공학석사 학위논문

Solution-Processed In-Cell Polarizer for Liquid Crystal-Based Emissive Display

액정기반 발광형 디스플레이를 위한 용액공정 내재형 편광판에 관한 연구

2020 년 8월

서울대학교 대학원

전기정보공학부

주 정

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Abstract

Recently, the advancement of the liquid crystal display (LCD) technology has greatly focused on the clear image quality together with the natural color. According to the demand for the image quality, the in-cell polarizers have been attracted much attention owing to the advantages of improving the contrast ratio and reducing the thickness of LCD.

In this work, we proposed the QD-based emissive LCD with the in-cell polarizer composed of dichroic dyes. The in-cell polarizer was fabricated through the solution-processing of a dichroic dye solution. The QD layer was constructed on the inner surface of the top substrate, and the in-cell polarizer was subsequently prepared on the QD layer to prevent the depolarization of the emission light and the degradation of the QDs. The intensity of the incident light for exciting QDs was modulated by the phase retardation through the LC layer, depending on the magnitude of the applied voltage. This leads directly to the modulation of the emission spectra of QDs with the color gamut extended to about 80 % of the BT.2020 standard. The architecture based on the in-cell polarizer will provide a simple and viable method of

constructing the QD-based emissive LCD with high color purity in a cost-effective manner.

Keywords: Liquid crystal display, In-cell polarizer, Quantum dot, Quantum dot color filter

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1. Introduction

1.1 Overview of liquid crystal-based displays

The liquid crystal display (LCD) is an active matrix LCD driven by a thin film transistor (TFT). Its principle is to use the photoelectric effect of liquid crystal (LC). LCD is a passive light-emitting display. It does not directly emit light but is modulated by ambient light and light from an external power source to produce a color or black-and-white image.

Austrian botanist F. Reinitge first observed the particular physical effects of LCs in 1888. In the 1960s, George Heilmeier [1] and others developed LCD for the first time based on dynamic scattering (DS) effect technology. In 1969, James Fergason [2] of Kent State University in the United States discovered the twisted nematic (TN) field effect of LCs and soon produced the first DS mode-type LCD based on this effect. Until 1973, LCDs based on this effect were introduced by Sharp Corporation of Japan and applied to the digital display of electronic calculators. Since then, the development of LCD technology has been advancing by leaps and bounds. With the continuous improvement of its defects, its characteristics of zero radiation, low power consumption, long display life, excellent display quality, and high stability have gradually emerged [3]. With huge commercial value, LCDs have become the main display equipment in television, computer, electrical appliances, meters, and other electronic industries.

Since the birth of TN-LCD, LCD in the early 1970s, the technology of the LC industry has continued to advance. Different types of LCD devices such as STN-LCD (Super Twisted Nematic) and TFT-LCD have appeared to meet users' changing needs. At the same time, after continually overcoming shortcomings, such as small viewing angles, slow response time, low contrast, and brightness, LCDs have gradually replaced traditional CRT displays as the most significant contributors in the display field. According to statistics, as early as 2004 [4], LCD sales were 72 million units, which exceeded the total global sales of CRT monitors for the first time. Until 2019, LCD sales continued to grow at a rate of 5% -8% per year. It is obvious that the LCD industry has enormous development potential.

1.1.1 Main LCD Modes

The LCD consists of the LC material sandwiched between upper and lower transparent electrodes on two substrates, and then an alignment layer and two polarizers are prepared. By controlling the voltage between the electrodes, the light transmission performance of the LC can be changed to display images with different characteristics.

There are many types of LCD classification. According to the material structure adopted by LCD, it can be divided into TN type LCD, STN type LCD, TFT type LCD, etc. According to the driving method classification, the LCD can be divided into two types: passive matrix and active matrix. According to their respective display characteristics, advantages and disadvantages, different LCD devices are suitable for ordinary electronic watches, low-end display devices, and high-end display devices. The following introduces several commonly used LCD modes, namely TN mode, vertical alignment (VA) mode, and in-plane switching (IPS) mode.

TN mode

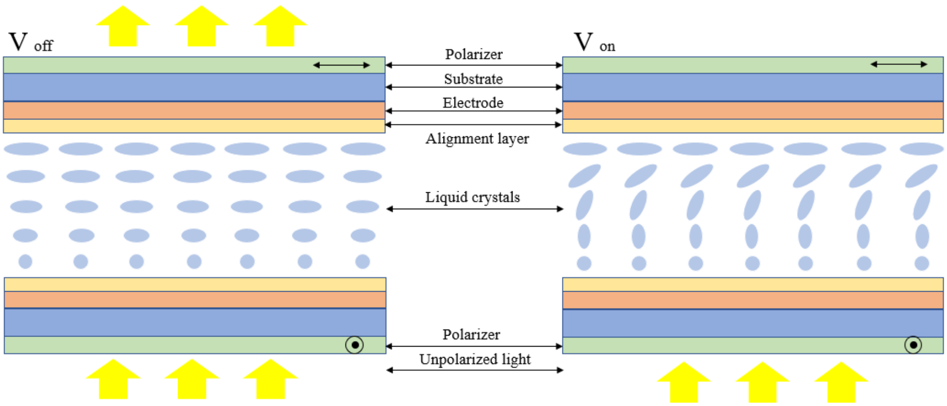

Figure1.1. Operating principle of TN mode in LCD

The TN is the most widely used LCD mode for applications ranging from watches to computer monitors.

