SHIJIAZHUANG.CHINA
ISITC 2017
OCT.19-21.2017

# ISITC | 2017 SHIJIAZHUANG

## Proceeding of International Symposium on Information Technology Convergence

October 19-21, 2017

Shijiazhuang Tiedao University, China

## Session 1C: Application of information technology convergence

14:45 - 17:50, October 20, 2017. Location: CPA Training Room, No1 Teaching Building, STDU. Session Chairs:

Prof. Jongsik Lim (Soonchunhyang University, Korea)

Dr. Guohui Zeng (Shanghai University of Engineering Science, China)

**ID.16.** Wide viewing angle negative dispersion retarder by stacking layers with opposite birefringence

*Hee Jung Ryu, Yongchae Jeong, Ji-Hoon Lee**

*Chonbuk National University, Jeonbuk, Korea*

**ID.20.** A Design of Impedance Transformer with Wide Stopband and $3f_0$ Harmonic Suppression

*Changyu Park, Phirun Kim, Yongchae Jeong, Hyongsuk Kim, and Dongsun Park, Jongsik Lim,*

[1]*Chonbuk National University Jeonju-si, Republic of Korea*

[2]*Soonchunhyang University Asan-si, Republic of Korea*

**ID.21.** A Design of Tunable Phase Shifter Using Capacitive Termination

*Boram An, Junhyung Jeong, Girdhari Chaudhary, Seok-Hawn Park, Ji-Hoon Lee and Yongchae Jeong*

*Chonbuk National University*

**ID.45.** Bidirectional Three-Level DC-DC Converter with Capacitor Voltage Balance Control

*Myung-Chul Lee, Min-Kwon Yang, Jun Heo and Woo-Young Choi*

*Chonbuk National University, Jeonju, South Korea*

**ID.46.** High-Efficiency Transformerless DVR with Bidirectional DC-DC Converter

*Myung-Chul Lee, Min-Kwon Yang, Jun Heo and Woo-Young Choi*

*Chonbuk National University, Jeonju, South Korea*

**ID.77.** Design and Implementation of Enterprise Credit Topic Crawler

*Zhang Cuixiao1,Li Xuan*[1], **Shao Yunxia*[2], *Wang Yunli*[2], *Gao Jing*[1], *Zhao Guangzhen*[1]

[1]*Shijiazhuang Tiedao University, Shijiazhuang China*

[2]*Hebei Academy of Sciences Shijiazhuang China*

**ID.94.** Intelligent management system for small gardens Based on Multi-sensor fusion

*Xiao-hui ZENG*[1,2]*, *Jing-xiang LV*[1,2], *Wen-lang LUO*[1,2]*

[1]*Jinggangshan University, China*

[2]*Key laboratory of watershed ecology and geographical environment monitoring, NASG, China*

# Wide viewing angle negative dispersion retarder by stacking layers with opposite birefringence

Hee Jung Ryu, Yongchae Jeong, Ji-Hoon Lee*

Division of Electronics Engineering, Chonbuk National University, Jeonbuk 54896, Korea

*E-mail : jihoonlee@jbnu.ac.kr

***Abstract*—We proposed through experiment negative dispersion retarder with wide field of view. We stacked a reactive mesogen(RM) and polymethylmethacrylate(PMMA) film. RM has a positive birefringence and PMMA has a negative birefringence. Both of materials feature positive dispersion of birefringence. The out-of-plane retardation($R_{th}$) of the stacked film was 6 nm. It means that the stacked film has a small dependence of viewing angle and change of retardation(Re). The stacked film has a negative dispersion of birefringence, where Re(450 nm)/Re(550 nm)=0.818 and Re(650 nm)//Re(550 nm)=1.110. The dispersion property was close to the ideal dispersion of an achromatic retarder at the short wavelength featured a small dependence of Re on the wavelength of light.**

***Index Terms*—negative dispersion, reactive mesogen, reactive, wide viewing angle.**

## I. Introduction

MATERIAL, which featured optical anisotropy in natural usually has positive dispersion(PD) that the longer the wavelength, the optical birefringence($\Delta$n) has decreased. In other words, optical compensation film featured PD is difficult to get the effect of optical compensation for a wide-range wavelength. So, it is necessary to develop material, which has negative dispersion(ND) that phase retardation is constant regardless of wavelength.

