August 23, 2001
RT0425
Display technology 4 pages

Research Report

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Abstract

Very thin quarter lambda plate was fabricated using liquid crystal polymer, aiming to use for parallax free high contrast G-H reflective displays. UV curable LC polymer was aligned by either by rubbed polyimide or UV alignment process. The film was thin enough by optimization of monomer composition, so that the voltage loss was small enough when the film is placed between two electrodes inside the cell. Contrast ratio of the G-H cell using this film was almost comparable to that using commercially available dispersion compensated multiplayer film.

1. Introduction

The reflective color liquid crystal display is the key enabler for low-power display devices. It is known that the displayed image looks like printed-paper when a reflectivity of 60% and a contrast ratio of 15:1 are realized.

Guest-host type liquid crystal display with either a stacked double guest-host layer structure or a structure with quarter lambda plate is expected to have high contrast and reflectivity, because they do not need polarizer which absorbs more than one half of the light.

Since dye molecules, at a dark state of guest-host cell, absorb only one of the two polarization components of the incident light, a double layer structure is proposed to improve their contrast, as is shown in figure 1(A). By using double guest-host layers with orthogonal orientation directions as a stacked structure, both polarization components of an incident light will be absorbed in a dark state. [1] However, the double layer stack structure is more difficult and complicated to manufacture as illustrated in figure 2(A).

By placing a quarter-lambda plate between a reflector and liquid-crystal layer of the guest-host cell, same effects as double-guest-host structure could be realized, as explained in figure 1 (B). [2]

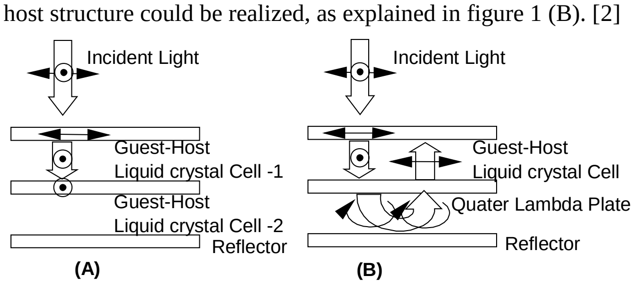


Figure 1. Function of double guest-host structure (A) and guest-host cell with 1/4-lambda plate (B) at dark state

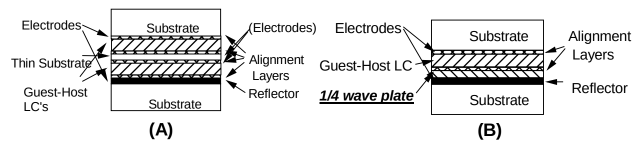
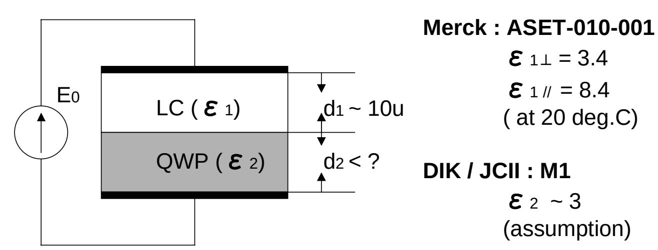


Figure 2. Structure of a double guest-host reflective display (A) and guest-host with 1/4 lambda plate (B)

Quarter-lambda plate with color compensation gives a good performance, however, the plate is placed outside the LC cell, which create a parallax problem, because the thickness of these plate is usually an order of hundred microns.

If a quarter-lambda plate is thin enough compared to G-H LC layer, it can be placed between electrodes, as shown in figure 2(B). This structure is simpler than double G-H LCD, and enables to solve parallax problem.

The film should be thin enough so that the voltage drop across the film could be reasonably low. Assuming the thickness of the guest-host LC layer to be 10um, the thickness of the quarter lambda plate should be less than 3.6um, as shown in figure 3.



$$E_{LC} = E_0 \times \frac{d_1/\varepsilon_1}{d_1/\varepsilon_1 + d_2/\varepsilon_2}$$

$$\Rightarrow \mathbf{d_2 < 3.6\ u} \quad (E_{LC} > E_{QWP})$$

Figure 3. Structure of guest-host cell with 1/4 lambda plate

We studied processes and materials of photo-polymerizable liquid crystal monomers for the fabrication of first order thin quarter lambda plate in our previous work. [3] In this work, we studied optical performance of reflective guest host liquid crystal display using these UV curable LC polymer films, compared with commercially available color compensated quarter lambda plate.