It can be seen from the figure that the LC material is encapsulated between the upper and lower transparent electrodes, and the alignment film is located on the transparent electrodes. The orientation directions of the up-and-down orientation film are perpendicular to each other at an angle of 90°. When there is no voltage between the two electrodes, the LC molecules are subjected to the vertical alignment film. They are arranged by twisting 90 ° between the upper and lower electrodes. When the incident natural light passes through the upper polarizer, it becomes the same as the polarization direction of the upper polarizer Linearly polarized light is incident into the LC layer and rotated through 90 ° along the twisting direction, passes through the lower polarizer, and becomes linearly polarized light perpendicular to the incident direction. In this case, the LCD is light-transmitting and appears bright. In contrast, when a voltage is applied between the two electrodes, the orientation direction of the LC molecules becomes parallel to the electric field. In this case, the direction of the incident polarized light is not twisted. Light cannot pass through the lower polarizer. At this time, the LCD is opaque and appears dark.

It is based on the electro-optical effect of the LC and the effect of the electric field that the LCD changes between light and dark so that the LC can display different contents.

VA mode

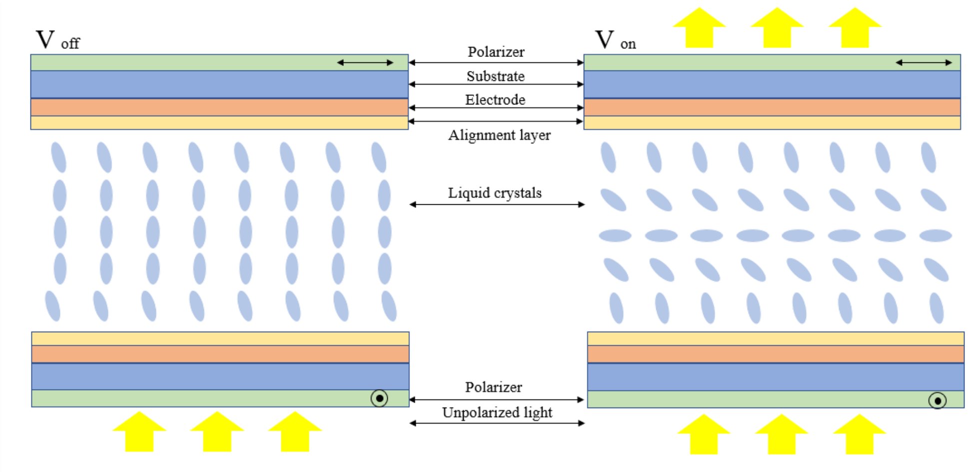

Figure1.2. Operating principle of VA mode in LCD

The most prominent feature of the VA mode is the typically black mode, which can be used as an ideal black screen.

In the VA mode, the vertically aligned LC molecules turn in a direction parallel to the surface of the glass substrate, and an electric field perpendicular to the substrate surface is applied to cause this transition. This requires an LC mixture with negative dielectric anisotropy, which is aligned perpendicular to the direction of the electric field. This is achieved by introducing laterally polar side groups into mesogenic molecules.

When no voltage is used, the molecules are arranged vertically, and the light cannot pass. After the voltage is used, the molecules are arranged obliquely, and the light can pass through the birefringence. When no voltage is applied, the vertically aligned liquid crystal produces an almost perfect black state between the two polarizers arranged in a cross. As a result, VA displays have excellent contrast and usually operate in commonly black mode.

IPS mode

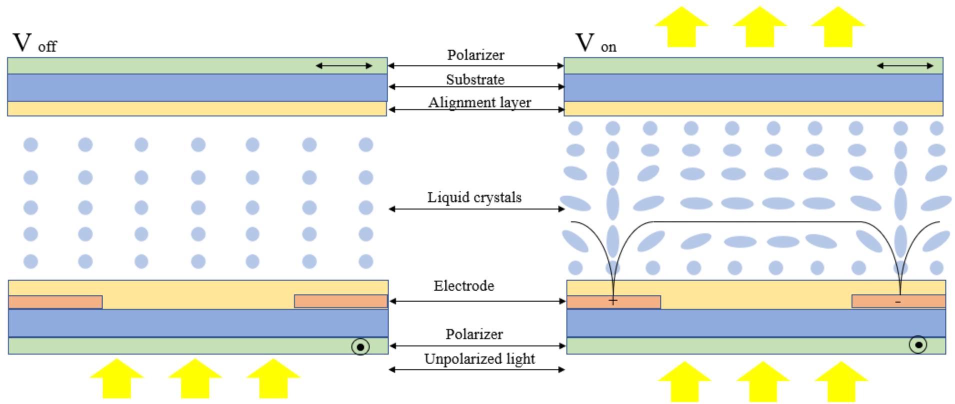

Figure1.3. Operating principle of IPS mode in LCD

In IPS technology, an electrode whose electric field is used to switch LC molecules exists as only a strip electrode on one of two substrates. The result is an uneven electric field parallel to the surface of the nearest substrate. The molecular switching direction corresponds to the substrate, so it is an "on-plane field". This results in lower viewing angle dependency than TN and VA displays. It is possible to improve viewing angle dependency without adding a compensation film, which is a crucial advantage of IPS technology, making it accessible in many applications.

The LC molecules are in a plane parallel to the glass substrate. When there is no voltage, the light passes through the lower polarizing plate and forms linear polarized light parallel to the short axis of the LC molecules. The polarization direction cannot be rotated, so it is absorbed by the upper polarizing plate and cannot be emitted. After the voltage is applied, the LC forms a lateral electric field from left to right, and the LC molecules are aligned along the direction of the electric field. The light passes through the lower polarizing plate and the LC layer in an elliptical polarization state and can be emitted through the upper polarizing plate.