The ideal negative dispersion of birefringence shows Re(450 nm)/Re(550 nm)=0.818 and Re(650 nm)/Re(550 nm)=1.181. Phase retardation is followed expression. $\Gamma = \frac{2\pi}{\lambda}[n_e(\theta) - n_o]d$. Re is in-plane retardation and followed expression. Re $= [n_e(\theta) - n_o]$d. θ is given by angle between incident light and optic axis. To obtain wide viewing angle property, the out-of-plane retardation becomes zero. Out-of-plane retardation $R_{th}$ is followed expression. $R_{th} = [\frac{n_x+n_y}{2} - n_z]d$.

In this report, we manufactured ND of birefringence retarder by using only materials featured positive birefringence. We stacked RM on PMMA film. RM and PMMA film have PD of birefringence. But, the retarder stacked RM-PMMA film has ND of birefringence. Thus, this retarder is able to perform constant retardation regardless of wavelength.

## II. Theoretical Background

Structure of Quasi-circular polarizer which used in the anti-reflection film of OLED was shown in Figure 1. (a). Here is anti-reflection(AR) process of incident light. First, incident white light is polarized to linear polarized(LP) by Half-Wave-Plate(HWP). Second, the polarization direction is rotated by the HWP. Third, passing through the Quarter-Wave-Plate(QWP), the LP light change Right Handed Circular Polarized(RHCP). When RHCP is reflected, it is converted to Left Handed Circular Polarized(LHCP). And then, LHCP is absorbed by the RHCP analyzer. This is the reason why Quasi-circular polarizer used in the anti-reflection film of OLED. Figure 1.(b) is optical circuit equivalent to (a). Two QWPs can be merged as one HWP with the same slow axis.

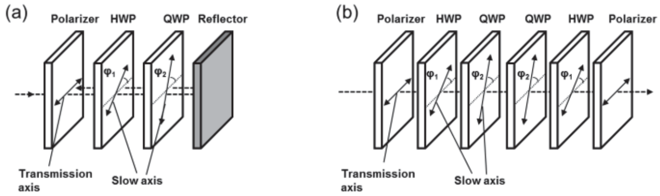


Figure 1. (a)Quasi-circular polarizer used in the anti-reflection film of OLED. (b)Optical circuit equivalent to (a)

The Jones matrices of the structures in Figure 1. (b) can be expressed as Eq.1. The slow axis of the HWP layers are supposed to be at $\varphi = 0$ in order to simplify calculation.

$$\begin{pmatrix} e^{-i\Gamma_1/2} & 0 \\ 0 & e^{i\Gamma_1/2} \end{pmatrix} \begin{pmatrix} e^{-i\Gamma_2/2}\cos^2\varphi + e^{i\Gamma_2/2}\sin^2\varphi & -i\sin(\frac{\Gamma_2}{2})\sin2\varphi \\ -i\sin(\frac{\Gamma_2}{2})\sin2\varphi & e^{-i\Gamma_2/2}\sin^2\varphi + e^{i\Gamma_2/2}\cos^2\varphi \end{pmatrix} \begin{pmatrix} e^{-i\Gamma_1/2} & 0 \\ 0 & e^{i\Gamma_1/2} \end{pmatrix}$$

$$= \begin{pmatrix} e^{-i\Gamma_e/2}\cos^2\varphi_e + e^{i\Gamma_e/2}\sin^2\varphi_e & -i\sin(\frac{\Gamma_e}{2})\sin2\varphi_e \\ -i\sin(\frac{\Gamma_e}{2})\sin2\varphi_e & e^{-i\Gamma_e/2}\sin^2\varphi_e + e^{i\Gamma_e/2}\cos^2\varphi_e \end{pmatrix} \quad (1)$$

