Field Assisted Unidirectional Alignment of Quantum-Rods with Polarized Light Emission

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Abstract

Owing to anisotropic light emission, an aligned quantum-rods (QRs) array paired with LCD backlight offers a viable option to achieve the light polarization and enhance the color gamut. Herein, we present a facile approach for the fabrication of a functional film with unidirectional ordered QRs by utilizing solvent-based UV-curable reactive-mesogen and an in-plane electric field. The film exhibits partially polarized light with polarization ratio value of 0.42, which was mainly attributed to the QRs alignment in the electrode gap area of IPS substrate.

Author Keywords

Reactive-mesogen; quantum-rods; polarization ratio

1. Introduction

In the recent years, quantum dot (QD) based LCDs have attracted the vested interest of both academicians and industrial sector to compete with the OLED devices. The outstanding features of QDs such as size-dependent emission wavelength, large stoke shift, high color saturation owing to the narrow emission, and higher photoluminescence (PL) quantum yield makes them beneficial for splendid image quality and wider color gamut. The QDs display technologies are utilizing QDs coupled with InGaN blue LED in the backlight unit in various configurations [1-2]. These QDs absorb photons from blue LED and down-convert into green and red-light matching with the transmission peaks of the color filters [3]. The narrow emission produced by QDs gives better color saturation when compared with the traditional phosphors [4]. Furthermore, the anisotropic quantum rods (QRs), due to their ability to emit polarized light along the longer axis, are more favorable contenders to achieve enhanced optical efficiency and wide color gamut in the LCD device. A unidirectional aligned QRs array coupled with the LCD backlight can provide partially polarized light that can improve the transmission through polarizer. Such QRs array can also be adjoin with the color filters that can help to reduce the color crosstalk for more vivid color images. However, the vigorous task of using these QRs for the desired purpose is to align them in a perfectly unidirectional array so as to get higher polarized light emission. Several approaches have been projected such as electric field-assisted assembly [5], using photo-alignment layer [6], arrangement in liquid crystal defects [7], solvent-based assembly [8] and embedding the QRs in nanofiber sheets using electrospinning [9].

Herein, we are presenting a much simplistic approach for the fabrication of unidirectional aligned QRs film, with the use of solvent-based UV curable reactive mesogen (RM). The RM/QRs mixture was uniformly coated on the in-plane switching (IPS) electrode substrate with the assistance of a shearing bar. The applied external AC square field controls the orientation and position of the RM and QRs. Thereafter, to fix the position of QRs the sample was exposed under UV light to achieve the polymerization of RM molecules. Thereafter the film was analyzed under polarizing optical microscope (POM) to confirm the RM alignment. The photoluminescence (PL) spectra was measured and degree of polarization (ρ) for QRs was calculated as $\rho=(I_{//}-I_{\perp})/(I_{//}+I_{\perp})$, where $I_{//}$ and $I_{\perp}$ represent the PL emission intensity parallel and perpendicular to the alignment direction, respectively. Furthermore, the high-resolution confocal microscope images of as-prepared film revealed the position of the QRs on the IPS substrate.

2. Results and Discussion

Here, we have used the CdSe/CdS QRs (CAN GmbH- Hamburg, Germany) showing red emission with PL peak maximum centered at 626 nm with the excitation of 405 nm wavelength light. The full width at half maximum (FWHM) was calculated from the PL spectra, gives the value of 26 nm (Figure 1a). The UV-Visible absorption peak maximum was recorded at 430 nm and TEM images showed the average length and diameter of QRs as 46 and 5 nm, respectively, (Figure 1b).