The main feature of the IPS mode is that both poles are on a plane, and the LC molecules remain parallel to the screen and twist in the plane.

1.1.2 Types of backlight unit for LCDs

The backlight unit is one of the key components of the LCD. The function is to provide sufficient brightness and uniformly distributed light sources so that they can display images normally.

There are three main types of light sources for backlight units, cold cathode fluorescent light (CCFL), light emitting diode (LED) and quantum dot (QD) based.

CCFLs are considered to be ideal backlights for TFT-LCD liquid crystal screens because they have the advantages of small lamps, simple structure, the low surface temperature of lamps, easy processing and forming, good color rendering, and uniform light emission.

From the perspective of its technical principle, CCFL is filled with inert gases Ne and Ar in a glass tube, which contains trace mercury vapor, and a phosphor is coated on the inner wall of the glass. Through the electrodes at both ends of the lamp tube, the ultraviolet light excited by the gaseous mercury in the lamp tube can collide with the phosphor powder on the wall of the tube, thereby emitting various colors of light.

The brightness of most CCFL backlights declines significantly after 2 to 3 years of use. Many LCD TVs will have a yellow and dark screen after a few years of use. This is due to the shortcomings of CCFL. So LED began to replace CCFL.

Since 2008, the LED backlight has gradually entered industrialization, and its market share has been continuously expanding. From the beginning of application in notebook computers to the application in monitors, LCD TVs, and smartphones, LED backlight products continue to emerge, and the market share continues to increase.

The LED light source is composed of many grid-shaped semiconductors, and each "grid" has an LED semiconductor so that the LED backlight successfully realizes the planarization of the light source. The planarized light source has excellent brightness uniformity and does not require complicated optical path design so that the thickness of the LCD can be made thinner. It also has higher reliability and stability.

Principles of quantum dots backlight units

Recent studies have found that QDs can also be used as backlights for

LCDs. Due to the quantum confinement effect and quantum size effect, semiconductor QD have attracted extensive attention due to their broad excitation spectrum, narrow half-value width, adjustable color, and solution processing. QD is divided into photoluminescence (PL) and electroluminescence (EL).

PL involves the absorption and re-emission of light. It is an essential feature of many dyes and semiconductor materials. It is widely used in commercial fields such as solid-state lighting, efficient color displays, and biological imaging [5].

With the continuous optimization of synthesis methods, structural design, and gradual improvement of QD performance, research and commercialization of PL-QD devices are also ongoing. At present, some PL-QD devices [6] have obtained commercial applications in LED lighting and LCD. In the application of LCD backlight display, due to the spectral defect of the phosphor, the LED backlight faces a more significant challenge in picture quality and color fidelity, and PL-QD makes up for this shortfall. Currently, TCL and Samsung and SONY companies have used this to launch QD televisions.

The introduction of QD technology has enabled LCD TVs to improve color reproduction and color gamut coverage. However, QD preparation materials and processes are relatively demanding. As a result, only a few companies currently have the ability to produce and have high costs. This also limits the large-scale application of QDs, and further optimization of the preparation process is required to reduce costs.

At present, the research of QDs in the field of display technology mainly includes two aspects: QD light-emitting diode technology based on EL-QD characteristics (QLED); QD backlight technology based on PL-QD characteristics (quantum dots backlight unit, QD-BLU).

At present, there are three main methods for the development of QD-BLU products based on PL technology [8]: (1) replacing the quantum powder with QD materials and directly packaging them with blue LED chips (On-chip) [9]; (2) red and green quantum. After the dot materials are mixed uniformly, they are sealed in a capillary glass tube under the conditions of water and oxygen, and the glass tube is arranged at the edge of the light guide plate (On-edge); (3) the red and green QD materials are made into a membrane to replace the current LC The lower diffusion film in the panel is placed on the light guide plate (On-surface). Among them, the "On-chip" method encapsulates QDs into LEDs. Due to the stability and lifetime of QDs, this method cannot yet be implemented in mass production. The "On-edge" method seals the QDs in a thin glass tube and installs them on the LED light incident part of the light guide plate. This method can save the raw materials of the QDs, the cost is relatively low, and the water and oxygen barrier properties of the glass are excellent Withstands more severe conditions and is ,therefore, the first form of a commercial product to be introduced. The earliest quantum dot televisions from Sony, TCL, and Hisense all adopted this method. The disadvantages of this method are that its design increases the thickness of the fuselage, affects aesthetics to a certain extent, and cannot achieve ultra-thin bezels. Besides, it needs to be used with distinctive fixtures, and the development cost is relatively high. The "On-surface" method places the QD film between the blue backlight and the LCD panel, making it easy to embed. This method needs to consume more QDs and needs to be protected by a barrier film up and down, which has a high cost. However, due to its convenient use and relatively easy structure development, it is widely welcomed by the market. As the cost of QD films continues to fall, it is expected that it will become a mainstream product form.

"On-chip" method or a QD film of the "On-surface" method, the technical principle is to use a blue LED backlight source to excite QD materials of different colors to obtain white light with the expected spectrum. The materials used are mainly green and red QDs that can produce high-purity green and red light, respectively. The color gamut of the display can be increased from the traditional 72% NTSC to more than 100% NTSC [10], which significantly improves the color effect of the display, and the colors are more vivid and vibrant. Closer to the real world. Furthermore, the QD material has a fast response speed, and the afterglow time is short, generally in the tens of nanoseconds, while the phosphor used in the LED backlight of the traditional LCD is generally in the hundreds of nanoseconds or even milliseconds [11], so the QD display is used to respond Faster speed, no afterimages, smearing and other phenomena, more suitable for high-end display applications.

