An Investigation on the Effect of Bending on the Circular Polarizer of an Organic Light Emitting Diode Display

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ABSTRACT

This work reports the experimental research results of the retardation change of a reactive mesogen type quarter-wave plate (QWP) by bending when the slow axis the QWP is oriented with the bending axis according to perpendicular or parallel directions. Moreover, the effect of the retardation changes on the antireflective properties of a quasi-circular polarizer taken accounts for an organic light-emitting diode in the simulation. Based on the obtained results, we assign that the light leakage reduced gradually with bending effect in the vertical viewing orientation, while it was increased in the horizontal viewing direction regardless of the orientation of the slow axis.

1 INTRODUCTION

Organic light-emitting diode (OLED) display is already known as a potential candidate for commercialization of the flexible displays soon. Because it has featured such as fast response and the electro-optical properties of each display component can be retained during the bending process of the plastic substrate [1-3]. A quasi-circular polarizer is generated by using a retarder film in flexible OLED to prevent reflective light from the metal cathode surface [4].

A circularly polarized light can be generated by a quarter-wave plate (QWP) which one of the two elements of the quasi-circular polarizer beside a linear polarizer. The handedness of the circular polarization is converted by the reflection at the metal surface and is therefore blocked by the polarizer. The retarders can be applied for traditional display devices with the stretched-film type [5] or with the coated reactive-mesogen (RM) type [6] for the application of flexible displays.

Alternative approaches to eliminate the reflected light without the circular polarizer e.g. an OLED with a top-emission structure composed of microcavities with thin-film encapsulation and a color filter [7] or an OLED device with a multilayered structure and absorber [8]. Until now, however, existing OLED devices still use circular polarizers to eliminate reflected light.

In this work, we investigated experimentally the retardation R_{in} of the RM-type retarder as a function of the radius of curvature R of the flexible substrate. As a comparison, the change of R_{in} depends on the radius of curvature R also taken into account once the slow axis of the retarder is perpendicular or parallel to the bending axis, shown Fig. 1. This aims to estimate the effect of the retardation change to an antireflection property of a quasi-circular polarizer attached on the OLED display.

2 EXPERIMENT

A schematic of the experimental setup to measure the R_{in} of the retarder films, shown in Fig. 1. The right-handed circularly polarized (RHCP) light can be generated when the slow axis of the retarder is oriented parallel to the x-axis, while the bending axis was always parallel to the y-axis and the sign of R_{in} is positive. Similarly, when the slow axis is parallel to the y-axis, the sign of R_{in} is negative, resulting in the left-handed circularly polarized (LHCP) light.

Polycarbonate (PC) film play role as a substrate in the fabrication of the QWP film. This (PC) film fabricated by a solvent-casting method with the small value of R_{in} at a given wavelength of 550nm. Moreover, the planar alignment of the RM molecules can be generated by rubbing PC film with a cotton cloth unidirectionally.

3 RESULTS

We measured the retardation R_{in} the QWP film versus the inverse of the radius of curvature (R^{-1}). Fig. 2(a) shows the positive values of the retardation of the QWP film for the RHCP light with the various curvature. For the wavelength case of 550 nm, at $R^{-1} = 0$, the obtained R_{in} is 138 nm while 130 nm is the obtained value of R_{in} at R^{-1} = 0.11 mm^{-1}. Therefore, the retardation parameter of QWP film caused the decreased RHCP light with greater R^{-1}. The retardation parameter of the QWP film is also investigated for the LHCP light. Fig. 2(b) shows the negative values of the R_{in} of the QWP film for the LHCP light with the various curvatures. For the wavelength case of 550 nm, at R^{-1}=0, the obtained R_{in} is - 138 nm while -147 nm is the obtained value of R_{in} at R^{-1} = 0.11 mm^{-1}. Therefore, R_{in} of QWP film is also decreased with greater R^{-1}.

To more understand about the R_{in} change of the QWP film, we measured the R_{in} of the bare substrate film. Then, we obtained R_{in} change of the QWP film defined as the expression of $R_{in}(R^{-1}) - R_{in}(0)$, where $R_{in}(R^{-1})$ and $R_{in}(0)$ are the retardation values at the bent and flat states in the change of the radius of curvature from R to 0, respectively. Fig. 3 shows $R_{in}(R^{-1}) - R_{in}(0)$ of the RM layer and the bare PC substrate versus R^{-1}. The R_{in} of the QWP film is always reduced when bending regardless of the direction of the slow axis provided that R^{-1} is about 0.1. In Fig. 4, we showed the simulated results the change of antireflection property in the bent state of the quasi-circular polarizer based on a commercial optical simulation program Techwiz 1D Polar.