Here, $\Gamma_1$ and $\Gamma_2$ are the phase retardation of the HWP and the merged QWPs layer, respectively. $\Gamma_e$ and $\varphi_e$ are the phase retardation and the orientation of the slow axis of the equivalent optical circuit, respectively. By substituting $\Gamma_1 = \Gamma_2 = \Gamma$ and comparing the corresponding matrix elements, we obtain two relations

$$\cos(\frac{\Gamma_e}{2})=\cos^2\varphi\cos(\frac{3\Gamma}{2})+\sin^2\varphi\cos(\frac{\Gamma}{2}) \quad (2)$$

$$\sin2\varphi_e=\frac{\sin(\frac{\Gamma}{2})\sin2\varphi}{\sin(\frac{\Gamma_e}{2})} \quad (3)$$

To satisfied with an achromatic retarder, $\frac{\partial\Gamma_e}{\partial\Gamma}$ must be zero. This gives,

$$3\cos^2\varphi\sin(\frac{3\Gamma}{2})+\sin^2\varphi\sin(\frac{\Gamma}{2})=0 \quad (4)$$

We can obtain $\varphi=\frac{\pi}{3}$ and $\Gamma_e=\pi$ by substituting $\Gamma=\pi$ in Eq.2. Followed this result, the orientation of the equivalent slow axis $\varphi_e$ should be $\pi/6$.

We can obtain the reflectance of the AR film by multiplying the Jones matrix of the linear polarizer at both sides of the series of the HWPs in Eq.1. Hence, the Jones matrix of the equivalent optical circuit is expressed by $M=M_{px}M_{H1}M_{H2}M_{H3}M_{px}$, where $M_{px}$ is the Jones matrix of the polarizer, $M_{H1}$ and $M_{H3}$ are that of the RM layer, and the $M_{H2}$ is that of the merged PMMA layer presented by Eq. 5-7.

$$3\ M_{px}=\begin{pmatrix}1 & 0\\ 0 & 0\end{pmatrix} \quad (5)$$

$$M_{H1}=M_{H3}=\begin{pmatrix} e^{-i\Gamma_1/2}\cos^2\varphi_1+e^{i\Gamma_1/2}\sin^2\varphi_1 & -i\sin(\frac{\Gamma_1}{2})\sin2\varphi_1 \\ -i\sin(\frac{\Gamma_1}{2})\sin2\varphi_1 & e^{-i\Gamma_1/2}\sin^2\varphi_1+e^{i\Gamma_1/2}\cos^2\varphi_1 \end{pmatrix} \quad (6)$$

$$M_{H2}=\begin{pmatrix} e^{-i\Gamma_2/2}\cos^2\varphi_2+e^{i\Gamma_2/2}\sin^2\varphi_2 & -i\sin(\frac{\Gamma_2}{2})\sin2\varphi_2 \\ -i\sin(\frac{\Gamma_2}{2})\sin2\varphi_2 & e^{-i\Gamma_2/2}\sin^2\varphi_2+e^{i\Gamma_2/2}\cos^2\varphi_2 \end{pmatrix} \quad (7)$$

Suppose that we set the orientation of the transmission axis of the polarizer to 0°, while $\varphi_1$ and $\varphi_2$ were the slow axis of the HWP and the QWP layers, respectively. Comparing with Eq. 1, $\varphi_1$ and $\varphi_2$ is rotated due to supposition in Eq.6 and 7. Then we can obtain the reflectance by $|M_{11}|^2$ and it has minimum value at $\varphi_1=15^{\circ}$ and $\varphi_2=75^{\circ}$, respectively.

## III. EXPERIMENT

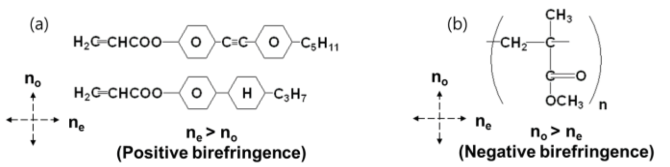


Figure 2. Chemical structure of the (a) UCL001 and (b) PMMA molecules.

We product HWP layer by using RM material UCL001 (DIC). The UCL001 featured two positive  n homologues whose  J is parallel to the longitudinal direction of molecular structure. That means the  J direction is followed the rubbing direction of the alignment layer. We fabricated The RM was planar aligned with a planar alignment polyimide (PIA-PT114-JU1, JNC), and then irradiated RM with UV light to polymerize The RM at an intensity of 10 mW/cm$^2$ for 1 min. When giving Re=268.6 nm at λ=550 nm, the  n of the UCL001 was 0.0597 and the thickness of samples was 4.5 µm.