1.2. Outline of thesis

This thesis contains five chapters. In **Chapter 1**, a general overview of the types of LCD. The types of backlight unit for LCDs are introduced. The application of LCD with quantum dot backlight unit is introduced. **Chapter 2** provides the theoretical background for understanding polarizing techniques in LCD, the importance of in-cell polarizer and QD color filters. **Chapter 3** presents the experimental procedures of this research are described. The fabrication process of solution-processed in-cell polarizer with QD-based LC cell is introduced. In **Chapter 4,** the results of the experiments are presented and discussed. Finally, in **Chapter 5**, some concluding remarks are made.

2. LCD with in-cell polarizer

2.1. Types of polarizers

The polarizer is one of the main structures of LCD. The primary function of polarizers is to convert natural light without polarization into polarized light. Through the turning of the LC, the penetration of light is controlled, and the display effect of the light and dark of the panel is produced. Polarizers have a significant influence on the display background color and driving voltage of the entire LCD.

There are two kinds of staining methods in the polarizer production process [12]: iodine staining method and dye dyeing method. The iodine staining method refers to the use of iodine and potassium iodide as a dichroic medium to produce polarized polarization characteristics in a Polyvinyl alcohol (PVA) film during the process of staining and stretching a polarizer. The advantage of this staining method is that it is relatively easy to obtain polarization characteristics of 99.9% or more and high transmittance of 42% or more. Therefore, most of the early polarizing material products were processed by the iodine staining process. However, the disadvantage is that because the molecular structure of iodine is easily destroyed under high temperature and high humidity conditions, the durability of polarizers produced using the iodine staining process is weak.

The production of polarizers mainly includes an extension method and a coating method, and the extension method is the current mainstream process. At present, the production technology is divided by the extension process of PVA film, and there are two categories of dry method and wet method [13]; by the PVA film dyeing method, there are two categories of iodine dyeing and dye dyeing. The method of drawing refers to the preparation process of stretching PVA film to a specific magnification in an inert gas environment under certain temperature and humidity conditions and then dyeing, fixing, compounding, and drying. The wet stretching process refers to a production method in which the PVA film is dyed first, followed by stretching, fixing, compounding, and drying in the solution.

Wet stretching can easily increase the stretching ratio and make the coloring uniform. In the past, there was a problem that the stability of PVA film in the liquid was difficult to control, that is, the production conditions were not easy to control, the film was more likely to break during the production process, and the film shrinkage rate was large, and the yield was low. With the continuous improvement of process technology, the limitations of width and the like have been overcome, and the process conditions have been optimized. The polarizer made by the wet stretching process is superior to the dry stretching in terms of color tone uniformity and durability. Although dry stretching has the advantages that it can be processed with a larger width of PVA film and has higher production efficiency, it has an influence on the uniformity of color tone and durability of the polarizer and is prone to unevenness in extension and roughness of the film surface. Japanese, Korean, Chinese, and domestic polarizer manufacturers all use the wet stretching process. The wet stretching process technology has become the primary production process technology for polarizer production for LCDs worldwide.

With the expansion of LCD products [14], the requirements for the hot and humid working conditions of polarizers are becoming more and more severe. In order to meet the new technical requirements, dyeing polarizing technology has appeared. The use of dyes with a high dichroic ratio in place of iodine produces polarizers that are resistant to high temperatures, high humidity, and light, and are particularly suitable for use in harsh environments, such as LCDs for automotive, outdoor, and projector applications.

2.2. Architecture of QD-LCD with in-cell polarizer

The color filter is the critical component of the LCD to realize color display. However, the traditional color filter is an absorption filter, the light source utilization rate is low, and the filter half-wave width is full, resulting in low color saturation. Therefore, with the full application of QDs in the display field, QD filters [15] came into being.

In general, red and green QD materials are mixed in glue to form QDs. QD light conversion color films are obtained through the photolithography process to achieve high color gamut panel display effects. QD color filter coupled with a blue LED can provide better color than the current white LED + color filter [16]. Current color filters are made by patterning photoresist. A combination of ultraviolet (UV) curing, etching, and heat treatment must be used to deposit and pattern each color over a large area to pattern and harden the photopolymer. QD can also be dispersed in a polymer and cured, so it is significant to consider replacing the current colored dyes with quantum dots to make active ingredients instead of passive ingredients. In the QD color filter, there are only red and green QD layers, and the blue sub-pixel is empty, which allows the transmission of blue LED backlight. Color filters do not block light but convert light.

QD color filters have the potential to surpass the vast advantages that QD film can provide. First, become brighter and more efficient. Light conversion is performed after the LC layer and other optical films instead of blocking light (from blue to red/green). This can bring a massive increase in efficiency and brightness. Second, it has a broader view. QD launches in all directions and is closer to the front of the screen. As an audience, we should see a considerable difference in wide-angle viewing. And lower luminous flux and temperature. Far away from the LED light source, and behind the LC and polarizer, QD can withstand less harsh environments. What is more important is to make the panel thinner. Reduced components and built-in polarizers mean thinner overall [17].

Because QD color filter has the characteristics of making energy more efficient and broader viewing angle, so we used QD color filters in this study.

In-cell polarizer

Usually, on-cell polarizers are used, but in this study, in-cell polarizers are used. When using QD color filters, using on-cell polarizers can cause a lot of problems. This will cause serious depolarization, loss of light through the substrate, and reduction in contrast ratio.

For using on-cell polarizer, when backlight goes through the front polarizer, it becomes linearly polarized, say along x-axis. Then after passing through the TFT substrate and LC layer, there is some light leakage along y-axis due to scattering effect [18]. After the light passing through color filters, the depolarization becomes more severe. When entering the analyzer, the x-polarized (dominant polarization direction) light is blocked as expected, while only the depolarized light could traverse through the analyzer. This undesirable light leakage degrades the contrast ratio [19].