2. Experiment

We fabricated a quarter lambda plate using photopolymerizable liquid crystal monomers and evaluated their optical performances. For the first, we used the mixture of UV-curable liquid crystal monomers shown in figure 4., which were supplied by DIK and Japan Chemical Innovation Institute (JCII). [7]

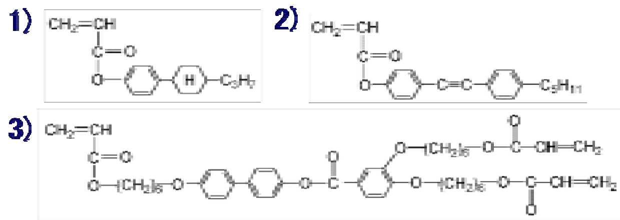


Figure 4. Liquid crystal monomers used in this study

Mixing ratio of the monomers was as follows.

1): 2): 3) = 35 : 35 : 30 (wt%)

DMAP (Dimethyloxy-2-phenylacetophenone,2,2, Aldrich) was used for the photo-initiator.

We fabricated quarter lambda plate between two glass substrates, as is shown in figure 5(A), for most of the measurements. We also made film between glass substrate and 1mm thick polycarbonate substrate, and then removed a polycarbonate substrate, as is shown in figure 5(B). Fabrication scheme is shown in figure 6.

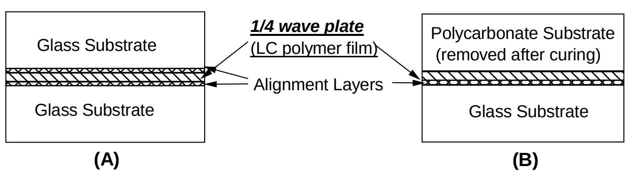


Figure 5. Structures of fabricated retardation films

The glass plates were spin coated with 30nm thick polyimide (AL1254, JSR Corp.) alignment layers.

Polycarbonate plates (1mm) were rubbed in the same way as the glass plates for alignment of LC polymer.

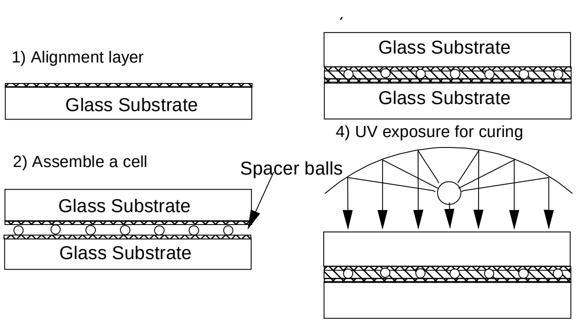


Figure 6. Fabrication process of the quarter lambda plate

The substrates were put together in parallel rubbing directions, with spacer balls that determine the film thickness, and then filled with the LC-monomer mixture with photo-initiator. Aligned liquid crystal monomer between substrates was polymerized using a high-pressure mercury lamp with a dosage of 0.6 J /cm^2.

We also used LPP and LCP supplied by Rolic/Chiba. [6] In this case, LPP was spin-coated, and then photo aligned by polarized UV (High pressure mercury lamp filtered through 313nm interference filter). LCP was also spin-coated, exposed to UV light from metal halide lamp without filter under nitrogen atmosphere. Optimum thickness of the film for quarter wave plate was 1 micrometer. We fabricated a test G-H LC cell with a QWP (Quarter Wave Plate) inside a cell, as shown in figure 7. G-H LC cell was homogeneously aligned with a normally black mode operation.