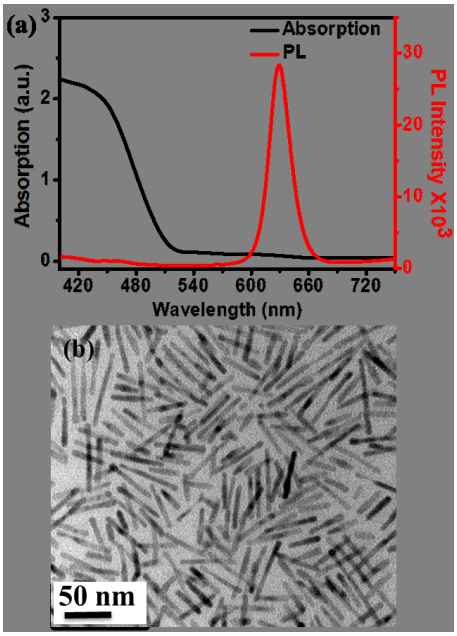

Figure 1. (a) Absorption and PL emission spectra of CdSe/CdS QRs and (b) corresponding TEM image.

RMS-03-013C (supplied by Merck), was used for this study, in which RM is dissolved in propylene glycol monomethyl ether acetate (PGMEA) solution and possesses positive dielectric anisotropy (Δn= 0.137 at 589 nm). The QRs concentration in RMS was maintained as 0.2 wt. % and the steps followed for the formation of QRs functional film are demonstrated in the figure 2a-c. The RM/QRs mixture was dropped on IPS substrate with electrode width (w) and gap (*l*) of 4 µm each (Figure 2a). Thereafter, the mixture was sheared perpendicular to the electrode direction with the help of a shearing bar (Figure 2b). The in-plane ac square field at constant frequency of 1 KHz was applied (Figure 2c) and the orientation of RM molecular with increasing voltage was monitored under optical microscope.

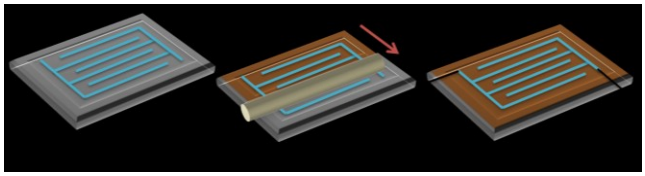

Figure 2. Pictorial depiction of method followed to prepare QRs functional film (a) IPS substrate (b) RM/QR mixture coating with shearing bar. (c) RM/QR mixture on IPS substrate under applied in-plane ac square field and illuminated with UV light.

The mixture showed excellent dispersion of QRs and no visible aggregates were found under the optical microscope after coating the mixture on the IPS substrate, although QRs cluster in the nanometer range cannot be ruled out. Figure 3 shows the optical microscope images of RM/QRs mixture on the IPS electrode substrate before exposure to UV light. The RM molecules stayed randomly oriented in the absence of electric field after coating on the IPS substrate (Figure 3a) and as the voltage was increased from 0 V, owing to the external bias, the LC director gradually started aligning parallel to the field direction (Figure 3b-d). At 80 V, the entire electrode area showed homogeneous alignment and the field value was estimated as 20 $V\mu m^{-1}$. The LC anchoring energy between QRs and LC can provide large alignment energy, which is expected to drive QRs along the RM molecule direction [10]. Also, due to large permanent dipole moment along the wurtzite c-axis of the QRs, the torque induced under applied field can result in their orientation along the field lines while evaporating the solvent, which confine them in a unidirectional array [11].

After getting uniform alignment of RM, the complete dark and bright state was observed under POM with cross polarizers, with electrodes direction positioned at an angle of 0^o and 45^o with one of the polarizer, respectively (Figure 4a). Subsequently, the orientation of the RM molecules and QRs was frozen after irradiating with UV light. The field was removed after polymerization and dark and bright state remained intact even without the field (Figure 4b).