Therefore we need to use in-cell polarizer to solve these problems. Insert an in-cell polarizer between the LC layer and the color filter. Due to the in-cell polarizer, the depolarization coefficients of each layer are decoupled. Under the polarizer in the unit, the depolarization mainly comes from the TFT substrate and the LC layer [20].

Figure2.1. Structure of in-cell polarizer in LCD

When above the LC layer, there is an in-cell polarizer for absorbing x-polarized light. Only scattered light leaks and enters the color filter array (although it has a strong scattering effect). Therefore, practical CR is significantly improved. Another important point that should be mentioned here is that the extinction ratio of the built-in polarizer is not critical. As long as most of the x-polarized light (the main polarization direction) is absorbed by the in-cell polarizer, the entire system should work the same. In this way, high transmittance is achieved.

The in-cell polarizer has the following advantages [21]: (1) replacing an attaching polarizer with a coated polarizer to reduce process time. (2) thinner polarizer thickness, eliminating base films. (3) higher reliability to protect polarizers with glass substrates. These advantages are useful for mobile LCDs.

3. Experiments

3.1. Fabrication of photoluminescence QD patterns

In this chapter, a new QD PL LCD for improving color purity is proposed. Traditional LCDs use traditional color filters and white backlight to achieve color. In this study, QD color filter was used to achieve color, so as to fundamentally eliminate the decrease in transmittance during passing through the color filter.

Fabrication process

The indium tin oxide (ITO) coated glass substrate was spin-coated with the reactive monomers (RMS03-015) and red QDs in toluene (CZO-620T) at a speed of 3000 rpm. It was soft annealed at 75 °C for 60 seconds to remove the solvent. Under the UV at the intensity of 20 mW / cm^2, the RM-QD mixture layer was photopolymerized with a photomask for 120 seconds. Toluene was used to remove the unpolymerized RM-QD mixture, and it was dried entirely at 75 ° C. Then, the same procedure was applied to RM-green

QD (CZO-530T) mixture and RM-blue QD (CZO-450T) mixture, and finally, the photoluminescence QD patterns were obtained.

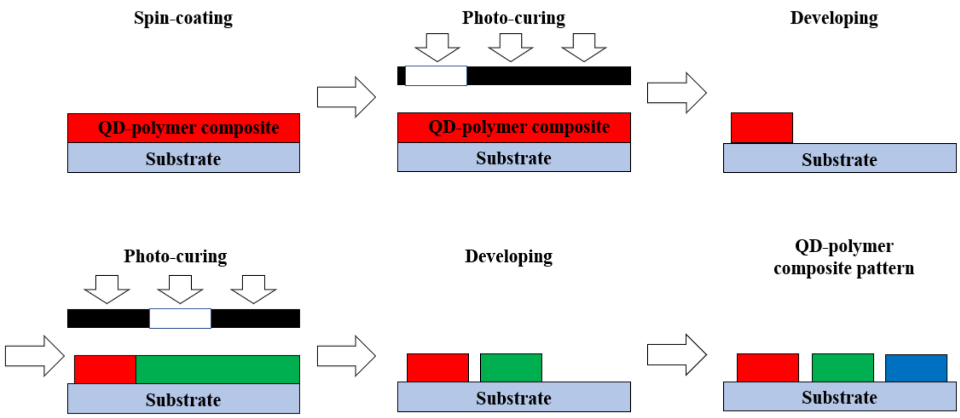

Figure 3.1. Illustration of fabrication process of photoluminescence QD patterns

3.2. Dichroic dye-based in-cell polarizer

Dichroic red 1

In recent years, among various existing thin polarizers, dye polarizers are widely used in LCD applications. The dichroic dye molecule shows a high dichroic ratio due to its elongated molecular structure, and it absorbs light polarized parallel to the molecular orientation direction [22].

When the azo dichroic dye molecule is irradiated with resonance light, its conformational change (photoisomerization) occurs between the anti-steady state and the cis-excited state. Through repeated excitation and relaxation processes, the trans isomers perpendicular to the polarization of light are statistically enriched. As a result, the azo dichroic dye molecules tend to be aligned perpendicular to the polarization of the irradiated light [23]. In this study, the dichroic red 1was used to study the process conditions of the dye-doped polarizer [24]. The dye has broad order parameters and has good solubility and dichroism in LC. The dye is stable and strong in polarity. Therefore, by applying an external electric field in the LC medium, the alignment can be easily controlled.

In this article, by using the dichroic red dye 1 for solution process, the in- cell polarizer was manufactured after UV light irradiation.

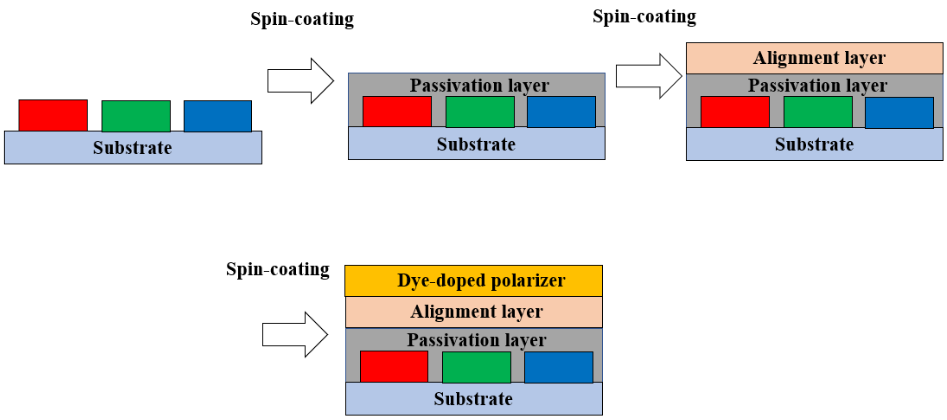

Figure 3.2. Fabrication process of dichroic dye-based in-cell polarizer on QD patterns