In the flat state, the quasi-circular polarizer generating RHCP light indicated that the light leakage is more when the light was incident along the azimuthal angle of 80°–260° or 170°–350°, shown in Fig. 4(a). In the bent state, the viewing angle dependence of the reflectance slightly decreased along 80°–260°, while it increased along 170°–350°, shown in Fig. 4(b). Similarly, in Fig. 4(c), the film generating the LHCP light showed more light leakage along the azimuthal angle of 10°–190° or 100°–280° at the flat state. The viewing angle dependence of the reflectance along the azimuthal angle of 10°–190° increased, while it decreased along 100°–280° in the bent state, shown in Fig. 4(d). From the results in Fig. 4, it could be concluded that the light leakage is more along the horizontal direction at the bent state. To verify this issue, we calculated the polarization states at various viewing angles from the experimental data in Fig. 2. The polarization states are shown by Poincaré spheres as in Fig. 5. The RHCP light is viewed at $\varphi = -10°$ in Fig. 5(a), The polarization state of the analyzer located at −S2 axis, away from the S2 axis leads to more light leakage. This result perfectly matches the results in Fig. 4 (a) and Fig. 4 (b), in which light leakage is increased along the horizontal direction in the bent state. On the other hand, when the RHCP light is viewed at $\varphi = 80°$, the final polarization state is closer to the S2 axis after bending. This result perfectly also matches the results in Fig. 4 (a) and Fig. 4 (b), in which the light leakage along the vertical direction was decreased by bending. Similarly, the LHCP light is viewed at $\varphi = 10°$ and $\varphi = 100°$ to investigate the light leakage, shown in Fig. 5(c) and Fig. 5(d), respectively. This result perfectly also matches the results in Fig. 4(c) and Fig. 4(d), in which the light leakages are increased and decreased along with the horizontal and vertical directions respectively by the bending effect.

4 DISCUSSION

The effect of the decrease of the R_{in} in Fig. 2 caused the increase of the light leakage along the horizontal direction. Based on the obtained results, we assign that the light leakage reduced with bending in the vertical viewing orientation, while it was increased in the horizontal viewing direction regardless of the polarization state. The decrease of R_{in} is the cause of the farther polarization state from the +S2 axis along with the horizontal view, while it causes polarized state closer to the + S2 axis along the vertical direction. These results play a role important information in the future flexible display devices. The efficiency of flexible display devices in the bent state concerning to the y-axis was better thanks to RHCP light generated from the quasi-circular polarizer. Moreover, the quasi-circular polarizer also generated LHCP light. This is beneficial for display devices in the bent stage with respect to the x-axis

5 CONCLUSIONS

The R_{in} change of QWP film was measured in the induction of bent stage. the orientation of the slow axis of the QWP film was not affected in the value of R_{in} which always decreased.

We carried out the simulation on the change of the R_{in} on the antireflection property of a quasi-circular polarizer used for the OLED display. According to which the light leakage was reduced gradually in the vertical viewing direction and was faded in the horizontal viewing direction in bending around the y-axis in the panel.

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REFERENCES

[1] S. Choi, S. Kwon, M. S. Lim, Y. Jeon, H. Kim, Y. M. Kim, J. H. Kwon, and K. C. Choi, “Clothing-shaped organic light-emitting devices (OLEDs) for wearable displays,” Dig. Tech. Pap. Soc. Inf. Disp. Int. Symp. Vol. 49, No. 1, pp. 486–488 (2018).

[2] C. I. Park, M. Seong, M. A. Kim, D. Kim, H. Jung, M. Cho, S. H. Lee, H. Lee, S. Min, J. Kim, M. Kim, J.-H. Park, S. Kwon, B. Kim, S. J. Kim, W. Park, J.-Y. Yang, S. Yoon, and I. Kang, “World’s first large size 77-inch transparent flexible OLED display,” J. Soc. Inf. Disp. Vol. 26, No. 5, pp. 287–295 (2018).

[3] G. Crawford, ed., Flexible Flat Panel Displays (Wiley, 2005), pp. 1–9.

[4] P. Yeh and C. Gu, Optics of Liquid Crystal Displays, 2nd ed. (Wiley, 2010), pp. 264–269.

[5] H. Yoshimi, T. Nagatsuka, Y. Fujimura, and T. Osuka, “Birefringent film with nx >nz >ny, process for producing the same, retardation film, elliptically polarizing plate, and liquid crystal display,” U.S. patent 5,245,456A (14 September 1993).

[6] J. Park, J.-H. Lee, “Bending effect on the circular polarizer of an organic light-emitting diode display,” Appl. Opt. Vol. 58, No. 13, pp. 3671-3675 (2019).

[7] S. Kim, H.-J. Kwon, S. Lee, H. Shim, Y. Chun, W. Choi, J. Kwack, D. Han, M. Song, S. Kim, S. Mohammadi, I. Kee, and S. Y. Lee, “Low-power flexible organic light-emitting diode display device,” Adv. Mater. Vol. 23, No. 31, pp. 3511–3516 (2011).