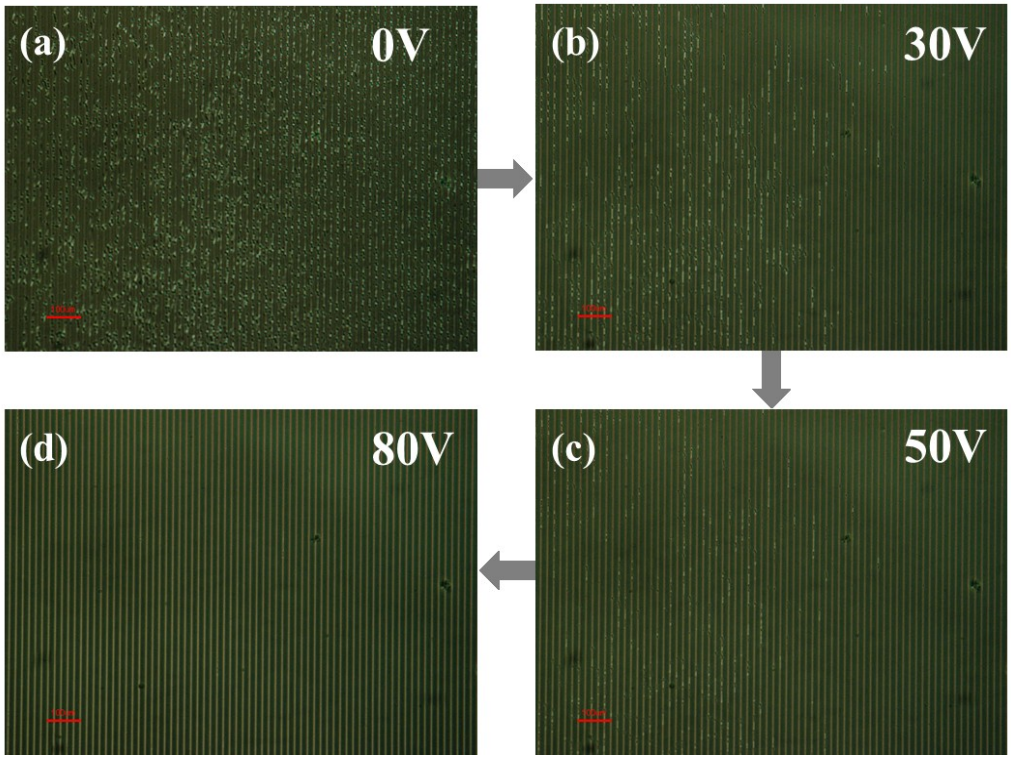

Figure 3. Optical microscope images of RM/QRs mixture after coating on IPS substrate (a) without any applied voltage and (b)-(d) with gradually increasing voltage. (Scale- 100 µm)

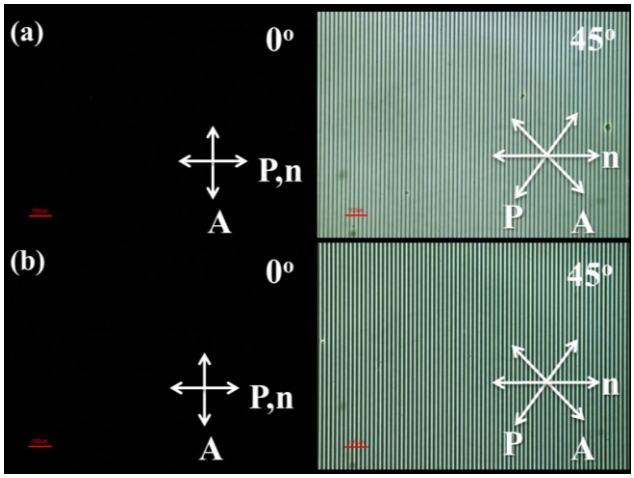

Figure 4. POM Images of film under cross polarizer. (a) RM/QRs mixture on IPS substrate under applied electric field before UV curing and (b) after UV curing (Scale-100 μm). n represents the alignment direction of RM.