Fabrication process

Poly(methyl-methacrylate) (PMMA) was dissolved in anisole at a concentration of 11 wt.%. And the QD substrate obtained in the previous section was spin-coated with it at 2000 rpm for 30 seconds. Then it was soft-annealed at 80 °C for 20 seconds. The LC polyimide SE6514H was spin-coated at a rotation speed of 500 rpm for 5 seconds, and then spin-coated at 3000 rpm for 25 seconds. It was heated at 180 °C for 1 hour to remove excess solution. Then the rubbing alignment process was carried out. Rubbed lightly and marked the rubbing direction on the back of the glass substrate. The dye-doped LC was prepared by dissolving the dichroic red 1 at a concentration of 1% in the polymer SE6514H. A rotation speed of 500 rpm was used for 5 seconds, and then a rotation speed of 3000 rpm was used for 25 seconds, baked at 65°C for 1 minute to remove residual solvent, and promote adhesion of dye-doped LC. UV light was exposed for 300 seconds. Then, the dichroic dye-based in-cell polarizer on QD patterns was completed.

3.3. Solution-processed in-cell polarizer with QD-based LC cell

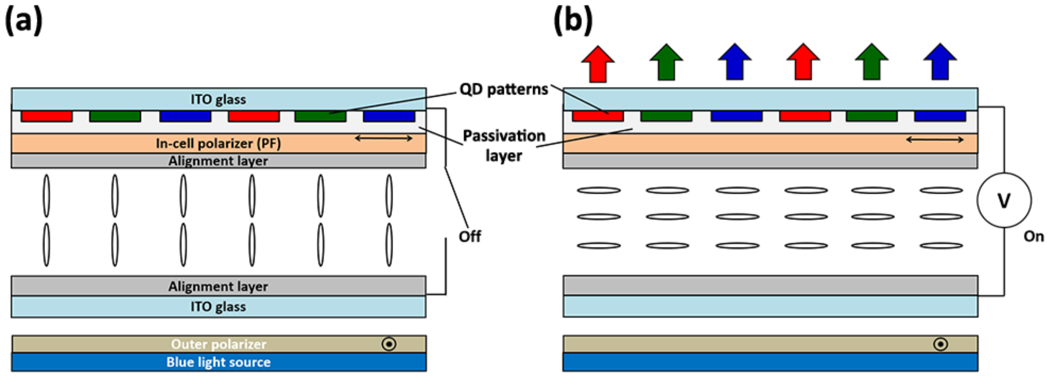

Figure 3.3. Operating principle of QD-based LC cell with in-cell polarizer

The aligned ITO substrate was attached to the sample obtained in the previous chapter. AL1H659 was used for spin coating on the substrate and rubbing process to complete the alignment, and the LCs were injected into the empty cell. A blue light source (Silver-LED-455Z) was used for illumination. Figure 3.3 shows the operating principle of the QD-based LC cell with in-cell polarizer. When no voltage is used, the LCs are arranged vertically, and the light cannot pass. After the voltage is used, the LCs are arranged obliquely, and the light can pass through the birefringence. Through the QD layer through light conversion, a variety of colored light is obtained.

3.4. Measurements of optical and photoluminescence characteristics

The experiment used a blue light source (Silver-LED-455Z) to illuminate and connected to the input voltage source (OPM-1001D). All the measurements of the electrical characteristics were carried out using an optical fiber spectrometer (S2000) under ambient conditions. It was used to detect the passing light, thereby obtaining the light transmittance.

4. Results and Discussion

4.1. Analysis of polarizing characteristics of in-cell polarizer

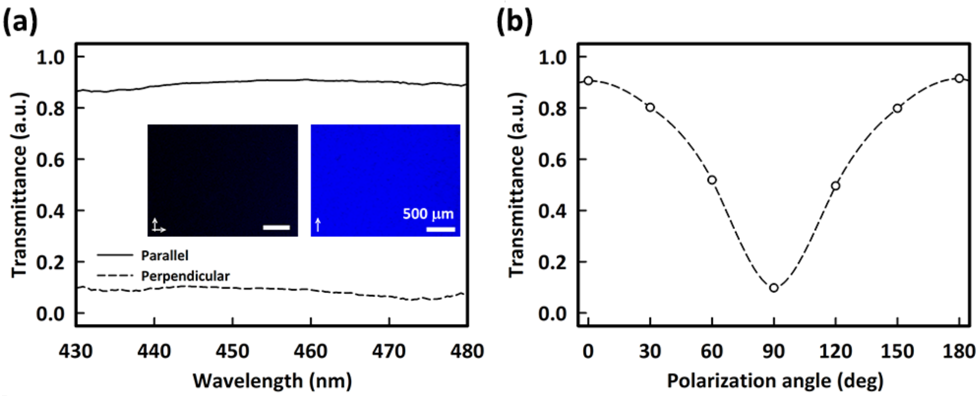

Figure 4.1. (a) Incident light wavelength-transmittance curve of the VA-LC cell with in-cell polarizer when polarizers are parallel and perpendicular to each other. (b) Polarization angle-transmittance curve of the VA-LC cell with in-cell polarizer

For the characteristics of the polarizer, a blue light source (Silver-LED-455Z) and an optical fiber spectrometer (S2000) were used for experiments. The experiment measured the transmittance when the polarizers were perpendicular and parallel to each other. As shown in the figure 4.1, the transmittance is highest when the polarizers are parallel and the lowest when perpendicular, and the in-cell polarizer has high contrast ratio. According to the angle change, the function of the polarizer can be well realized.