We used PMMA film as QWP. The PMMA features negative  n. The main chains and the side chains of stretched PMMA are respectively aligned parallel and perpendicular to the stretched direction. When giving Re=-146.3 nm at λ=550 nm, the  n of PMMA layer was -0.00281 and thickness was 52 µm.

We stacked The RM and PMMA layers. Between slow axis of RM and that of PMMA are formed 60 .¶We measured the Re and $R_{th}$ of the RM-PMMA film with a retardation measurement instrument (Axo Scan-OPMF2, Axo Metrics) based on Muller matrix method. We used the commercial LCD simulation program Techwiz 2D (Sanayi System) to obtaine the optical simulation.

## IV. RESULT AND DISCUSSION

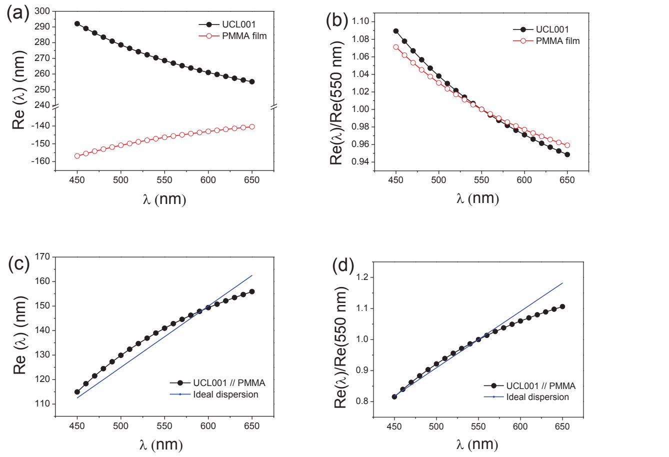


Figure 3. (a) Re(λ) of the separate UCL001 and PMMA film (b) Re(λ) of the separate UCL001 and PMMA film normalized to Re(550 nm). (c) Re(λ) of the UCL001-PMMA stacked film (d) Re(λ) of the UCL001-PMMA stacked film normalized to Re(550 nm).

Figure 3. (a) shows that UCL001 and PMMA film was close to HWP and QWP, respectively. Figure 3. (b) shows that RM and PMMA feature the PD property. Figure 3. (c) shows that the stacked film has ND property with QWP. Figure 3. (d) shows that how close the property of stacked film was to ideal ND values. Re(450 nm)/Re(550 nm)=0.818 and Re(650 nm)/Re(550 nm)=1.110 in Figure 3. (d). According to Figure 3. (d), when λ<550 nm the stacked RM-PMMA film was very close to the ideal ND. When λ>550 nm, however, it was relatively deviated from ideal ND.

| | λ =450 nm | λ=550 nm | λ=650 nm |
|---|---|---|---|
| UCL001 | 70 nm | 64 nm | 60 nm |
| PMMA | -119 nm | -112 nm | -109 nm |

| | | | |
|---|---|---|---|
| UCL001-PMMA stacked | -27 nm | 6 nm | 5 nm |

Table 1. $R_{th}$ value of the separate UCL001, PMMA and the UCL001-PMMa stacked films vs. λ, $\Gamma_e$ of the three films was set to be π/2 at λ=550 nm by adjusting the thickness.

We measured the $R_{th}$ value of the separate UCL001, the PMMA and the UCL001-PMMA stacked film vs. λ in order to evaluate the viewing angle property of the retarder film. By adjusting the thickness of three films, the $\Gamma_e$ of the three films was set to be π/2 at λ=550 nm to compare quantitative of Table 1.'s values. The $R_{th}$ of RM was 64 nm and that of PMMA film was -112nm. The Re of separate layers are dependence of viewing angle. When stacked two separate layer, The stacked RM-PMMA film was 6 nm at λ=550 nm. We obtain significant reduction of the viewing angle dependence of the Re of stacked film. It was about a tenth of a general retarder.

