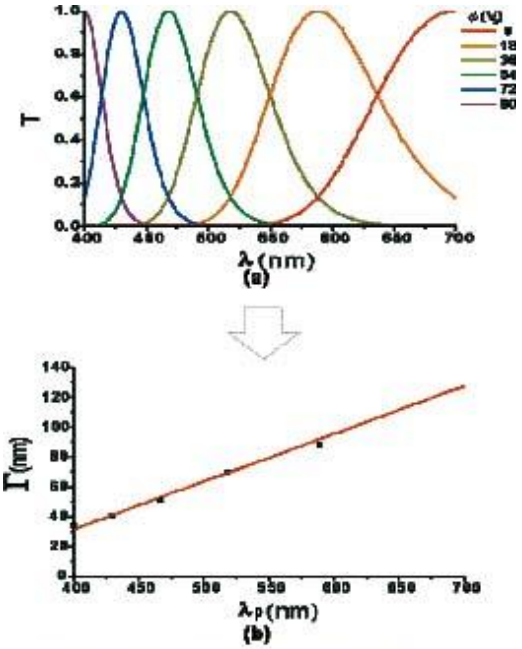

Fig.7 (a)Transmitting spectra for $\phi(V_p)$ applied to LCD plate.
(b)Bandwidth (Γ) versus to the wavelength (λ) of incoming light.

B. Experiments In Fig.8 and Fig.9, we can see clearly how the peak move whileφr(V) Changes. In terms of bandwidth, three-pass is much narrower than sin gle-pass, which agrees well with numerical sim u la tion (Fig.5). Fig.10 demonstrates the transmitting spectra of ray passing through the colorful liquid crystal filter at dif fer ent voltage. As applied voltage increases, the peak wavelength moves from red (620nm) to green(520nm) and the bandwidth is also narrowed down. Advanced analysis of Fig.10 is shown in Fig.11 & Fig.12. The peak wavelength(λp) is linear to applied voltage(Va). This implies that we can ad just the transmitting band of the filter lin ear ly by voltage control (Fig. 11). On the other hand, the bandwidth becomes nar row er at shorter peak wavelength as shown in Fig.12.

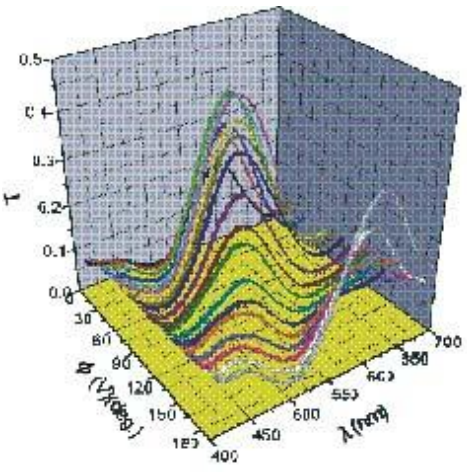

Fig.8 Transmitting spectra for φ(V) by single pass

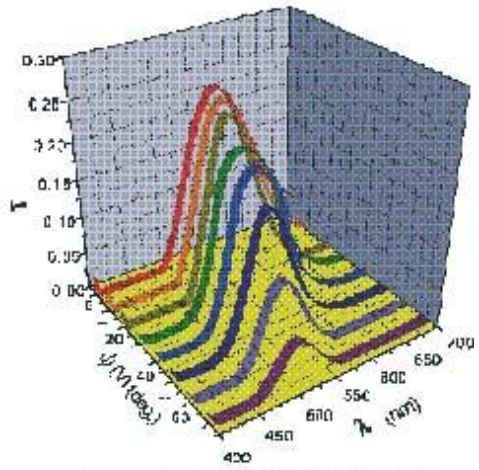

Fig.9 Transmitting spectra for φ(V) by three pass

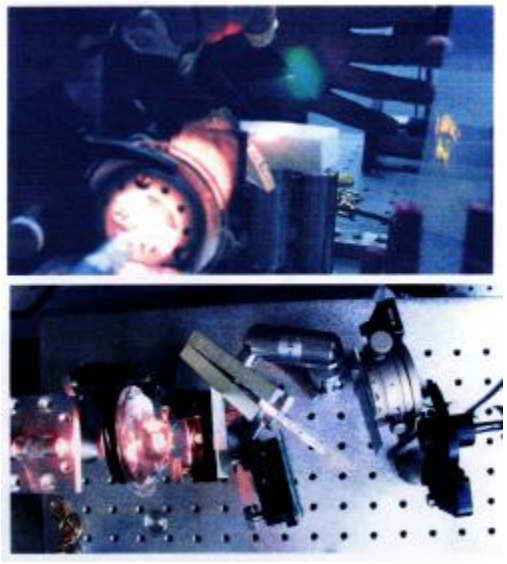
Fig.4(b) Photo of the setup.