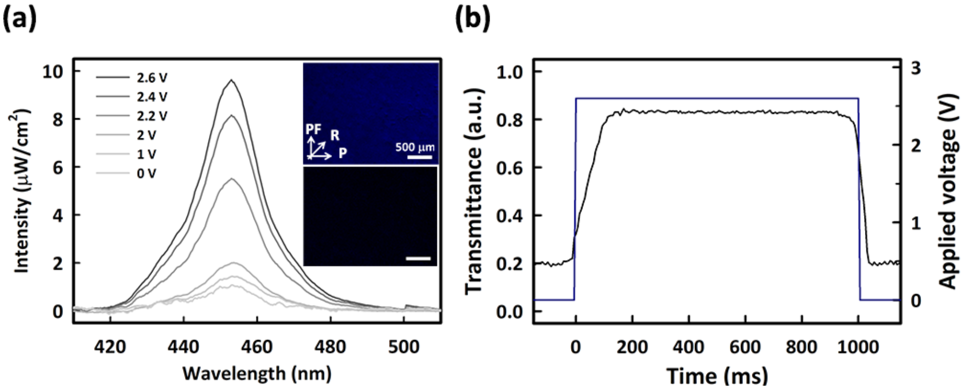

Figure 4.2. (a)The voltage-intensity curve of the VA-LC cell with in-cell polarizer. (b) The applied voltage-response time curve of the VA-LC cell with in-cell polarizer.

The input polarization is set at an angle of 45 ° relative to the alignment direction and perpendicular to the polarizer. Figure 4.2 (a) shows the voltage-intensity curve of the VA-LC cell with in-cell polarizer. As shown in figure

4.2 (a), the light intensity was found to increase with increasing the applied voltage as normal VA mode. Figure 4.2 (b) shows the applied voltage-response time curve of the VA-LC cell with in-cell polarizer. Figure 4.2 (b) uses response time as a parameter. The definition of the response time is to measure at the frequency of the square wave under the applied voltage, the frequency is 1 kHz, and the amplitude is 2.6V. The rising and falling time estimated from the transmittance curve (from 10 % to 90 % and vice versa) was 64 milliseconds and 42 milliseconds, respectively. So it has short response time.

4.2. Photoluminescence characteristics of QD-based LC cell with in-cell polarizer

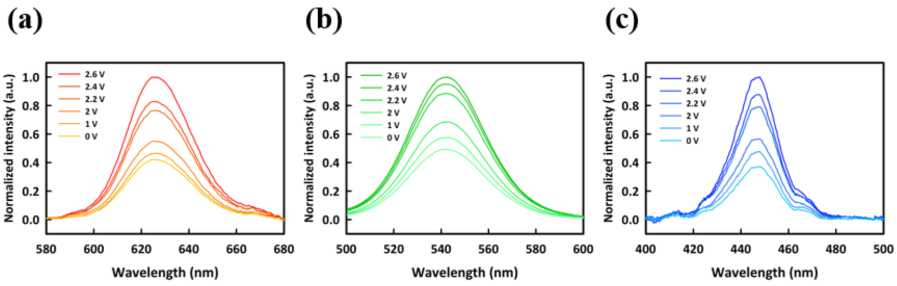

Figure 4.3. The voltage-intensity curve of the (a) red QD-RM layer (b) green QD-RM layer (c) blue QD-RM layer on the QD-based LC cell.

For the characteristics of the QD-based LC cell with in-cell polarizer, a blue light source (Silver-LED-455Z) and an optical fiber spectrometer (S2000) were used for experiments. The input polarization is set at an angle of 45 ° relative to the alignment direction and perpendicular to the polarizer. Figure 4.3 shows the voltage-intensity curve of the (a) red QD-RM layer (b) green QD-RM layer (c) blue QD-RM layer on the QD-based LC cell. As shown in figure 4.3, the light intensity was found to increase with increasing the applied voltage. It can also be found that it has a constant full width at half maximum

(FWHM) with increasing the applied voltage. In Figure 4.3 (a), the peak wavelength of the red QD-RM layer is 625 nm, and the FWHM value is 29.45 nm. In Figure 4.3 (b), the peak wavelength of the blue QD-RM layer is 540 nm, and the FWHM value is 30.33 nm. In Figure 4.3 (a), the peak wavelength of the blue QD-RM layer is 455 nm, and the FWHM value is 31.18 nm.

4.3. Microscopic images of QD-based LC cell with in-cell polarizer

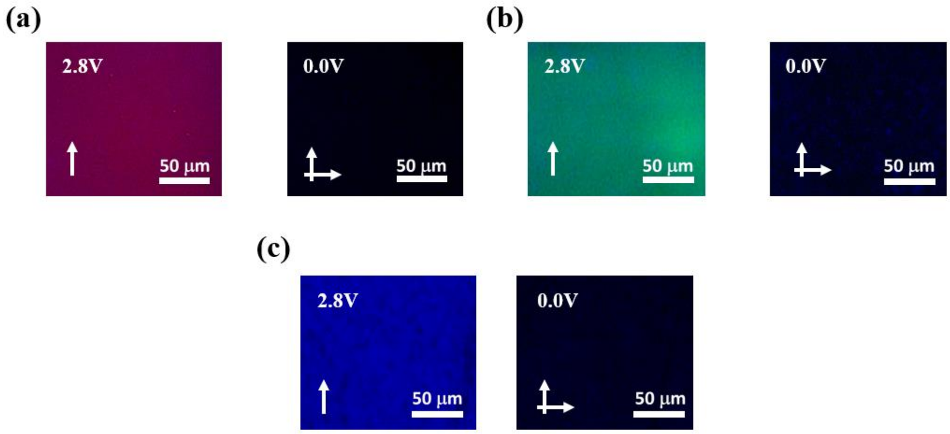

Figure 4.4. Microscopic images of the (a) red QD-RM layer (b) green QD-RM layer (c) blue QD-RM layer on the QD-based LC cell.