## V. Conclusion

We suggested a negative dispersion retarder with a wide field-of-view by stacking the RM layer and the PMMA film. The $R_{th}$ of retarder film was 6 nm and led to a small change of *Re* at oblique viewing angle. The stacked film also featured a negative dispersion of birefringence which was close to the ideal dispersion of an achromatic retarder with a small dependence of *Re* on *λ*.

## Acknowledgment

This paper was supported by Ministry of Trade, Industry, and Economy (MOTIE) and Korea Display Research Consortium (KDRC) (10051334).

## References


[1] P. Yeh and C. Gu, *Optics of Liquid Crystal Displays*, 2nd edi. John Wiley & Sons, Chap. 4, Chap. 6 (2010).

[2] B. Lyot, "Filter monochromatique polarisant et ses applications en physique solaire," *Ann. Astrophys*. **7**, 31-79 (1944).

[3] J. W. Evans, "The birefringent filters," *J. Op. Soc. Am*. **39**, 229-342 (1949).

[4] S. Pancharatnam, "Achromatic combinations of birefringent plates. Part I. An achromatic circular polarizer," *Proc. Ind. Acad. Sci. A* **41**, 130-136 (1955).

[5] J. M. Beckers, "Achromatic linear retarders," *Appl. Opt*. **10**, 973-975 (1971).

[6] T.-H. Yoon, G.-D. Lee, and J. C. Kim, "Nontwist quarter-wave liquid-crystal cell for a high-contrast reflective display," *Opt. Lett*. **25**, 1547-1549 (2000)

[7] A. Geivandov, A. Lazarev, P. Lazarev, and S. Palto, "Negative dispersion retarder for 3D TV applications," *International Display Workshop*. 265-267 (2010).

[8] S.-W. Oh and T.-H. Yoon, "Elimination of light leakage over the entire viewing cone in a homogeneously-aligned liquid crystal cell," *Opt. Express* **22**, 5808-5817 (2014)

[9] S. Shen, J. She, and T. Tao, "Optimal design of achromatic true zero-order wave plates using twisted nematic liquid crystal," *J. Opt. Soc. A* **22**, 961-965 (2005)

[10] R. K. Komanduri, K. F. Lawler, and M. J. Escuti, "Multi-twist retarders: broadband retardation control using self-aligning reactive liquid crystal layers," *Opt. Express* **21**, 404-420 (2013).

[11] A. Uchiyama and T. Yatabe, "Control of wavelength dispersion of birefringence for oriented copolycarbonate films containing positive and negative birefreingent units," *Jpn. J. Appl. Phys*. **42**, 6941-6945 (2003).

[12] A. Uchiyama, Y. Ono, Y. Ikeda, H. Shuto, and K. Yahata, "Copolycarbonate optical films developed using birefringence dispersion control," *Poly. J*. **44**, 995-1008 (2012).

[13] K. Kuboyama, T. Kuroda, and T. Ougizawa, "Control of wavelength dispersion of birefringence by miscible polymer blends," *Macromol. Symp*. **249**, 641-646 (2007).

[14] O. Parri, G. Smith, R. Harding, H.-J. Yoon, I. Gardiner, J. Sargent, and K. Skjonnemand, "Patterned retarder films using reactive mesogen technology," *Proc. SPIE* 7956, 1-11 (2011).

[15] H. Lee and J.-H. Lee, "Negative dispersion of birefringence in two-dimensionally self-organized smectic liquid crystal and monomer thin film," *Opt. Lett*. **39**, 5146 (2014).

[16] S. Yang, H. Lee, and J.-H. Lee, "Negative dispersion of birefringence of smectic liquid crystal-polymer composite: dependence on the constituent molecules and temperature," *Opt. Express* **23**, 2466-2471 (2015).

[17] A. Kumar Srivastava, S. Yang, and J.-H. Lee, "Negative dispersion retarder using two negative birefringence films," *Opt. Express* **23**, 13108-13114 (2015).

[18] H. Kikuchi, H. Yamamoto, H. Sato, M. Kawakita, K. Takizawa, and H. Fujikake, "Bend-more liquid crystal cells stabilized by aligned polymer walls," *Jpn. J. Appl. Phys*. **44**, 981-989 (2005).