Polarization dependent PL emission spectra of the film were measured by placing the polarizer parallel and perpendicular to the orientation of RM and QRs alignment direction (Figure 5a). When polarizer was positioned parallel to the alignment direction, the PL intensity was measured higher than in the perpendicular position. The polarization ratio value of the film was calculated as 0.42 from the PL spectra (Figure 5b).

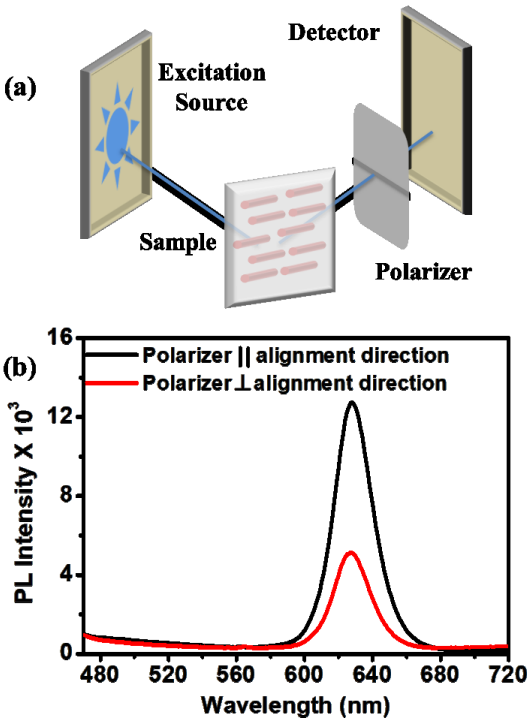

Figure 5. PL measurement (a) Experimental setup for measuring the PL (b) PL spectra measured from functional film with polarizer position parallel and perpendicular to the alignment direction.

High magnification fluorescence microscope images were taken to check the position of QRs in the functional film more closely (Figure 6). The maximum red emission was recorded from the electrode gap (figure 6a,b) which is due to the presence of a majority of QRs in between the electrode gap area. Few QRs were also found on the top of the electrode area. The film thickness was estimated from the retardation plot as 1.1 μm and thereafter was carefully peeled from the substrate (Figure 6c,d).

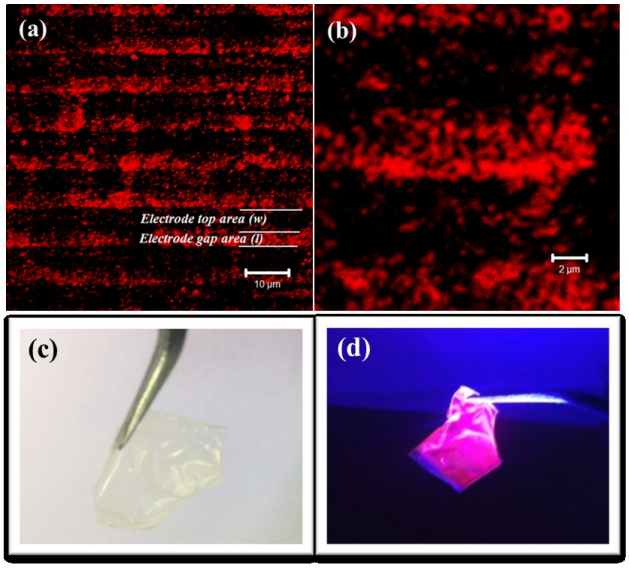

Figure 6. (a-b) High magnification confocal fluorescence microscope images of functional film on IPS substrate. The film detached from the IPS substrate (c) under normal and (d) UV light.

3. Conclusion

We facilitate a fabrication technique for unidirectional alignment of QRs functional film by mixing them in RM solution. The presence of solvent in RM prevents the formation of large QRs aggregates and external electric field permits the QRs to orient along the field direction and guided their unidirectional assembly within the electrode gap area of IPS substrate. Further improved fabrication system to apply an in-plane electric field over whole area will improve the polarization ratio of functional film.

4. Acknowledgements

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5. References

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