[8] G. Tan, R. Zhu, Y.-S. Tsai, K.-C. Lee, Z. Luo, Y.-Z. Lee, and S.-T. Wu, “High ambient contrast ratio OLED and QLED without a circular polarizer,” J. Phys. D. Vol. 49, pp. 315101 (2016).

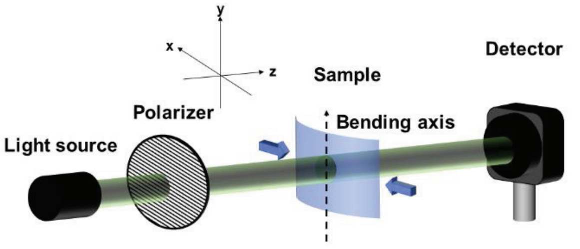
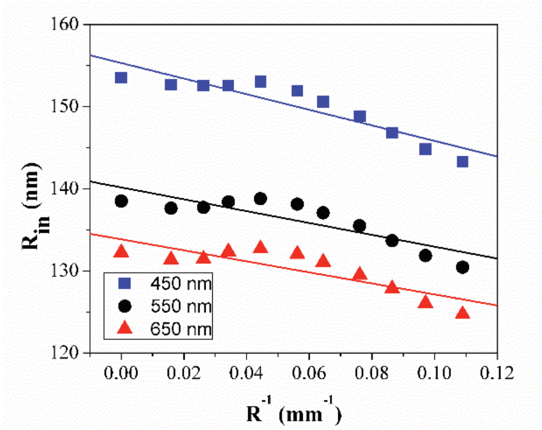
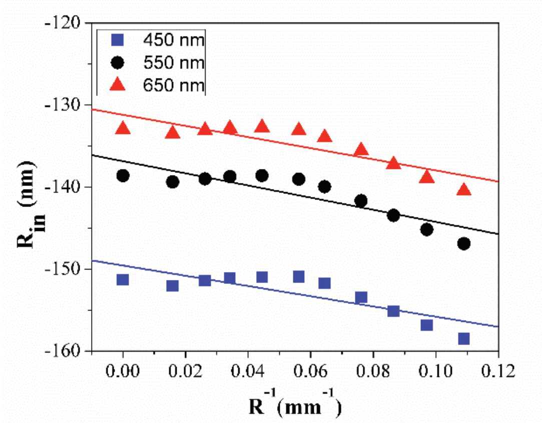


Fig. 1. Sketch of the retardation measurement with the retarder film bent.

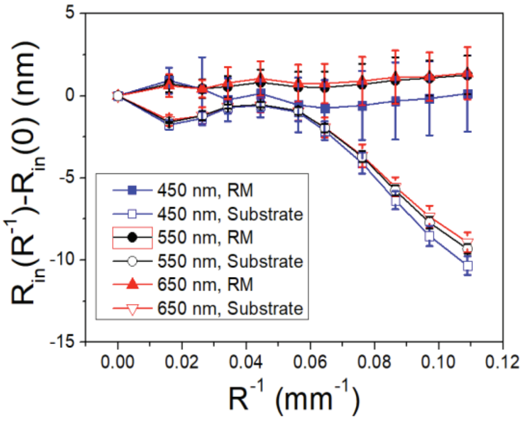


(a)

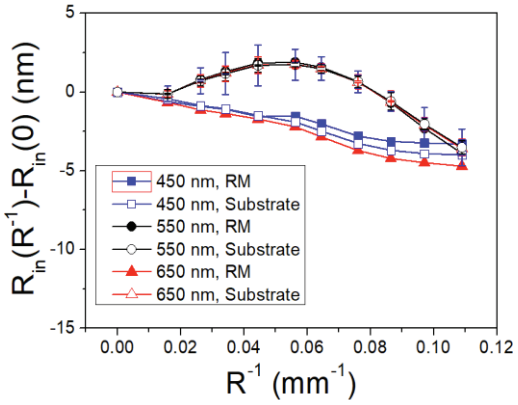


(b)

Fig. 2. The R_{in} of the QWP retarder film as a function of the inverse of the radius of curvature R. The slow axis of the sample is parallel with the *x*-axis (a) and *y*-axis, respectively.