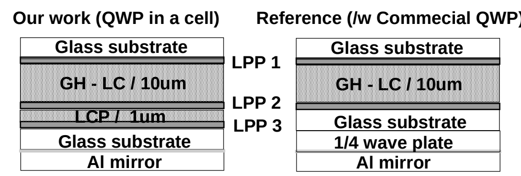


Figure 7. Structures of fabricated G-H LC cell with a 1/4 Lambda retardation film using LPP/LCP, and a reference cell

Polarization direction of alignment UV light for LPP1 and LPP2 were parallel each other, and LPP3 was 45 degree relative to LPP1/2.

We also fabricated a cell with a same configuration but without QWP, and put a commercially available QWP outside the cell, as a reference.

3. Results and discussions

Figure 8 shows the measurement results of the retardation dependency to the wavelength. Film is fabricated between two glass substrates and the thickness of the film was 2.5 micrometer.

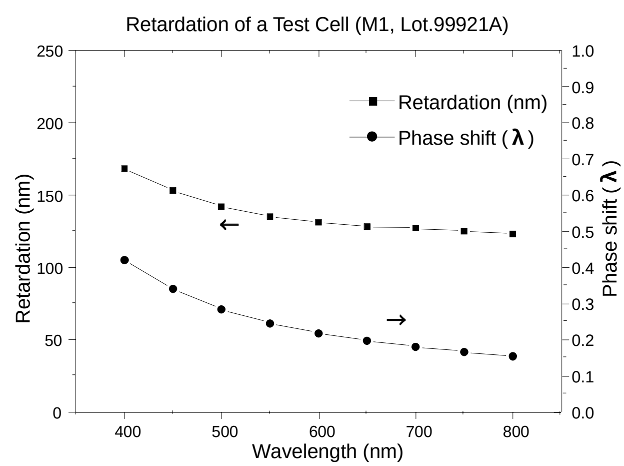


Figure 8. Optical retardation of the polymer film as a function of wavelength.

Contrast ratio of the cell was calculated using LCD master, and compaired with commercially available quarter wave plate, which has a thickness of about 100microns and is dispersion compensated.

Figure 8(A) corresponds to the result using our quarter wave plate, which is thin but has a wavelength dependency. Figure 8(B) is a result using commercially available film.

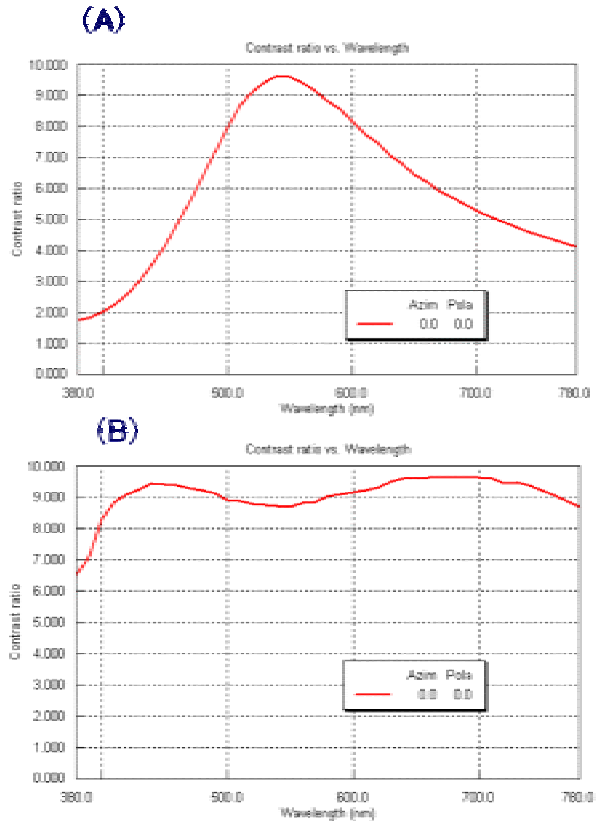


Figure 8. Wavelength dependency of the Contrast ratio calculated for our QWP and commercial QWP