Figure 4.4 Microscopic images of the (a) red QD-RM layer (b) green QD-RM layer (c) blue QD-RM layer on the QD-based LC cell, observes the POM, at different values of the applied voltage (0,2.8V). Red, green and blue all generally operate in the open state, and the light emission is very uniform, as shown in figure 4.4.

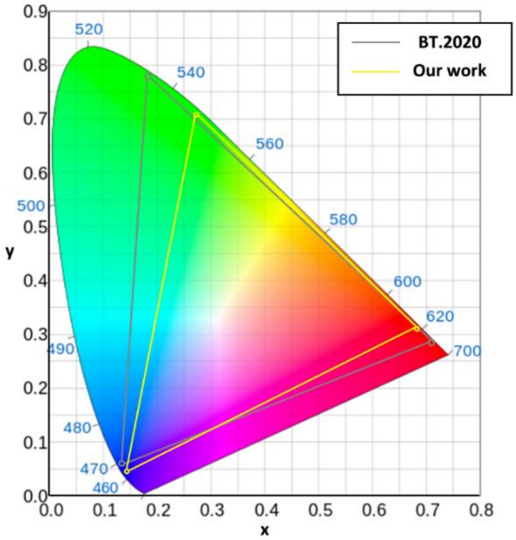

Figure 4.5. Color gamut of the QD-based LC cell with in-cell polarizer compared with BT.2020

Finally, the color coordinates of the QD-based LC cell with in-cell polarizer are calculated and compared with BT.2020. In order to calculate the color coordination, a computer program (Matlab) is used and has the emission characteristics of the on state and the color matching function. The peak wavelength and FWHM values of the red QDs are obtained from Figure 4.3 (a). By using Matlab, the color coordinates of the red QD are calculated. The peak wavelength and FWHM values of the red QRs were 625 and 29.45 nm, respectively, and their color coordinates were (0.67, 0.31). The peak wavelength and FWHM values of the green QRs were 540 and 30.33 nm, respectively, and their color coordinates were (0.27, 0.71). The blue light source that was used to excite these QRs had a peak wavelength of 455 nm, the FWHM of 31.18 nm, and color coordinates of (0.14, 0.05). Therefore, the QD-based LC cell with in-cell polarizer can cover 80% of the BT.2020 gamut, as shown in Figure 4.5. The architecture based on the in-cell polarizer will provide a simple and viable method of constructing the QD-based emissive LCD with high color purity in a cost-effective manner.

5. Conclusion

In this thesis, solution-processed in-cell polarizer for QD-based LC cells for the expansion of color gamut was proposed. This article explained the advantages of in-cell polarizer and applied it to the QD-based LC cells. The key concept described in this thesis is to use the in-cell polarizer to obtain higher contrast.

Through experiments, solution-processed in-cell polarizer for QD-based LC cells was fabricated. First, a QD layer was constructed on the substrate, and then the dye-doped LC was spin-coated on the QD layer to prepare an in-cell polarizer. By analyzing the experimental results, the in-cell polarizer has excellent polarization characteristics. As the applied voltage increases, the light intensity of the outgoing light also increases. Finally, the color coordinate is analyzed, and the color gamut is expanded to about 80% of the modulation of the QD emission spectrum of the BT.2020 standard.

It can be concluded that by using in-cell polarizers architecture can provide a simple and feasible method to construct the LCD with high color purity in a cost-effective manner.

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국문 초록

최근 액정 디스플레이(LCD) 기술들은 자연스러운 색상과 더불어 선명한 화질을 중심으로 크게 발전했다. 고화질 영상에 대한 수요와 함께, 내재형 편광판 (in-cell polarizer)는 대조율 향상과 LCD 두께 감소라는 다양한 장점들로 인해 더 많은 관심을 끌었다.

본 연구에서는 이색성 염료로 구성된, 내재형 편광판를 적용한 양자점 기반 광 발광 액정 디스플레이를 제안하였다. 양자점 층은 상단 기판의 내부 표면에 구성되었고, 이후 양자점 층에 내재형 편광판를 도입하여 입사광의 편광상태를 유지하고 양자점의 성능 저하를 방지하였다. 내재형 편광판은 용액 공정을 통해 이색성 염료를 정렬하여 제작되었다. 양자점 광 발광을 위한 입사광의 세기는 적용된 전압의 세기에 따라 액정 셀을 통한 위상 지연에 의해 변조되었다. 이는 색 영역이 BT.2020 표준의 약 80%까지 확장된 높은 색 순도를 보여준다. 내재형 편광판에 기반한 액정 디스플레이 구조는 비용-효율적인 방법으로 높은 색 순도를 가진 양자점 기반 광 발광 액정 디스플레이를 구성하는 간단하고 실행가능한 방법을 제공할 것이다.

주요어: 액정 디스플레이, 내재형 편광판, 양자점, 양자점 컬러 필터

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