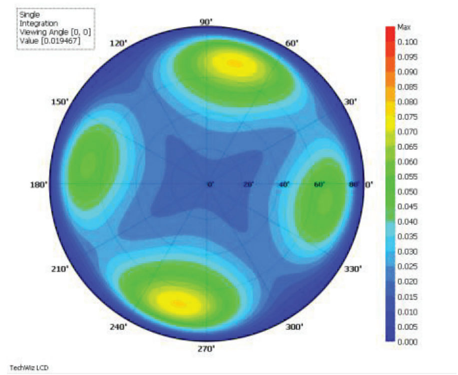


(a)

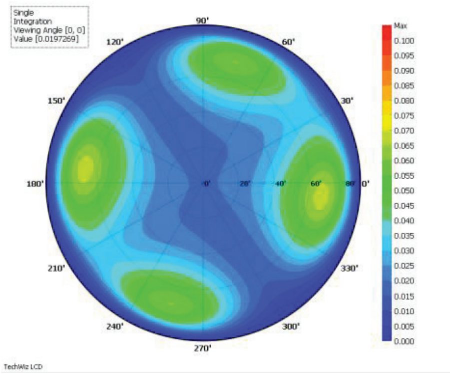


(b)

Fig. 3. The change of the retardation of the RM and the substrate layers as a function of R^{-1}. The slow axis of the sample is parallel with the *x*-axis (a) and (b) *y*-axis, respectively.



(a)



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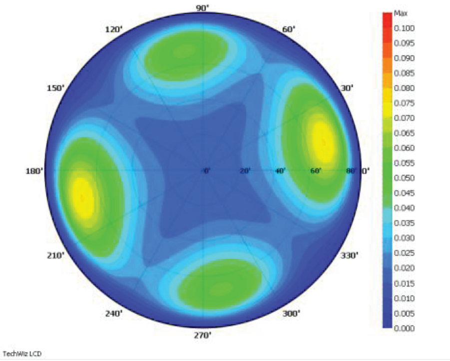
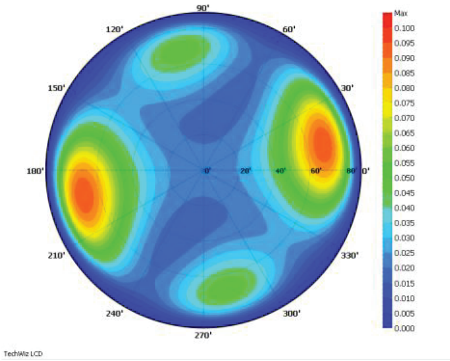
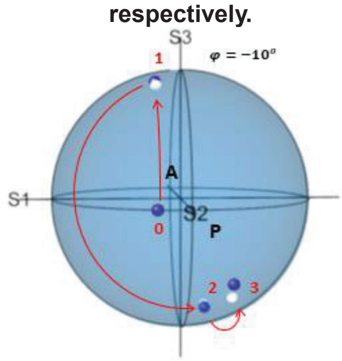


(c)

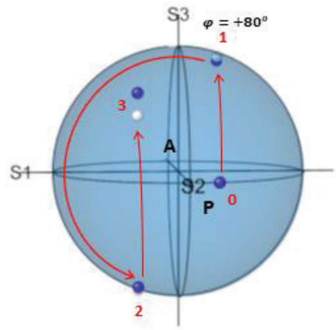


(d)

Fig. 4. The viewing angle simulation of the antireflection property of the quasi-circular polarizer at the flat (R^{-1} = 0) and (R^{-1} = 0.11 mm^{-1}) bent states. For RHCP light (a), (b) and LHCP light (c), (d), respectively.



(a)



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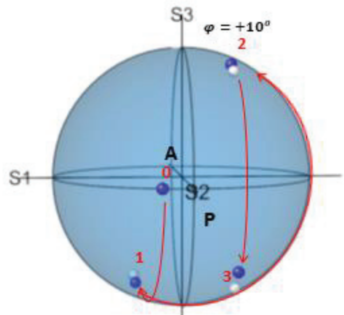
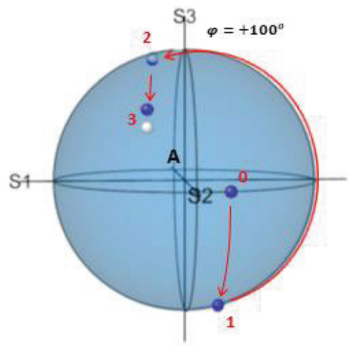


(c)



(d)

Fig. 5. At a various azimuthal angle φ, Poincaré graphs of the polarization state through the optical components of the quasi-circular polarizer-attached OLED shown. (a), (b) The incidence of light was the RHCP and the viewing direction was $\varphi = -10^o$ and $\varphi = +80^o$, respectively. Similarly, (c), (d) The incidence of light was the LHCP and the viewing direction was $\varphi = +10^o$ and $\varphi = +100^o$, respectively. Polarized states are marked with the numbers 0, 1, 2, 3 after passing the polarizer, the QWP, the reflector, and the QWP, respectively. Polarized states at flat and bent states are also marked with blue and white spheres, respectively.