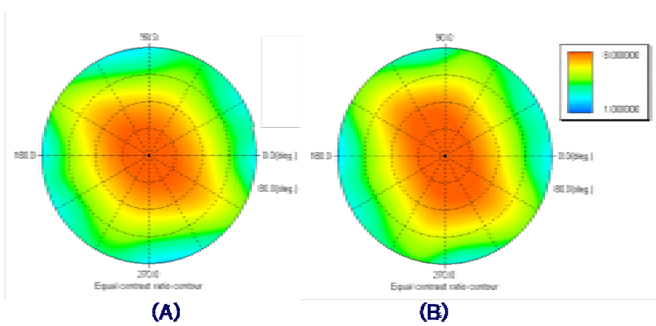


Figure 9. Contrast ratio of LC polymer film (A) and commercially available 1/4wave film

Figure 9(A) and 9(B) is calculated chart of angular dependency of contrast ratio for our LC polymer film and commercially available 1/4wave film, respectively. 9(A) was not so bad compared to that of (B) when we took our eye sensitivity into account.

Figure 10(A) is contrast ratio and its angular dependency of LPP/LCP film compared to the commercially available film. Viewing angle dependency of these films are shown in figure 11. Single layer films has color dependency, however, contrast ratio was not so bad. Single layer quarter lambda plate has an advantage to reduce parallax problem without having much complexity of display structure.

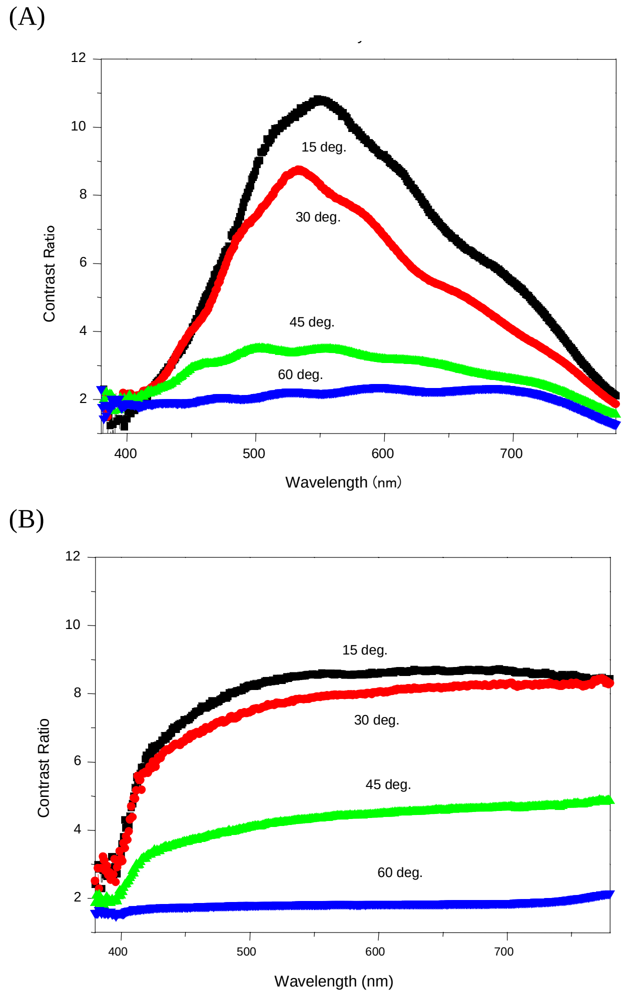


Figure 10. Contrast ratio of LPP film (A) and commercially available 1/4wave plate as a function of wavelength and incident light angle

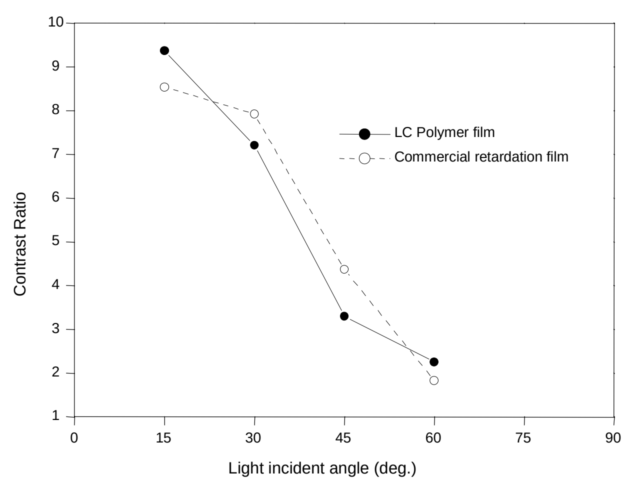


Figure 11. Contrast ratio of LPP film (A) and commercially available 1/4wave plate (B) as a function of incident light angle