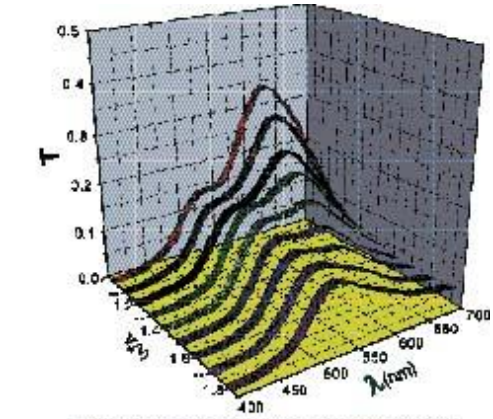

Fig.10 Transmitting spectrum for applied voltage(V) 1.1~1.8V

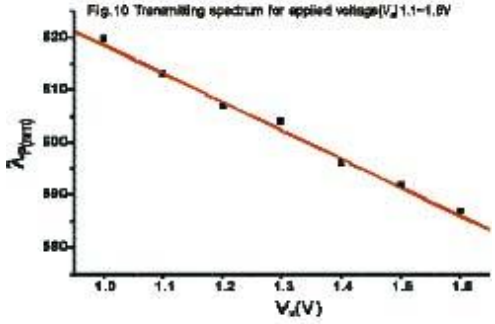

Fig.11 Peak wavelength(λ_p) versus to applied voltage(V) 1.0~1.8V

7.Discussion 1. From experimental measurements, we have found that the bandwidth(λ) of the transmitting spec trum is linear to the wavelength (Fig.12), which agrees well with the results from numerical simulation(Fig. 7). Therefore, the filter would have better per for mance in the blue part of the spectrum. 2. The transmission of the filter decreases as the peak wavelength decreases, which can be ac count ed for the decreasing transmission of poly mer polarizers at shorter wavelength. 3. These filters can provide immediate ap pli ca tions such as color light control in stage or var i ous il lu mi na tion setups. 4. Materials with high optical activity dispersion would further facilitate the developments of such color filters and extend the wavelength range of application to UV and IR. 5. Furthermore, we can make use of Fabry-Perot interference to narrow the bandwidth of trans mit ting spectrum.8.Conclusion In this work, we have successfully simulated and designed as well as developed a tunable color fil ter based on the dispersion of optical activity. The transmitting spectral band can be tuned by ad just ing the applied voltage on the LCD plate. Nar row er transmitting band can be im proved through multi-pass setup and dis per sion control by adjusting the thickness of the quartz plate. This new colorful fil ter offers a device to the ap pli ca tion of the electric con trolled color light. 4

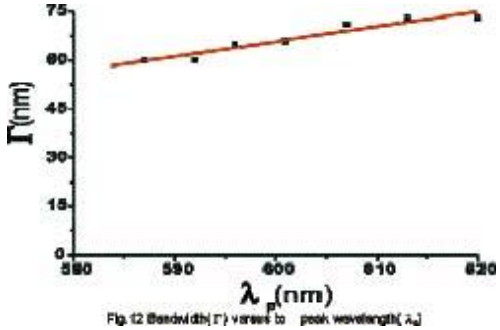

Fig.12 Bandwidth(Γ) versus to peak wavelength(λ_p)

9.References 1. E. Hecht, Optics, pp309-314, Addison-Wesley Pub. Comp., MA,1990 2. Y. P. Chiao, Liquid Crystal & Liquid Crystal Display, http://www.ep.nctu.edu.tw/teachercamp/water%20con.htm, 1999 3. A. Yariv and P. Yeh, Optical Waves in Crystals, pp. 94-103, John Wiley, New York, 1984 4. Floch, Selective Optical Resonator, p1, US. Patent, 1984