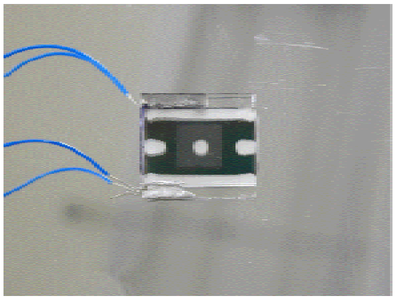


Figure 12. Appearance of our G-H LC test cell with built in QWP

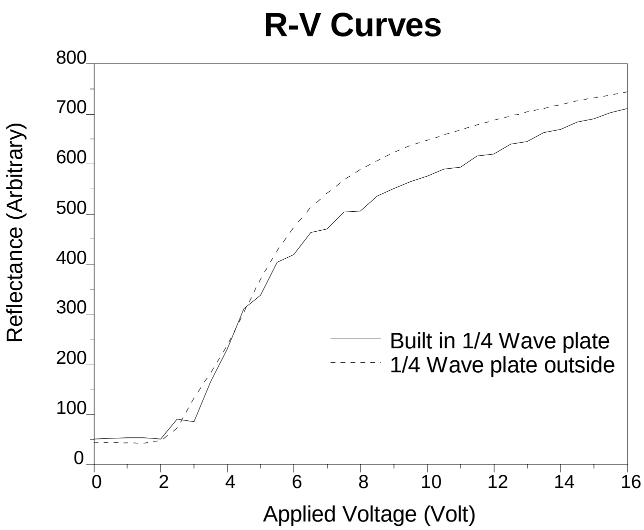


Figure 13. Reflectivity at a write angle was measured as a function of applied voltage across the cell electrodes. We measured our cell with a built in QWP (Solid line) and a cell without QWP stacked to commercial QWP (Color compensated) outside the cell for a reference.

Reflectivity dependency on applied voltage was measured for both G-H LC cells with and without built in QWP. Reflectivity was measured using He-Ne laser as a light source with an incident angle of 15 degree. Reflected light by the cell was detected by silicon photo-diode at a direction of specular reflection. Reflection at the surface of the cell was blocked by placing an iris. 0 to 16 volts, 2KHz square wave was applied to the cells to measure their voltage dependency. As shown in figure 13, the difference of threshold voltages for these two types of cells was smaller than expected. The voltage drop across the built in QWP was small enough at this operating region.

The dielectric constant for short axis of the liquid crystal molecule is much smaller than that of long axis. The liquid crystal molecules are still homogeneously aligned, at the threshold voltage. As a result the dielectric constant of liquid crystal is small, so that the voltage across the QWP layer is not so large.

On the other hand, at a higher applied voltage region, the reflectivity curves of those two cells start to separate each other. This can be explained that the ratio of the voltage across the QWP becomes larger because the effective dielectric constant of liquid crystal increases.

The contrast ratios of the cell with built in QWP and the cell with external QWP were 13.7 and 16.9 respectively, at an applied voltage of 16volt and a wavelength of 633nm.

4. Conclusion

We fabricated a very thin quarter wave plate using polymer liquid crystal material, for parallax free high reflectivity guest host liquid crystal display. Threshold voltage, viewing angle, and the contrast ratio of our cell with QWP placed between two electrodes were comparable to that without built in QWP.

5. Acknowledgements

This work is supported by NEDO.

We thanks to Dainippon Ink and Chemicals (DIK) and Japan Chemical Innovation Institute (JCII) for the chemical supply. We also thanks to Rolic (Dr. M. Schadt, Dr. H. Seiberle) and Chiba (Dr. Y. Matsumoto) for the supply of LCP and LPP.

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